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VIEWS

Insight of chemical environmental risk and its management from the vinyl chloride accident

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Abstract The combustion of vinyl chloride (VC) after the train derailment accident in Ohio, USA in February, 2023 has caused widespread concern around the world. This paper tried to analyze several issues concerning the accident, including the appropriateness of the VC combustion in the emergency response in this accident, the meanings of so-called "controlled combustion", the potential environmental risks caused by VC and combustion by-products, and follow-up work. In our view, this accident had surely caused environmental and health risks to some extent. Hence, a comprehensive environmental risk assessment is necessary, and then the site with risk should be comprehensively remediated, hazardous waste should be harmlessly treated as soon as possible. Finally, this accident suggests that further efforts should be taken to bridge the gap between chemical safety management and their environmental risk management.

Keywords Vinyl chloride, Combustion, Chemical safety management, Environmental risk, Emerging contaminants

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On February 3, 2023, a freight train derailed in Ohio, USA, 20 tank cars of which were loaded with dangerous materials, and 5 ones were loaded with 115,580 gallons (~438 m^3) of vinyl chloride (VC), causing a serious chemical accident (NTSB, 2023). VC is a volatile, flammable and explosive chemical, which is classified as a class I carcinogenic compound to human by the International Agency for Research on Cancer (IARC). For storage and transportation, it is usually stored as a liquid in special double-layer tanks. In the emergency treatment of the accident, the VC was directed into a trench and burned off, producing a huge mushroom cloud of black smoke, arising global concern on the following questions.

1 Whether should VC be burned on the spot after the train derailment or not?

In accidents like the Ohio derailment, moving the derailed chemical tank cars are very difficult and dangerous, so it is better to deal with them on the spot. Further, the tank temperature rise indicated a polymerization reaction of VC and its explosion risk (NTSB, 2023). Compared with ignition, explosion is more dangerous and less controllable, and also will inevitably pollute the environment, causing environmental risks. Explosion is

the most frequent chemical accidents (Zhang et al., 2021b), which should be the most preferentially avoided in the emergency response. Quite a lot of VC explosion accidents happened all over the world, resulting in serious casualties. Controlled combustion can reduce the casualties caused by more dangerous explosion (Wang et al., 2016). Some opinions suggested to dilute VC with water to avoid explosion. However, VC is very volatile, and its water solubility is so low that water dilution of such a large volume of VC would be inefficient and inappropriate in such an emergency. On the other hand, if VC was released directly into the environment without ignition, it would cause an environmental and health disaster due to its huge amount and various toxic effects, as well as a more extensive explosion risk associated with the spread of VC and air mixture. Therefore, this option is totally unaccepted.

2 Was VC burned under control in this accident?

The leaked VC itself as well as the hydrogen chloride and phosgene generated during combustion would cause acute hazard effects, which made the evacuation of up to 2000 local residents necessary. However, this so-called "controlled combustion" can only control the combustion zone, not the generation more hazardous by-products, such as polychlorinated dibenzodioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs), polychlorinated naphthalenes (PCNs), and polycyclic aromatic hydrocarbons (PAHs) (Liu et al., 2021; Wang et al., 2003; Zhang et al., 2021a). Benzene, an important precursor, was also found in some tank cars (NTSB, 2023), which can make the de novo synthesis of such by-products easier.

At present, chlorinated chemicals are still being produced worldwide and a large amount of chlorinated legacy chemicals have not yet been safely disposed of after being banned for decades, due to insufficient non-incineration and controlled incineration treatment capacities. Chlorinated substances should be disposed of using best available techniques (BAT) by licensed hazardous waste incineration institutions, under strict conditions, including maintenance of combustion temperature (> 1100 °C), oxygen, residence time, and appropriate turbulence in the combustion chamber. The exhaust gas and flying ashes should be strictly treated, and discharged only after meeting the emission standards. Open-air combustion of VC will inevitably produce various hazardous by-products, such as PCDD/Fs, PCBs, PCNs, and PAHs, which are much more stable than VC, phosgene, and hydrogen chloride, with half-lives of several years to decades, posing long-term effects.

3 What environmental risk was caused by the combustion of VC in this accident?

Publicly, there are mainly two conflicting views on the environmental risk caused by the combustion of VC. One view is that the environmental risk is very high. Some people thought that this accident would pollute Lake Erie and the Ohio River in a large range, endangering drinking water sources for millions of people. Some experts considered that this accident destroyed the town, and worried about the cancer outbreak in a few years. It was even exaggerated that the harm of this incident was comparable to the explosion accident of Chernobyl nuclear power plant. Another view is that the environmental risk is very small. Based on this view, the mandatory evacuation order of local residents was revoked on February 8, because the sample monitoring showed that the local air and water were safe, without any "noteworthy" pollutants. However, this conclusion could be questionable without comprehensive and adequate monitoring and risk assessment of all possible pollutants in all environmental media.

Both of the above views might be biased. This accident had surely caused environmental and health risks to some extent. The most likely environmental risk is the impact on soil and groundwater. Soil is the medium directly receiving non-ignited VC and combustion by-products, which would inevitably infiltrate and diffuse in the soil and groundwater. These pollutants degrade slowly in the anaerobic and light-deficient underground environment, and their removal from soil and groundwater is difficult. Especially, PCDD/Fs are more noteworthy due to its persistence in the environment and high toxicity. We should avoid the painful lessons of PCDD/F pollution in human history, such as PCDD/F pollution in Times Beach, Missouri, USA in the 1970s, PCDD/F pollution of "Agent Orange" in Vietnam in 1960s and 1970s, and PCDD/Fs generated by an explosion in Icmesa chemical company, Seveso, Italy in 1976.

Although some measures have been taken to prevent surface water pollution, it is inevitable that a certain amount of VC and combustion by-products will enter the nearby surface water and diffuse with water flow. The Ohio governor recommend local residents to drink bottled water, indicating the potential risk of local drinking water source (Gans, 2023). A large number of dead fishes also occurred in the adjacent surface waters, indicating the input of VC and other chemicals with acute toxicities and their obvious impact on water environment. However, whether a larger range of drinking water sources are polluted still needs further evaluation.

In the process of VC leakage and combustion, the levels of harmful chemicals in the air must be high in a short period, posing a high risk of inhalation. However, after the combustion process, there is no continuous input source. The volatile chemical gas will soon diffuse and

dilute or precipitate to the ground. Volatile VC is easy to be photodegraded in the atmosphere. The pollutant levels in the air would be quickly decreasing over time. However, if the chemicals in the soil and groundwater were not cleaned, they would release volatile toxic organic pollutants for a long period, resulting in the long term air inhalation risk for local residents. Some local residents who returned home complained of peculiar smell, headache and nausea, which proved the potential air risk (Goodman and Alvarado, 2023).

4 What follow-up work should be taken?

Currently, the public information is too little to conduct a comprehensive risk assessment, hence the follow-up work should be done, including monitoring and evaluation, hazardous waste disposal, site remediation, and resident relocation before ensuring safety (Fig. 1).

First, the water, soil, groundwater, air, local vegetables, fish and other food sources should be continuously monitored. Ohio is an agricultural region in USA. Due to the potential soil and groundwater pollution, the local agricultural crops should be continuously monitored to ensure their safety. The derailed train was not only loaded with VC, but also some other chemicals. A variety of by-product chemicals were also generated by combustion. These pollutants form a complex mixture, whose risk is particularly difficult to evaluate due to their cocktail effect. The monitoring should not only take VC as the monitoring target, but also other potential chemicals, to provide basic data for comprehensively assessing ecological and residential exposure risks, and determining the impact range of this accident.

After the risk assessment and determination of the impact range, the site with risk should be comprehensively remediated as soon as possible. The solid waste should be incinerated in the high-temperature incinerator under strict conditions, or safely buried in landfill after stabilization. The wastewater should be collected and harmlessly treated to remove toxic chemicals. As reported, some high-risk solid wastes and wastewater generated in this accident were transported for *ex-situ* treatment. Compared with in situ treatment, long-distance hazardous waste transportation for ex-situ treatment may cause secondary pollution. Therefore, during the waste transportation, storage, and disposal process, strict supervision and management should be carried out to ensure environmental safety.

Currently, some local residents are worrying about their potential exposure to the toxic chemicals, and are considering moving out of this place. The comprehensive risk assessment and remediation will take a long time, and the local residents should be relocated responsibly. Only when it is confirmed that all environmental media are free of risks caused by all the potential pollutants, can residents return to their place of residence.

5 Bridge the gap between chemical safety management and environmental risk management

With the development of modern industry and agriculture, more and more chemicals have been produced in large quantities to meet our need, and unfortunately pollute the environment. The number of chemical substances registered in the Chemical Abstracts Service of American Chemical Society, which is coincidentally located in Ohio, increases rapidly, and at present, reaches 204 million (CAS, 2023). We are facing the threat of more and more chemicals, and VC is only one of them.

It is better to solve the chemical risks from the source. Substitution of highly hazardous chemicals and their end products is a priority if possible, for example, a more environment-friendly substitution of PVC plastic can eliminate the production of most VC. If substitution is unfeasible in the short period, the whole hazardous chemical industry chain should be completed at the same place as far as possible to reduce transportation. If transportation is necessary, strict transportation management and risk prevention measures should be taken to ensure safety. The Bureau of Transportation Statistics showed 54539 train derailments occurred in USA from 1990 to 2021, with an average of 1704 per year (Kika,

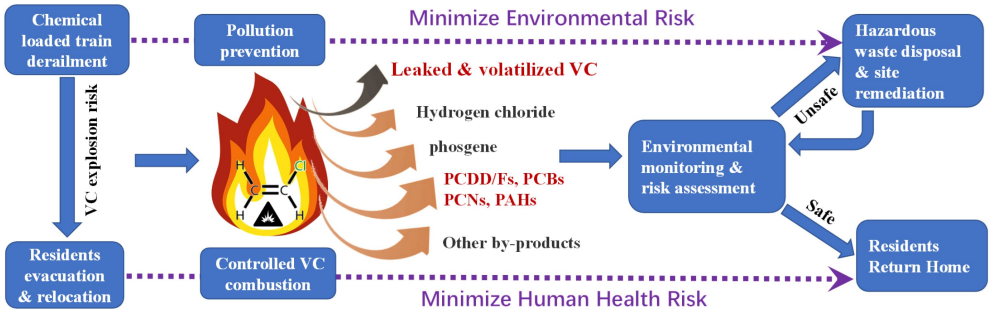

Fig. 1 The vinyl chloride accident and the follow-up work should be taken.

2023). Transportation is an important risk source of chemical safety in USA. While, among 64 major hazardous chemical accidents occurred in China from 2016 to 2020, only two of which were caused by transportation, accounting for 3.1% (Zhang et al., 2021b).

Environmental risk may arise in the whole life cycle of chemicals (Zimmerman et al., 2020). Accidents can occur during chemical production, use, storage, and waste disposal, besides transportation, causing potential environmental and health risks (Fig. 2). Chemical risk management is a complex system, which should include chemical safety management and its environmental risk management. However, there is always a gap between them, which is also reflected by the emergency responses of this accident (NTSB, 2023). In environmental risk assessment of chemical accident, various complicated environmental factors should be considered, and inevitable uncertainties will lead to variable results and even disputes.

This accident should elicit thinking all over the world, including China. In 2019, the global chemical industry production value was about 3415 billion US dollars, and China was the largest chemical industry producer, accounting for about 36% of the global total. It is estimated that by 2030, China's chemical industry production value will reach 50% of the global total (CIRN, 2022). The production and use of chemical substances are the main sources of environmental pollutants. In the past, the environmental chemical pollution management in China mainly focused on comprehensive indicators, such as COD, BOD. These comprehensive indicators are not clearly linked with the source chemicals. In most recent years, China has initiated emerging contaminant (EC) control action (Wang and Yu, 2022). The chemical pollution prevention will focus more on individual EC-source chemicals with high environmental risks one by one.

The EC control involves a long chemical industry and life chain. It requires the coordination of multi-departments involved in the life-cycle of EC-source chemical. This is reflected in China's EC control action plan, that is, to carry out a comprehensive control over the whole life of the production, import and export, storage, sales, use and disposal of EC-source chemicals. However, the current EC control action plan does not involve the transportation process. It is suggested that the transportation management department be included in the responsible departments to reduce the transportation risk of EC-source chemical. In short, it can be expected that the EC control action will bridge the gap between chemical safety management and their environmental risk management in China (Fig. 2).

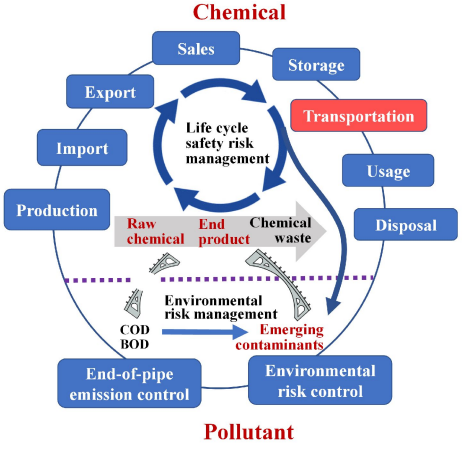

Fig. 2 Bridge the gap between chemical safety management and environmental risk management.

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