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Inherently ill-defined nature of waste: Fatal outdoor poisoning of hazmat waste collection driver – lessons learned

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Inherently ill-defined nature of waste: Fatal outdoor poisoning of hazmat waste collection driver – lessons learned

The paper examines the fatal poisoning of a vacuum truck driver who inadvertently mixed sulfuric and formic acid waste, which reacted to produce carbon monoxide gas in the truck's tank. The case highlights multiple systemic issues in the chemical waste disposal industry which may lead to repeat accidents. The paper argues that an ill-defined composition is an intrinsic property of any waste. Therefore, the guiding safety principle should be to avoid mixing and minimize manual handling to the widest extent possible. Transport for disposal of hazmat waste in non-conforming 1,000-liter pallet tanks presents two unattractive options: 1) A vacuum truck is a simple and cost-effective solution but entails chemical reactivity hazards upon mixing. 2) A 1:1 transfer of the contents to new compliant containers avoids mixing hazards but introduces manual handling hazards. The option of placing the pallet tank inside another approved enclosure appears unavailable in practice. Currently, the overall best option in many cases may be to transport the waste in the formally non-compliant pallet tanks, by having guidelines for when and how to relax compliance requirements. The paper argues that the current ADR regulatory regime and the hazmat disposal industry offer insufficient support in making safer options available.

Keywords: chemical waste; ADR road transport of dangerous goods; chemical incompatibility; formic acid; carbon monoxide;

Introduction

In 2009, carbon monoxide fumes killed a chemical waste collection vacuum truck driver. The waste generator was a mink feed producer with an unsophisticated hazardous chemicals management system. The waste was declared as an 80/20 mixture of sulfuric/acetic acid waste stored in nine 1,000-liter Intermediate Bulk Container (IBC) pallet tanks. One pallet tank however, contained another acid product: A proprietary animal feed preservative of which a main component was formic acid.

The driver trusted the transport documents and transferred the contents of all the pallet tanks into the vacuum truck. When mixed in the vacuum truck's tank, sulfuric acid and formic acid reacted to produce odorless and poisonous carbon monoxide which killed the driver. It may be the first reported outdoor fatal carbon monoxide poisoning due to accidental mixing of sulfuric acid and formic acid.¹

Road transport of hazardous materials (hazmat), including hazardous waste, is governed by the United Nations treaty concerning the international carriage of dangerous goods by road, abbreviated ADR for its French name. As of 2020, a total of 52 states, the European Union Member States included, are party to ADR.

The case offers an opportunity to examine the systemic failures and the human mistakes that led to this preventable accident, and present lessons learned to prevent recurrence. The accident has broad learning potential because:

- the individual portable tanks were not accepted for road transport due to ADR compliance concerns (inspection interval expired),
- ADR offers few options in the case of non-compliant IBCs, specifically that no approved outer enclosure, a so-called salvage packing, is available for 1,000-liters containers,
- the decision to use a vacuum truck was influenced by mundane cost-efficiency considerations,
- the widespread usage of the two incompatible chemicals (formic acid and sulfuric acid), particularly in the agricultural sector,
- the absence of chemical hazard labelling on formic acid warning users of evolution of toxic gas if mixed with strong acids, and
- the hazmat truck's vacuum pump discharge pipe was so located that fumes can pollute the driver's workspace

Background

Formic acid and sulfuric acid

Formic acid is an organic acid with a pungent odor not unlike acetic acid. It has antibacterial properties and has important applications as a feedstock preservative.

Formic acid is corrosive but has low toxicity (hence its use as a food additive).

Sulfuric acid is a low-cost strong inorganic acid. The main hazard is chemical burns upon contact with skin, inhalation of aerosols or ingestion. In contact with concentrated sulfuric acid, formic acid readily decomposes to toxic carbon monoxide and water.

Common applications

Formic acid is used widely in the agricultural sector, as is sulfuric acid, and both acids are used for common applications. Animal biomass can be preserved with formic acid and it is used extensively in the production of silage. Ensiling is based on fermentation under anaerobic conditions, whereby acidification due to the action of lactic acid producing bacteria preserves the silage. The addition of formic acid results in a rapid initial drop in pH, which promotes the growth of lactic acid bacteria and suppresses the growth of unwanted bacteria. Low-cost mineral acids (e.g. sulfuric acid) can be added to help lower the pH.^{2,3}

Large amounts of formic acid are used in the production of fish silage from fish industry by-products. Formic acid is the preferred acid in this application, often together with low-cost strong mineral acids.³⁻⁵ One of the biggest users of formic acid globally is the tanning industry. Pre-treatment of hides leaves them in a slightly alkaline state, but tanning requires acidic conditions. Therefore, the hides are treated with acid (typically sulfuric and formic acids) prior to tanning in a process called pickling.³

Carbon monoxide toxicity

Carbon monoxide is a colorless, odorless, and nonirritating gas with a density similar to that of air. CO lacks sensory warning properties which makes it difficult for those who are exposed to detect it. Initial poisoning is often asymptomatic. Mild effects are subtle and non-specific such as headache, nausea and dizziness. Moderate effects are weakness, confusion, chest pain and syncope. Severe effects are seizures, coma, and respiratory and cardiac arrest.⁶ Originally, the toxicity was exclusively explained by the ability of CO to bind to hemoglobin (CO-Hgb) with an affinity more than 200 times that of oxygen, decreasing oxygen delivery to the tissues and resulting in tissue hypoxia. More recent findings, however, indicate that CO poisoning is far more complex than initially presumed and has many mechanisms of toxicity directly at the cellular level. This can help to explain why CO-Hgb levels do not correlate well with the severity of clinical effects.⁶

In the United States, CO is the most frequent cause of fatalities from occupational inhalation exposure.⁷ Accidents almost exclusively take place in enclosed or partially enclosed spaces. In the case of CO deaths from motor vehicle exhaust, the majority of garage-related episodes occurred despite open garage doors or windows, underscoring the failure of passive ventilation to be a reliable means of removing CO from semi-enclosed spaces.⁸

While CO poisoning associated with outdoor activities occurs rarely, there are reported cases with e.g. recreational boating and agriculture. Exposure to the propulsion engine exhaust of water ski boats and cabin cruisers have led to severe poisonings. Fatalities are reported when swimming near the swim platform (a platform attached to the stern a few inches above the surface of the water) near the boat exhaust.⁶ Fatalities have occurred among persons seated in the stern of the boat.⁹ Outdoor carbon monoxide

poisoning have also been attributed to tractor exhaust when workers sit side by side with their backs to the tractor and set tobacco plants into the ground. The victims were working in an open field in minimal breeze conditions and exposed for many hours.¹⁰

The sparsity of reported outdoor CO poisonings and the absence of reported fatal accidents involving sulfuric acid and formic acid lead the authors of this paper to agree with the conclusion of Djafari et al.¹ that the present case may be the first reported outdoor fatal carbon monoxide poisoning due to accidental mixing of sulfuric acid and formic acid.

Material and methods

Primary sources are, unless otherwise indicated, dockets of the Danish Working Environment Authority obtained through the Danish equivalent of a Freedom of Information Act, a joint memo of the accident written by the hazardous waste disposal company and the haulage company and publicly available court documents.

Representatives from the waste disposal company, the haulage company and the maker of the vacuum truck have been interviewed in order to reconstruct the accident and for general clarification. ADR practitioners have been consulted for clarification of ADR rules and current practice when handling non-conforming 1,000-liter IBCs.

The accident case

Mink feed preservation chemicals

Mink animals are bred in farms for production of their furs. Being carnivores, the animals prefer to eat raw meat or fish. Freshness of the feed and a carefully adjusted diet are essential to obtain high quality furs. In Denmark, mink feed processing plants receive a wide variety of animal protein waste streams such as fish and abattoir offal.

Because offal is used and because the mink feed must be raw, spoilage and toxin formation from bacterial and fungal growth is naturally a concern. Mixtures of formic, propionic and sulfuric acid are often used for preservation.⁵

Furacid (trade name) is a preservative for abattoir and poultry by-products. It contains an inorganic acid, which lowers the pH, and combinations of organic acids that kill or inhibit bacteria. On the accident Furacid pallet tank, a scratched contents declaration label stated these substances (listed in this order): E200 sorbic acid, E236 formic acid, E260 acetic acid, E270 lactic acid, E280 propionic acid, E295 ammonium formate, E300 ascorbic acid, E330 citric acid, E338 orthophosphoric acid, and E471 mono- and diglycerides of fatty acids. Concentrations are not stated. The order seems to reflect ascending E-numbers, not mixture concentrations. The product was labelled: "UN 3265, 8 PG II, corrosive liquid, acidic, organic, n.o.s. (contains a.o. formic acid and lactic acid)".

The hazmat waste disposal request

Some days before the accident, Fodercentralen for Holstebro og Omegn, a Danish mink feed producer, approached Kommunekemi, the largest Danish hazardous waste disposal company, for disposal of some 'waste acid'. The two companies had not done business before. Communication was by telephone and exactly what was said was later subject to controversy in court.

The waste disposal company claim that they were asked to collect nine 1,000-liters IBC pallet tanks with about 6 m³ of a mixture of 80 % sulfuric acid and acetic acid. No detailed declaration of content was available for the mixture. The waste generator claimed they requested a professional waste management company to dispose of 'all the waste acids' in their warehouse. The latter claim was unsuccessful in court.

The decision to use a vacuum truck

The waste acid mixture had been used to test a new mink feed preservation recipe some time ago, but the results had been unsatisfactory, and the tests terminated. ADR requires that IBC tanks shall be inspected to the satisfaction of a competent authority at intervals not exceeding two and a half years¹¹. Because the waste acid had been kept in the warehouse for considerable time, the pallet tanks were clearly non-compliant with ADR inspection requirements and therefore not acceptable for transport.

The standard solution would be for the waste generator to order nine new IBC pallet tanks and transfer the contents of each tank to a new one. This option was unattractive however, as the means (transfer pump etc.) were not available at the site.

The transfer option would also leave unresolved the fate of the emptied non-compliant IBCs, which remained covered by ADR and were not acceptable for transport until rinsed, which the waste generator had no means to do either. The rinse water would also be covered by ADR. Workplace and handling hazards during transfer and rinse operations of the hazardous chemical waste tanks would also have to be managed. All in all, an arduous and costly affair. Eventually, it was decided to use a vacuum truck. Conveniently, this was also the least costly option.

The waste disposal company prepared transport documents for UN 1830, 8 PG II (sulfuric acid with more than 51% acid) and approached a major Danish transportation operator, which confirmed that an almost new vacuum truck was available for the job. It was arranged for the vacuum truck to bring a vacuum carriage trailer and an optional set of transport documents for the rinse water, in case the waste generator opted for disposal of this as well. The truck and the trailer tanks were to be completely clean and dry. An experienced 41 years old driver was chosen for the job. He was known as reliable and careful hazmat driver. The fact that rinse water disposal

had been discussed, but not agreed yet, is indicative of a casual commercial agreement with little formal planning and, conceivably, also of price haggling.

Reconstruction of the fatal poisoning of the driver

On the morning of September 16, 2009, the driver was directed to an alley, where the nine pallet tanks had been set out. The east-west oriented alley was about 7 m wide with a 2 m tall fence to the south and a 3-5 m tall building to the north. The temperature was 6°C, the wind was still (0.5 m/s), the relative humidity was about 100 percent and there was low lying fog.

A reconstruction of the poisoning concludes that the driver was exposed to dangerous CO fumes three times. Many vacuum trucks vent the vacuum pump's discharge gases upwards at height. The accident vacuum truck tank had tipping action however, which limited routing options for discharge gas piping. After passing through a flame trap, discharge gases terminated in a quick coupling located behind the left front wheel. This permits the driver to connect a hose and direct discharge gases away from the work area. A hose was not used however, as no dangerous fumes were expected.

The first exposure took place when the driver emptied the pallet tanks and CO rich vacuum pump discharge gases filled the narrow alley in wind still conditions. Using a remote-control panel, the driver walked from pallet tank to pallet tank with a suction spear, being 15-20 m from the vacuum pump's discharge pipe. The driver noticed that the vacuum pump had had some difficulty in maintaining suction. When done, he furthermore noticed that the vacuum tank had become warm, too hot to touch comfortably. Worried, he called his foreman. They decided that the driver should return the acid waste to the pallet tanks, flush the vacuum tank and hurry the vacuum truck to a service facility for a thorough rinse. During this conversation, he was likely near the

driver's cabin where CO rich discharge gases were released. Initially, CO poisoning can be asymptomatic.

The second exposure took place when he returned the waste mixture to the pallet tanks. The driver operated the vacuum pump's switch-over valve from suction to pressure in order to pressurize the vacuum tank. The waste mixture gave off CO fumes, and as the pallet tanks filled, the rising liquid forced the fumes out of the tank opening. Standing right next to the pallet tank, the driver would be exposed to those displacement gases. Initial symptoms of poisoning such as headache and dizziness are subtle and non-specific and may be mistaken for general stress and concern for the new vacuum truck.

Poisoned, but unaware of it, the driver tipped the vacuum tank for any remaining acid waste to flow towards the rear discharge valve. The third exposure took place when he climbed the vacuum truck with a rinse water hose and opened the forward dome hatch in order to flush the tank. CO fumes emitted from the open manhole caused the driver to collapse, and eventually, his death.

The initial response

An employee discovered the lifeless driver on the top of the tank, called the alarm number 112 and initiated CPR and mouth-to-mouth resuscitation. The employee soon felt unwell, left the scene and was later admitted to hospital for observation.

A chemical expert from the waste disposal company arrived in the afternoon and took samples. There was a dark organic or oily surface layer, which made representative sampling difficult. A scratched Furacid label on one of the pallet tanks led to a carbon monoxide poisoning hypothesis. An autopsy found no airway corrosions, hence sulfuric acid inhalation was ruled out, but confirmed CO poisoning with a blood CO-Hgb level at 62%.¹

Discussion

The inherently ill-defined nature of waste

Some years ago, an experienced operations manager of a hazardous waste incineration facility in Finland enlightened the first author of this paper on the very nature of chemical waste. An ill-defined composition is a fundamental property of chemical waste, he said. Indeed, probably an inherent property of any kind of waste. If the waste had a well-defined or homogeneous composition, he argued, some clever use of it could probably be devised. Waste is often waste however, precisely because its composition is not known in detail or its variability is too large. Asked about the reliability of hazardous waste content declarations, he simply replied: 'Paper is paper, but waste is waste'.

Other authors have remarked that the concentrations of chemical constituents in hazardous waste can vary greatly from one load to the next.¹² This poses practical difficulties for prospective assessment of risk because a chemical reactivity hazard is often a function of the concentrations of constituents within the waste.¹³ Because of its ill-defined nature, managing waste is inherently more challenging than managing typical chemical process hazards.¹⁴ A study of 142 incidents reported to UK HSE caused by unintentional mixing of incompatible waste chemicals found that 62% of the incidents occurred at waste generator sites. The practice of bulking of batches, i.e. the placing of smaller quantities of what should be similar materials into larger containers, accounted for approximately 70% of incidents at waste generator sites.¹⁵

At the waste generator site, the pallet tanks had languished in a warehouse after an abandoned mink feed conservation test series. Detailed knowledge about the contents seems to have been lost over time. This paper argues that for the hazardous waste collection industry, this situation is only to be expected as imperfect knowledge and

some uncertainty about contents are fundamental challenges. Therefore, mixing of chemical waste has elements of inherent unpredictability. So has management of manual handling hazards. Both are unsafe activities and should be avoided.

Compliance concerns, petty bureaucracy, few available options

The decision to use a vacuum truck, where mixing of the contents of the pallet tanks is unavoidable, was guided by ADR compliance concerns, because the inspection intervals of the IBC pallet tanks had long expired. With the benefit of hindsight, the more laborious and more expensive 1:1 transfer to new IBCs should have been chosen. We believe that petty bureaucracy, perfunctory compliance with safety rules and concerns about costs were detrimental to safety in this case.

We argue that the key underlying problem is that available options are few. While damaged, defective, leaking or non-conforming packages are not acceptable for transport, ADR nevertheless permits that such packages may be carried for purposes of recovery or disposal if placed inside a salvage packaging.^{16,17} In ADR terminology, *packaging* refers to the enclosure, *package* refers to the enclosure and its contents, and *overpack* refers to placing one or more packages in a packaging.¹⁶ ADR practitioners inform us that damaged or otherwise non-conforming hazmat cans, jerricans and pails are routinely carried by placing them in larger ADR approved containers as overpack. The salvage packaging used is typically an open-top drum with a separate lid secured by a metal locking band. In practice, the largest open-top drum available has a capacity of about 300 liters allowing transport of a damaged standard 200-liter (55 US gal)

drum/barrel. For a non-conforming 1,000-liter IBC with strong acid however, no standard salvage packing is available. ADR practitioners questioned if it existed at all¹.

Practitioners also inform that applications for waiving ADR requirements are very rarely used in practice. ADR standardizes rules for cross-border transport of dangerous goods. The rules ensure safe transport over long distances that may involve intermediate storage at transportation hubs, different modes of carriage and the occasional rough handling. Transport of hazardous waste by only one operator over a short distance directly to a disposal facility presents a more controllable and hence benign environment. We argue that for this special situation, the provision of a mechanism for short-term ADR exemptions could be considered. The basic argument is that if compliance with certain ADR safety requirements creates new hazards (mixing, handling etc.), the provision of a mechanism to waive those requirements may be reasonable and defensible, if it improves overall safety. The classic prescriptive command-and-control approach with its emphasis on safety rules and procedures has undeniably led to improvements in safety¹⁸ but some adaptation, even improvisation,

¹ The 2015 edition of ADR introduced a so-called large salvage packaging, which exceeds 400 kg net mass or 450-liters capacity but has a volume of not more than 3 m³.¹⁶ A larger size packaging such as an IBC of type 11A can also be used.¹⁷ As per ultimo 2020, an Internet search finds that a few vendors offer 11A IBCs with a drop-down front door allowing easy access for a forklift. However, IBCs of type "11" are approved for solids only.³² Other vendors offer large salvage packagings made of galvanized steel, presumably for liquids, but how to lower a non-conforming IBC safely into the enclosure may be a challenge. Furthermore, standard galvanized steel is not resistant to attack by acids, which would be a concern in case of leakage of such substances.

may be required in the process of transforming fluctuating inputs into low-variability outputs.¹⁹ More research on how to do this in practice is required.

Observed temperature rise unexplained

Formic acid can decompose by dehydration and liberate gaseous carbon monoxide. The reaction is catalyzed by strong acids.²⁰ A few cases of suicide due to this reaction are reported in the literature.^{21,22}

The enthalpy of reaction ($\Delta_r H^\circ$) is positive, i.e. the reaction is endothermic, it consumes energy and cools the mixture. The observed temperature rise in the vacuum tank can therefore not be explained by the decomposition reaction *per se*. The reaction produces some water however, and heat is liberated by hydration of the concentrated sulfuric acid due to its negative enthalpy of dilution.²³ Any other water added will also contribute with enthalpy of dilution.

Lack of information on the composition of Furacid and the sulfuric acid waste place further analysis in the realm of conjecture. Google can find sources in Dutch and Ukrainian languages which indicate that the product contains 46% formic acid and 16% water. Assuming the Furacid pallet tank was half full and the sulfuric acid strength was 80 %-weight, sketch calculations show the chemical reactions would generate 180 kg of CO and heat the mixture by 7 °C. This cannot possibly explain that the vacuum truck became too warm to touch comfortably, perhaps 50 °C.

Sketch calculations show that for the tank to reach 50 °C, 1,200 kg of water would need to find way into the vacuum truck. A plausible source is that at least one of the pallet tanks did not contain acid waste, but the contents of an old offal preservation

test run, which had turned into liquid silage over time. This could also explain the observed oily layer, which troubled taking samples of the post-accident waste mixture.

The observed temperature rise in the vacuum tank was therefore no sign of a chemical reaction liberating poisonous gas, but a sign of water being present in the substances mixed.

Information asymmetries in the owner – contractor – subcontractor chain

Using common contractual terminology, an owner of hazardous waste hires a specialist contractor to perform an activity (hazardous waste disposal). In turn, the specialist contractor hires a subcontractor to perform a part activity (waste collection). There are several challenges to the management of safety critical information in this chain of entities.

Important information asymmetries exist. Such asymmetries can be a source of moral hazard that leads to opportunistic behavior.²⁴ The waste generator has far better information on the hazardous waste than the waste disposal company. The retrieval of this information may require effort and time however, which are always in scarce supply. In theory, limiting the flow of information in a low-trust commercial arrangement may be perceived as advantageous, if it is believed that the opponent will use the information to demand a higher price.

Knowledge asymmetries exist. The hazardous waste disposal contractor has superior knowledge on chemical incompatibility hazards. The task of waste collection was passed to a haulage contractor, and the hazard was managed by ADR transport documents, a blunt bureaucratic instrument. When problems arose, the driver contacted his foreman at the haulage company, whose chemical knowledge was limited or non-

existent and naturally was concerned about the condition of the new vacuum truck, an expensive asset. This led to the sad decision to return the waste acid to the pallet tanks.

Labelling of formic acid is silent on chemical incompatibility with sulfuric acid

As stated earlier, formic acid and sulfuric acid are widely used in common applications. Common sense suggests that accidental mixing is only to be expected due to human error, slips and mistakes, certainly if users are unaware of CO hazards if mixed. We have perused many Material Safety Data Sheets (MSDS) for formic acid. We observe that most are silent, at best vague, on the reactivity hazard and offers no warning that mixing with concentrated sulfuric acid may produce poisonous carbon monoxide gas.

The hazard classification and labelling section on the European Chemicals Agency's (ECHA) Infocard on formic acid states the corrosive (GHS05), flammable (GHS02), acute toxicity and health hazards (GHS06/07) only.^{25,26} ECHA's guidance on safe use Section 10 (Stability and reactivity) mentions hazardous reactions with alkalis and amines only, not acids.²⁷

Similar labelling is provided in the US CDC/NIOSH Pocket Guide to Chemical Hazards stating formic acid's corrosive properties and health hazards only. The pocket guide's section on Incompatibilities & Reactivities lists: 'Strong oxidizers, strong caustics, concentrated sulfuric acid' but does not mention that carbon monoxide can be released.²⁸

The International Chemical Safety Cards (ICSCs) correctly informs about the hazard. It states: 'Decomposes on heating and on contact with strong acids. *This produces carbon monoxide.*' (emphasis added).²⁹ This appears to be a sole voice of caution.

There seems to be an unresolved broader regulatory issue on the need for and how to label chemical incompatibilities. The international Globally Harmonized System of Classification and Labelling of Chemicals (GHS) offers pictograms for some mixing hazards, e.g. substances which in contact with water emit flammable gases (division 4.3), oxidizing substances (division 5.1), and organic peroxides (division 5.2). But there is no pictogram for the release of poisonous gases if mixed with strong acids. Besides formic acid, such a pictogram would be relevant for e.g. sulfides (H₂S hazard), cyanides (HCN hazard), and hypochlorites (Cl₂ hazard). The concept of 'compatibility groups' does exist in the GHS system, but only for Class 1 Explosives, not for chemicals. Only the US-EPA has suggested a definition for 'hazardous waste reactivity' but it has several limitations.¹³

The accident revisited – root causes

The brief root cause analysis below will follow established principles aiming to trace direct causes back to organizational shortcomings and system failures in conjunction.³⁰ Specifically, it will not accept human error as a valid cause because it diverts attention from what can be done by better design, technical as well as organizational and institutional.³¹ From an accident prevention point of view, we consider it futile to blame the driver and his supervisor for the decision to return the waste as we believe that most people with their background would react similarly, if put in the same situation.

The following terminology is used. Immediate cause: the unsafe act or condition that led to the accident. Underlying cause: the failures in the way risks are managed that allowed the unsafe act or condition to arise, Root cause(s): the events or situations that started the chain of events that resulted in the underlying and immediate causes; typically a failure of management, planning or organization.

The obvious immediate cause was setting out the Furacid pallet tank for disposal. Even more important but less obvious, setting out one or more pallet tanks with much water (likely silage) for disposal. This was the trigger event that led to the temperature rise in the tank, which in turn led to the fatal decision to return the acid waste to the pallet tanks. The underlying cause for setting out wrong pallet tanks for disposal was a deficient hazardous chemical management system and poor labelling practices at the waste producer. The underlying cause for the poor decision to use a vacuum truck was a weak and informal managerial process at the waste disposal company. The underlying cause for the ill-advised decision to return the acid waste to the pallet tanks was a weak and informal managerial process and lack of response plan at the haulage company when things did not go as planned (warm tank discovered etc.). The root cause at the organizational level is that an overall strategy of avoiding any mixing of hazmat waste was given insufficient priority.

The root cause at the institutional level, i.e. circumstances that are beyond managerial control, is that the ADR regime offers insufficient support in making safer options available. The term large salvage packagings was only introduced in the 2015 ADR edition. While ADR does not prevent the use of large salvage packagings, no standardized solution to non-conforming 1,000-liter IBCs is available in practice. Additionally, there is no mechanism for waiving ADR requirements for short transport of chemical waste directly to disposal and no guidance on when and how this would be a sensible and sound course of action.

Conclusion

Common sense suggests that a request for disposal of chemical waste in 1,000-liter IBC containers for which ADR compliance is in doubt, is no extraordinary occurrence in

industry. How to deal with this situation in a safe manner is essential. Imperfect knowledge and some uncertainty about contents are fundamental challenges in the hazardous waste collection industry. Therefore, the guiding safety principle should be to prevent mixing and minimize manual handling to the widest extent possible.

The root cause analysis argues that the current regulatory regime and the hazmat industry offers insufficient support in making safer options available. Regarding salvage packaging, no standardized solution to non-conforming 1,000-liter IBCs in liquid service is available in practice. Studies should be launched to find simple and preferably low-cost solutions to rectify this situation. Additionally, the possibility of waiving certain ADR requirements for short transport of chemical waste directly to disposal seems to be unexplored. Studies are required to provide practical guidance on when and how such waivers could be a sensible and sound course of action. Research into such solutions, their pros and cons and how to manage them in practice is required.

The current practice for classification and labelling of formic acid does not warn users that mixing with strong acids may produce toxic carbon monoxide. This is unfortunate as formic acid and strong mineral acids appear to be in widespread and common use. More attention to this labelling practice is warranted.

The case exposes fundamental and structural issues in the chemical waste disposal industry. Economic incentives and cost-competitive pressures favor collection of chemical waste by vacuum truck in order to satisfy ADR requirements in the case of non-conforming IBCs. Hence, the scene appears set for future repeat accidents.

Conflicts of interest

The authors declare they have no conflicts of interest.

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