INVESTIGATION INTO A FATAL FIRE AT CARNAULD METALBOX LTD

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This paper covers a joint Health and Safety Executive/Health and Safety Laboratory (HSE/HSL) investigation of a fatal fire inside a 60 m high redundant steel chimney at the Carnauld Metalbox (CMB) Factory, Westhoughton, Nr. Bolton. The incident occurred at around 5.00 pm on 23/5/2002, whilst two contractors were working inside preparing the chimney for demolition. It is hoped that publishing the findings of this investigation will raise awareness of the issues and prevent further occurrences of this type of avoidable incident.

BACKGROUND

Prior to becoming redundant, the chimney in which the fire occurred had been used to vent fumes from a number of drying ovens/lines associated with the application of paint/lacquer to steel sheet used in the food canning industry. Over many years, these fumes coated the inside of the chimney and extract ductwork, giving a tarry layer several millimetres in thickness, which, it was thought, rose for a considerable height inside the chimney. The appearance of the deposit within the ductwork can be seen in Figure 1.

A specialist contractor was appointed to demolish the ductwork and chimney, using a hot cutting method from the interior of the chimney. Prior to this, a limited number of ad-hoc tests were undertaken by the contractor and CMB to establish the properties of the deposit. These concluded that it was not a fire risk, even though it burned while a flame was applied and created large amounts of smoke.

At the time of the incident two men were cutting holes through the wall of the chimney with an oxy-propane torch and were some 30-40 m above ground level. These holes were being made to allow the two men to form working platforms using scaffolding poles and wooden planks at various heights.

Having successfully cut a number of holes from the top in the upper portions of the chimney, they continued to work their way downwards towards the ground. Near the end of their working day a serious fire took hold whilst they were inside the chimney. This fire caused the ropes supporting their gantry to fail, allowing it to free-fall to the ground with the men in it. When the fire was extinguished the bodies of the two men were found in the wreckage of the gantry.

Figure 1. Appearance of tarry deposit in extract ductwork

THE INVESTIGATION

In common with many incident investigations, the exact cause of the fire could not be established, as the only two direct witnesses had been killed. The joint HSE/HSL investigation therefore concentrated on the four following areas.

1) Study of the accounts of eyewitnesses and supplementary information.
2) Examination of the oxy-propane cutting equipment being used by the victims.
3) Studies of the tarry waste including:
   a. chemical composition;
   b. properties of the chemicals liberated;
      thermal stability using thermo-gravimetry (TG) and differential scanning calorimetry (DSC); and,
   c. flash/fire point.
4) Studies of the potential combustibility of the tarry waste on samples of steel plate taken from the chimney.

EYEWITNESS ACCOUNTS AND SUPPORTING INFORMATION

EYEWITNESS STATEMENTS

Apart from a small number of points, little useful information could be gained from the direct observations of people who witnessed the event. Pertinent features were:

1) Material safety data sheets indicated that the paints/lacquers in use were all flammable;
2) It was plant policy to issue a periodic contract to chip the tarry deposit from the inside of ductwork and the lower reaches of the chimney;

3) Pre-demolition tests on the tarry deposit wrongly concluded that:
    a. the deposit was non-combustible, even though flames were formed on applying a
        cutting torch as well as significant quantities of smoke and it had historically been
        regarded as a fire hazard; and,
    b. for various reasons the contractor chosen was allowed to work on the inside of the
        chimney using hot cutting, even though other tenders suggested this was unsafe.
4) Hole cutting started at the top of the chimney and the workers progressed towards the
    ground, smoke seen to be emitted intermittently from the top of the chimney;
5) The thickness of the deposit in the chimney was reported to increase closer to the
    ground, with the centre portion containing a flaky deposit, rather than one which
    tightly adhered to the walls;
6) It was reported that the deposit glowed during cutting and produced black smoke;
7) No external indication of a fire was seen or heard until flames were seen coming from
    the latest holes cut through the wall, followed shortly after by flames shooting out of
    holes progressively higher up the chimney until they emerged from the top; and,
8) A small powder fire extinguisher taken into the chimney by the deceased was found to
    be discharged, it was not known if this had been used, or whether it was empty as a
    result of it being punctured when it fell to the ground.

   No indication was given by any party of faults with the equipment, complaints that
the deposit actually burned, (other than that it glowed and created black smoke), or early
signs of panic from the two workers inside the chimney which would suggest the start of
a fire. The major supporting evidence as to the potentially combustible nature of the deposit
comes from the material safety data sheets (MSDSs) for the products used at CMB.

SUPPORTING INFORMATION ON PAINTS/LACQUERS USED AT CMB
All six MSDSs for paints/lacquers used in the processes at CMB were listed as being either
flammable or highly flammable. Flash points listed range from less than 21°C to 32–62°C,
and lower flammable limits range from 0.8–1.2%, when quoted.
Taking one lacquer as an example, the following compounds were present. (Table 1)

Table 1. Major components present in a typical lacquer formulation

Compound	Concentration range
n-Butanol	Above 20%
2-Butoxyethanol	10–25%
Methoxy propanol	1–5%
Methyl iso-butyl ketone	1–5%
Shellsol A	10–25%
Phenol	Below 0.3%

With the exception of Shellsol A, for which no data on flammability is available to the authors, all other materials present are known to be flammable.

In view of this, and information given in all six of the MSDSs studied, it is concluded that there was a potential for fires occurring in plant associated with the painting/drying process, as all these products would carry over into the ventilation system to varying degrees.

EXAMINATION OF THE CUTTING EQUIPMENT

The cutting equipment used by the contractors was examined at HSL and few deficiencies found. The cylinders and regulators being used appeared adequate, were of the correct types and were fitted with flashback arrestors at the regulator, although none were fitted near the torch. No damage was found to the equipment remaining after the incident, other than that which could be attributed to fire damage, or to the fall. It was evident, however, that there were a number of connections in the hoses as, by necessity, they had to be long enough to allow them to reach to the top of the chimney (at least 60 m). As the relevant portions of these hoses within the chimney were destroyed in the fire, it was impossible to determine their state and provide comment on whether they were leaking or not. It is, however, understood that the oxygen and propane hoses were checked for leaks by the contractors and they found that all was in order. Furthermore, examination of the undamaged lengths of the hoses indicated that they were in good condition and as such it is unlikely that they were leaking at the time of the incident.

EXAMINATION OF THE TARRY DEPOSIT

As the cutting operations undertaken in the chimney would lead to a large area of the tarry deposit inside the chimney being affected by heat, it was necessary to understand what products were liberated, in what quantities, and whether the material showed any energetic decomposition. The results of these studies are as follows:

CHEMICAL ANALYSIS OF DEPOSITS COLLECTED AT INCIDENT SITE
Two types of test were performed. Firstly, the determination of products liberated at room temperature and secondly, the analysis of compounds formed on heating.

Table 2 contains a list of compounds detected along with approximate relative proportions. The most prevalent species are those listed on the MSDS, or their thermal breakdown products.

EXAMINATION BY TG AND DSC
Results obtained using TG and DSC are given in Table 3.

As would be expected, these results show increasing mass loss with temperature, with 95 % of the materials volatilising at temperatures up to 520°C.

Table 2. Relative chromatographic peak areas

Compound name	Retention time (min)	Relative peak areas			
		Headspace in sample tin	100°C	200°C	400°C
n-Butanol	3.5	2400	10	1200	3030
Methanol/butene	2.15	180	—	—	320
Ethanol	2.25	470	—	40	230
Acetone	2.35	130	—	—	120
t-Butanol	2.45	90	—	—	—
Butyraldehyde	2.8	50	—	—	—
Isobutanol	3.1	30	—	—	—
Amine	4.4	—	—	230	400
Butyl formate	4.5	110	—	—	—
Butyl acetate	7.6	20	—	—	—
Xylenes	9.5–11.5	40	—	—	—
C_3-Benzenes	15–17	110	—	—	—
Phenol	16.7	—	—	120	—
Isophorone	21.3	—	20	170	—
Phthalic anhydride	24.5	—	—	1300	2500
Other aromatics	25–31	—	—	530	3300
Tributyl aconitate	31.5	—	—	—	440
Tributyl acetylcitrate	32.4	—	—	920	6600

Table 3. Mass loss data for samples of the tarry deposit examined using thermo-gravimetry

Sample A		Sample B	
Temperature 0°C	Percentage mass loss	Temperature 0°C	Percentage mass loss
25–100	1.0	25–100	1.0
100–139	5.0	99–140	4.8
139–451	55.2	141–451	49.9
451–599	33.4	452–599	39.0
599–800	0.4	599–800	0.5
Total % loss	95.0	Total % loss	95.2

The DSC studies on the samples showed slight decomposition and energy release on heating, but at levels which would not be deemed to have contributed significantly to the incident. This can therefore be ruled out as a possible cause for the fire.

PROPERTIES OF THE CHEMICALS LIBERATED ON HEATING

Table 4 lists the physical properties for compounds detected on heating. Included is information on flash point, autoignition temperature, flammable limits and vapour density. It is evident that all vapours for which data could be obtained are denser than air and would tend to sink once initial buoyancy due to heating was lost.

It can be seen that the lower flammable limits (LFL) for the compounds present vary from 1.4% for butanol to 3.3% for ethanol. Not unsurprisingly, no specific data is available on the LFL of the mixture of components found during the chemical analysis, so the actual LFL of the mixture of compounds cannot be determined with any certainty. It will, however, be between these limits.

Table 4. Physical properties of materials detected in the tarry deposit

Temperature °C	Compound	LFL % volume	UFL % volume	Flash point °C	Autoignition temperature °C	Boiling point °C	Density g.cm^{-3}
Headspace in	n-Butanol	1.4	11.2	35–38	365	117.4	2.55
sample tin	Methanol	6	36.5	12	470	64.8	1.11
at room	Butene	1.6	9.3	−62	384	−6.3	1.93
temperature	Ethanol	3.3	19	13	423	78.32	1.59
	Acetone	2.6	12.8	−18	465	56.2	2.0
	t-Butanol	2.4	8.0	10	480	82.8	2.55
	Butyl formate	1.7	8.0	18	322	106.0	3.52
100	n-Butanol	1.4	11.2	35–38	365	117.4	2.55
200	n-Butanol	1.4	11.2	35–38	365	117.4	2.55
	Phthalic anhydride	1.7	10.4	152	570	284	5.10
	Tributyl acetylcitrate	No data available		204	Not available	172–174	Not available
	Ethanol	3.3	19	13	423	78.32	1.59
	Triethylamine	1.2	8.0	−7	—	89.5	3.48
400	Tributyl acetylcitrate	No data available		204	Not available	172–174	Not available
	n-Butanol	1.4	11.2	35–38	365	117.4	2.55
	Phthalic anhydride	1.7	10.4	152	570	284	5.1

Examination of the boiling points listed in Table 4 shows that, of the major components present, n-butanol has the lowest boiling point at 117°C (and was also present in the highest proportion). It is therefore likely that the onset temperature for mass loss from the samples tested using TG was due to boil-off of n-butanol.

FLASH/FIRE POINT OF DEPOSIT

The information presented in Table 4 may lead to the conclusion that the flashpoint of the deposit should lie somewhere around 40°C, taking the flashpoint for butanol as a major component. However, the actual situation is more complex as the deposit comprised of a mixture of compounds, each of which would contribute towards the development of a flammable atmosphere; and it was also a thick, viscous liquid which inhibited normal vapour evolution.

As a result of the non-standard nature of the material, it was decided to undertake both a standard flash/fire point determination, as well as performing a number of ad-hoc tests on large quantities.

The ad-hoc tests involved heating the material in a 2 litre sample tin fitted with a lid with a central 29 mm diameter hole. A small pilot flame was applied periodically to the hole in the lid and the occurrence of any burning noted. Some evidence of transient burning of vapours was observed from 260°C and persistent burning at 285°C.

Following these ad-hoc tests, a further more accurate flash/fire point determination was undertaken using the Cleveland Open Cup flash point apparatus. Briefly, the behaviour of the sample was as follows.

70°C	begins melting
112°C	sample bubbles and fumes – similar to a boiling liquid
145°C	flash of flame if pilot flame is present when gas bubble in sample bursts
195°C	burning on liquid surface for over 5 s
200°C	burning for 20 s

These results equate to a flash point of 145 ± 5°C and a fire point of 195 ± 5°C. It should be noted, however, that these results could be subject to some variation as the concept of a flash point is normally applied to a mobile liquid, rather than the viscous tarry liquid formed when the deposit from the chimney melted.

HOT CUTTING TESTS ON SAMPLES OF COATED STEEL PLATE

A number of tests were undertaken where sections of coated and uncoated steel plates were cut with an oxy-propane torch. The objectives of these tests were to:

1) determine the behaviour of the deposit when heated using a cutting torch and to compare the appearance of any flames with those seen with 'normal' cutting operations; and,
2) to establish the pattern of heat distribution through the metal using thermal imaging.

A direct comparison between the behaviour of coated and un-coated steel plate is evident in Figure 2.
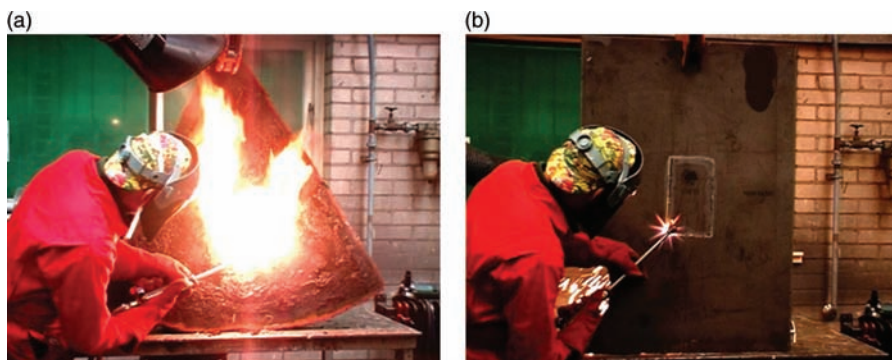
Figure 2. Behaviour of coated and un-coated steel plate during oxy-propane cutting

It is immediately apparent from Figure 2 that large flames are produced on applying the cutting torch to the coated plate, along with significant quantities of smoke. This should have been taken as a strong indicator that, given the wrong circumstances, the deposit was able to continue to burn. This behaviour also would have been seen during initial screening tests to establish the properties of the material prior to commencing work on demolition.

The appearance of flames such as these led to CMB undertaking further screening tests, which concluded incorrectly, that the deposit did not present a fire risk. CMB and the contractors wrongly assumed that because the material did not continue to burn after the removal of the cutting torch it would not pose a risk. A working procedure was therefore adopted of pre-heating the deposit with the cutting torch and then scraping the softened material away from the area to be cut. This would have limited the potential for clogging the nozzle of the cutting torch with tarry material, but instead introduced the alternative hazard of allowing significant quantities of flammable vapours to form.

CONCLUSIONS

The circumstances surrounding this incident are complex, with many mitigating factors requiring consideration. However, our investigations have demonstrated that the deposit should have been regarded as a fire risk and that hot cutting should not have been allowed. If trained fire scientists had been consulted, this incident could have been avoided.

There was definite evidence before the fire that the paints/lacquers were listed as being flammable, and that the tarry residue was regarded as a fire hazard by the factory's insurers. Despite these factors, plant personnel, as non-fire specialists, were misled by the outcome of the ad-hoc flammability tests they conducted and wrongly concluded that the deposit did not burn.

Our investigations established that many compounds present in the original paints/lacquers used at CMB were carried over into the extract system and were present in the

tarry deposit. When heated, these compounds were evolved giving a flammable vapour mixture. The flashpoint of this mixture was determined as $145 \pm 5°C$ and the fire point as $195 \pm 5°C$ using the Cleveland Open Cup method. In large scale ad-hoc tests using several hundred grams of material, the flash and fire points were around $260°C$ and $285°C$, respectively.

As well as the above direct evidence that the deposit represented a fire risk, further evidence of combustibility comes from tests where samples of steel plates taken from the chimney were cut using an oxy-propane cutting torch. During these tests it was confirmed that:

a) Large flames up to 60 cm high were formed while the torch was applied to the deposit and it continued to glow for a short time after removal of the flame; and,

b) Large areas of the deposit would have been subjected to heating, either by direct flame contact or thermal conduction, leading to the liberation of a large amount of flammable vapour in the chimney – if ventilation were poor, these vapours could have accumulated, possibly leading to an explosion risk.

Search for possible ignition mechanisms for the deposit pointed to four possible causes, these were:

1) Direct ignition of the deposit coating the chimney by the cutting torch, with the fire being fuelled by fresh material running from above;

2) Propane leak or rupture of the propane hose following a flashback, giving either an explosion in the chimney, or a large permanent flame from a ruptured/cut propane hose;

3) Oxygen leak, or accumulation of excess oxygen used in the cutting process, leading to enhanced combustion in the deposit by oxygen enrichment; or,

4) Accumulation of flammable vapours liberated by the tarry deposit when heated.

A major finding of our work was that whilst the above mechanisms could have ignited the material, it would not continue to burn when spread as a thin layer on a steel plate. It was therefore proposed that its combustion probably required the presence of a certain 'critical mass' in order to liberate sufficient heat to maintain combustion. In order for this to take place, either: the deposit in the area being cut must have been thicker; or, a large area of the chimney was suddenly heated - for instance by a gas/vapour explosion, or a major hose failure.

Experience gained during our experimental tests and observations inside the chimney after the fire, indicted that once a fire had become established it would rapidly heat material in the vicinity. The heated material would liberate flammable vapours and also melt. This flow of molten material into the burning zone would both feed the burning fire and give rise to increased fire spread by the direct flow of burning liquid.

As the only two direct witnesses to the event were tragically killed, a definitive answer as to the actual cause of the fire will never be known. What is certain is that any process involving flammable materials which can be deposited inside extract ductwork should be regarded as a fire hazard, and any restrictions on zoning or permits to work should also be extended into the extract system.

Subsequent to this investigation, the authors of this paper have found that a similar fire has occurred elsewhere in the UK where a process oven was used to drive off volatiles from a product. These volatiles accumulated in ductwork and a large chimney, and were also periodically removed to limit the fire risk - a direct comparison with the situation at CMB. In this second incident, changes to the oven's operating temperature led to a fire occurring in the ductwork which subsequently spread to the chimney, almost causing its collapse.