Study on influencing factors of atmospheric environmental risk of bulk liquid chemical leakage at wharf

Shou Youping¹,a, Zhao Junjie¹,b*, Qian Lihong²,c, Zhu Yuxin¹,d, Qiao Jianzhe¹,e, Wang Ning¹,f

¹Laboratory of Waterway Environmental Protection Technology, Tianjin Research Institute for Water Transport Engineering, Tianjin 300456, China
²Hangzhou Environmental Protection Research Institute Of China Coal Technology & Engineering Group, Zhejiang 311201, China

a,e-mail: syp851228@126.com, c,e-mail: 284990817@qq.com,
d,e-mail: 55450526@qq.com, e-mail: 77406661@126.com
f,e-mail: 15644457@qq.com,
* Corresponding author: b ppurelife@163.com

Abstract—In this study, 10% pipe diameter leakage was taken as a typical accident of liquid chemical leakage in bulk at wharf. The leakage rate and evaporation rate of 8 common chemicals were calculated using Bernoulli equation of fluid mechanics and mass evaporation rate. The evaporation rate and the concentration of toxic endpoint were compared. SLAB model was adopted to analyze the atmospheric environmental risk of chemical leakage under typical accident conditions. According to the calculation results, the atmospheric environmental risk under the scenario of 10% pipe diameter leakage accident was acceptable.

1.INTRODUCTION

According to data reports, among the chemical accidents registered in 95 countries, the common negative chemicals with sudden leakage were analyzed according to their morphology: liquid 47.8%, liquefied gas 27.6%, gas 18.8% and solid 8.2%. From the perspective of accident sources, transportation is 34.2%, collision is 26.8%, human factors are 22.8%, external factors (earthquake, lightning, etc.) are 16.2%[1]. According to the above data, the proportion of accidents caused by liquid chemicals is the highest.

The International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk[2] defines liquid chemicals in bulk as those whose absolute vapor pressure does not exceed 0.28MPa at a temperature of 37.8℃. The physical and chemical properties of liquid chemicals mainly include inflammability, toxicity, corrosiveness and reactivity. Among them, toxic hazards include direct contact toxic hazards and indirect contact toxic hazards. In the process of loading and unloading, people will avoid liquid chemicals when liquid chemicals leak. Therefore, the impact of liquid chemicals on human health is mainly reflected in indirect toxicity, that is, the impact of liquid chemicals on human health after leaking into the air. The toxic effect on human health is mainly determined by the volatilization and toxicity of liquid chemicals themselves [3].
According to the Technical Guidelines for Environmental Risk Assessment of Construction Projects (HJ169-2018) [4], the impact of liquid chemicals on human health is mainly reflected by the concentration of atmospheric toxicity endpoint.

According to accident statistics at home and abroad, 10% pipe diameter leakage is the most common accident occurring on the wharf surface[5]. At present, domestic liquid and chemical terminals are required to construct a barrier and set up a liquid collecting tank in the loading and unloading area to collect the leaked materials in the loading and unloading operation[6].

The study on DN200 diameter pipe aperture leakage as a typical accident risk, 10% chose styrene, benzene, methyl methacrylate, dimethyl formamide, acetic acid, phenol and chloroform, epoxy propane as a typical material, 8 kinds of common chemicals used to analysis the atmospheric environment caused by liquid chemicals pipeline leakage.

2. TECHNIQUES AND METHODS

2.1. Leakage rate calculation formula

The pipe diameter of the chemicals loading and unloading at the dock is DN200, which is taken as a case for study in this study. According to technical Guidelines for Environmental Risk Assessment of Construction Projects (HJ169-2018), the maximum possible accident is the leakage condition of 10% pore diameter.

The maximum land-area leakage velocity of the loading and unloading pipeline can be calculated by Bernoulli equation of fluid mechanics, and the leakage velocity can be calculated by the following empirical formula:

\[ Q_L = C_d A \frac{\sqrt{2\rho g h (P - P_0)}}{\rho} \]

Where:
- \( Q_L \) -- liquid leakage rate, kg/s;
- \( C_d \) -- liquid leakage coefficient, 0.65 according to the circle.
- \( A \) -- Fracture area, pipe diameter DN200, 10% pipe diameter leakage was considered in this evaluation, pipe diameter is DN200, \( A = \pi R^2 = 3.14 \times 0.012 = 0.000314 \text{ m}^2 \).
- \( \rho \) -- The density of fluid leakage.
- \( P \) -- Pressure of medium in the container, design pressure of pipeline is 1.8MPa.
- \( P_0 \) -- environmental pressure, 101325Pa;
- \( g \) -- acceleration due to gravity;
- \( h \) -- the height of the liquid level above the breach, m; in case of pipeline leakage, the height is 0.

Considering the leakage caused by pipeline disconnection during loading and unloading operation, the valve can be closed within 5 minutes and the leakage can be stopped within 10 minutes. Leakage occurs during loading and unloading. Due to the concrete floor and necessary cofferdam at the wharf, the loading line will not flow into the accident pool immediately. Under the action of wind evaporation, it will volatilize into the atmosphere and produce atmospheric environmental impact. Considering the physical and chemical properties, volatilization and toxicity of materials, it is assumed that leakage can be stopped within 10 minutes after the occurrence of a leakage accident. According to the physical and chemical properties and toxicological properties of loading and unloading cargo, the minimum liquid level thickness of concrete floor is 0.005m.

2.2. Evaporation rate calculation formula

According to technical Guidelines for Environmental Risk Assessment of Construction Projects, the evaporation of leaking liquids is divided into three types: flash evaporation, heat evaporation and mass evaporation, and the total evaporation is the sum of these three types. This project does not involve low temperature storage, and the evaporation involved is mass evaporation. Mass evaporation velocity \( Q_3 \) is calculated as follows:

\[ Q = \frac{\alpha \rho M}{\sqrt{RT}} \left\{ (\alpha + \delta) \rho (\alpha + \delta) \right\} \]

Where:
- \( Q \) - mass evaporation rate, kg/s.
\[ \alpha, n - \text{Atmospheric stability coefficient, selected according to Table A2-2 HJ/T169-2004, is 0.005285 and 0.3 respectively.} \]

\[ p -- \text{Liquid surface vapor pressure, Pa.} \]

\[ R - \text{Gas constant; J/mol \cdot k.} \]

\[ T_0 -- \text{ambient temperature, k.} \]

\[ u -- \text{wind speed, m/s.} \]

\[ r- \text{pool radius, m.} \]

3. THE CALCULATION RESULTS

3.1. Calculation of leakage quantity of dangerous goods and radius of liquid tank

The most unfavorable meteorological conditions were F stability, wind speed of 1.5m/s, temperature of 25°C, and relative humidity of 50%. According to the calculation, the evaporation capacity of each substance is listed in Table I. Combined with the calculation formula and results of evaporation rate, this study considers that the factors that influence evaporation rate the most are liquid and saturated vapor pressure and liquid pool radius.

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

3.2. The selection of the most influential factor

Reductions toxicity concentration - 2 short-term exposure to personnel health effects of air pollutants concentration, concentration of toxic end - 1 for personnel short-term exposure in the concentration of air pollutants of death, according to the evaporation rate of hazardous substances and the ratio of the toxic atmosphere end density listed in table 2, according to table II, this study represented by epoxy propane for atmospheric environmental risk prediction factor evaluation.

3.3. The impact analysis

In this study, the prediction factor of continental leakage was propylene oxide and the grid spacing was 100 meters.

According to HJ169-2018, category F stability, wind speed of 1.5m/s, temperature of 25°C and relative humidity of 50% were selected as the most unfavorable meteorological conditions for the second-level evaluation. The integrated Service Center of Sunshine Island was located in the north side of the project, and the unfavorable wind direction was selected as S.

According to the formula in Appendix G of Technical Guidelines for Environmental Risk Assessment of Construction Projects (HJ 169-2018), epoxypropane is a heavy gas, and SLAB smoke mass diffusion model is adopted for calculation in this study.

The range and harm degree of epoxy propane leakage were simulated and calculated, and the prediction results were shown in the table III.

From the analysis of the predicted results, it can be seen that when the epoxy propane pipeline leaks, under the most adverse meteorological conditions, the maximum axis concentration is 351mg/m³, which can meet the requirements of the toxic end point concentration -1 (2100mg/m³) and toxic end point concentration -2 (690mg/m³), and there is no excess area.

Due to the short duration of the leakage, this evaluation considers the impact of the chemical leakage on the atmospheric environment to be acceptable.

| commodity | The molecular weight (g/mol) | Saturated vapor pressure (kPa) | The temperature(°C) | The liquid density (g/m³) | Leakage area (m²) | Leakage rate (kg/s) | 10min leakage (m³) | Radius of liquid pool (m) | The wind speed (m/s) | Evaporation rate (g/s) |
|-----------|-----------------------------|--------------------------------|---------------------|--------------------------|-----------------|------------------|-----------------|--------------------------|-------------------|----------------------|
| styrene   | 104                         | 1.0767                         | 30                  | 0.9                      | 0.000314        | 3.66             | 0.02            | 1.16                     | 1.5                | 0.4182               |
| benzene   | 78                          | 22.6907                        | 25                  | 0.77                     | 0.000314        | 3.17             | 0.02            | 1.25                     | 4.3223             |
Table 2. Calculation of leakage quantity of dangerous goods and radius of liquid tank

| Pollution factors | Endpoint concentration - 1/ (mg/m^3) | Endpoint concentration - 2/ (mg/m^3) | Ratio of evaporation rate to endpoint concentration -1 | Ratio of evaporation rate to endpoint concentration -2 |
|-------------------|--------------------------------------|--------------------------------------|------------------------------------------------------|------------------------------------------------------|
| styrene           | 4700                                 | 550                                  | 8.90E-05                                            | 7.60E-04                                             |
| benzene           | 13000                                | 2600                                 | 3.32E-04                                            | 1.66E-03                                             |
| methyl methacrylate | 2300                                | 490                                  | 6.44E-04                                            | 3.02E-03                                             |
| dimethylformamide | 1600                                | 270                                  | 3.96E-04                                            | 2.35E-03                                             |
| acetic acid       | 60.05                                | 3.9                                  | 30                                                  | 0.94                                                 |
| phenol            | 0.0717                               | 100.12                               | 3.00                                                 | 0.02                                                 |
| chloroform        | 119.38                               | 32.17                                | 30                                                  | 1.48                                                 |
| epoxy propane     | 58.08                                | 86.9916                              | 30                                                  | 0.83                                                 |

Table 3. Calculation of leakage quantity of dangerous goods and radius of liquid tank

| The serial number | Distant (m) | Time of maximum concentration (mg/m^3) | Distance (m) | Time of maximum concentration (mg/m^3) | Concentration (mg/m^3) | Distance (m) | Time of maximum concentration (mg/m^3) | Concentration (mg/m^3) |
|-------------------|-------------|----------------------------------------|--------------|----------------------------------------|-----------------------|--------------|----------------------------------------|-----------------------|
| 1                 | 10          | 7.73                                   | 170          | 36.92                                  | 6.99                  | 3410         | 58.37                                  | 1.75                   |
| 2                 | 60          | 8.87                                   | 351.00       | 37.60                                  | 6.64                  | 3460         | 58.96                                  | 1.69                   |
| 3                 | 110         | 10.01                                  | 297.70       | 38.28                                  | 6.29                  | 3510         | 59.55                                  | 1.64                   |
| 4                 | 160         | 11.15                                  | 228.80       | 38.95                                  | 5.95                  | 3560         | 60.14                                  | 1.60                   |
| 5                 | 210         | 12.29                                  | 179.93       | 39.62                                  | 5.64                  | 3610         | 60.73                                  | 1.55                   |
| 6                 | 260         | 13.43                                  | 144.35       | 40.29                                  | 5.35                  | 3660         | 61.31                                  | 1.51                   |
| 7                 | 310         | 14.58                                  | 118.77       | 40.95                                  | 5.08                  | 3710         | 61.89                                  | 1.47                   |
| 8                 | 360         | 15.65                                  | 120.33       | 41.61                                  | 4.84                  | 3760         | 62.47                                  | 1.43                   |
| 9                 | 410         | 16.62                                  | 91.44        | 42.27                                  | 4.62                  | 3810         | 63.05                                  | 1.40                   |
| 10                | 460         | 17.58                                  | 73.51        | 42.92                                  | 4.42                  | 3860         | 63.63                                  | 1.36                   |
| 11                | 510         | 18.50                                  | 62.17        | 43.57                                  | 4.23                  | 3910         | 64.21                                  | 1.33                   |
| 12                | 560         | 19.40                                  | 52.58        | 44.21                                  | 4.06                  | 3960         | 64.78                                  | 1.29                   |
| 13                | 610         | 20.28                                  | 45.31        | 44.85                                  | 3.90                  | 4010         | 65.35                                  | 1.26                   |
| 14                | 660         | 21.14                                  | 39.72        | 45.49                                  | 3.73                  | 4060         | 65.93                                  | 1.23                   |
| 15                | 710         | 21.99                                  | 34.79        | 46.13                                  | 3.57                  | 4110         | 66.50                                  | 1.19                   |
| 16                | 760         | 22.82                                  | 30.85        | 46.77                                  | 3.42                  | 4160         | 67.07                                  | 1.16                   |
| 17                | 810         | 23.64                                  | 27.69        | 47.40                                  | 3.27                  | 4210         | 67.64                                  | 1.13                   |
| 18                | 860         | 24.45                                  | 24.92        | 48.03                                  | 3.14                  | 4260         | 68.20                                  | 1.10                   |
| 19                | 910         | 25.24                                  | 22.45        | 48.65                                  | 3.02                  | 4310         | 68.77                                  | 1.07                   |
| 20                | 960         | 26.03                                  | 20.38        | 49.28                                  | 2.90                  | 4360         | 69.33                                  | 1.05                   |
| 21                | 1010        | 26.80                                  | 18.63        | 49.90                                  | 2.80                  | 4410         | 69.90                                  | 1.02                   |
| 22                | 1060        | 27.57                                  | 17.17        | 50.52                                  | 2.70                  | 4460         | 70.46                                  | 1.00                   |
| 23                | 1110        | 28.33                                  | 15.75        | 51.14                                  | 2.60                  | 4510         | 71.02                                  | 0.97                   |
| 24                | 1160        | 29.08                                  | 14.48        | 51.75                                  | 2.52                  | 4560         | 71.58                                  | 0.95                   |
| 25                | 1210        | 29.82                                  | 13.38        | 52.36                                  | 2.43                  | 4610         | 72.14                                  | 0.93                   |
| 26                | 1260        | 30.55                                  | 12.41        | 52.97                                  | 2.36                  | 4660         | 72.69                                  | 0.91                   |
| 27                | 1310        | 31.28                                  | 11.57        | 53.58                                  | 2.29                  | 4710         | 73.25                                  | 0.89                   |
| 28                | 1360        | 32.01                                  | 10.84        | 54.18                                  | 2.20                  | 4760         | 73.80                                  | 0.87                   |
| 29                | 1410        | 32.72                                  | 10.13        | 54.79                                  | 2.13                  | 4810         | 74.35                                  | 0.85                   |
| 30                | 1460        | 33.44                                  | 9.46         | 55.39                                  | 2.06                  | 4860         | 74.91                                  | 0.84                   |
| 31                | 1510        | 34.14                                  | 8.85         | 55.99                                  | 2.00                  | 4910         | 75.46                                  | 0.82                   |
| 32                | 1560        | 34.84                                  | 8.31         | 56.59                                  | 1.92                  | 4960         | 75.91                                  | 0.80                   |
| 33                | 1610        | 35.54                                  | 7.82         | 57.19                                  | 1.86                  | 5010         | 76.56                                  | 0.79                   |
| 34                | 1660        | 36.23                                  | 7.38         | 57.78                                  | 1.80                  | 5060         | 77.10                                  | 0.78                   |
4. CONCLUSION

Based on Bernoulli equation of fluid mechanics and calculation method of mass evaporation rate, this paper estimated the evaporation rate of ambient air after liquefied chemical leakage. According to the unfavorable situation in Technical Guidelines for Environmental Risk Assessment of Construction Projects, SLAB model was adopted to predict. The specific conclusions are as follows.

The leakage rate of liquid chemicals mainly depends on the area of the leakage port, while the evaporation rate mainly depends on the saturated vapor pressure of the liquid and the area of the liquid pool. Therefore, setting reasonable barriers and reducing the area of the liquid pool in the dock operation area can effectively reduce the evaporation rate of chemical leakage.

The toxic degree of liquid chemical leakage to the environment is jointly affected by evaporation rate and toxic end point concentration.

This article selects the selection of the styrene, benzene, methyl methacrylate, dimethyl formamide, acetic acid, phenol and chloroform 10%, 8 kinds of epoxy propane chemicals leakage pipe diameter as a typical accidents were analyzed, and according to the prediction result shows that the leakage of liquid chemicals 10% diameter on the influence of the atmospheric environment is acceptable.

ACKNOWLEDGMENT

This paper is one of the phased achievements of the National Nonprofit Institute Research Grants of Tianjin Research Institute for Study on emission Characteristics and Low emission technology of air pollution sources from ships (No. TKS160210).

REFERENCES

[1] Xiang P.(1995) Epa and hazard scope determination of inflammables and explosives. CHONGQING ENVIRONMENTAL SCIENCE.17:39-41.
[2] Resolution MSC.176(79) (adopted on 10 December 2004) international Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk.
[3] Zhou H.(2002) Study on regional environmental risk assessment of liquid chemical terminals in bulk. Dalian Maritime University.
[4] Ministry of Ecology and Environment(2018) Technical Guidelines for Environmental Risk Assessment of Construction Projects.
[5] Deng R.T.(2011) Environmental risk assessment and preventive measures for alumina projects. Chemical engineering and equipment, 1:191-197.
[6] Xu X.F. (2012) Study on Characteristics of Aquatic Ecological Environment of Tianjin Coastal Water and Its Spatial Decision Support System. Journal of Tianjin University, 26-27.