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Analysis of Hazardous Range Leakage of Ammonia Storage Tanks and its Strategy

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Abstract: Based on related models, the damage area after ammonia leakage has been assessed. The calculation of severely hazardous radius and area of the leaky ammonia provides theoretically basis for working out emergency succor plan. Person mistake behaviors, equipment danger condition and mistake management are three major causes for the leakage of ammonia tank from the man-machine system. This paper provides not only important information to prevent ammonia leakage to control and disposal accident, but also emergency succor plan.

Key words: ammonia leakage; ammonia poison; hazardous characteristics; emergency succor plan

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氨泄漏范围的危险分析和对策措施

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摘　要: 根据有关模型,氨泄漏的危险范围可以计算出来.预测液氨泄漏的重度危险半径和面积,为企业事故应急预案的制定提供理论依据.从人机系数来看,人的不安全行为、物的不安全状态和管理缺陷是氨贮罐泄漏的3个主要原因，提出了防止氨泄漏和控制及处理氨泄漏事故的重要信息,以及应急救援预案.

关键词: 氨泄漏； 氨气中毒； 危险特性； 应急救援预案

1 Introduction

The quantity of ammonia consumption increases rapidly with the development of chemical industries. The pressure inside ammonia storage tank is stronger than outside. The ammonia which leaks from tanks if the defensive measures don't work correctly, will hurt people and damage objects, pollute environment. Based on Gauss model, the damage range area, where leakage ammonia affects human, can be calculated in the paper. Further the other model is established in the paper. The two models are correct by comparison with the other models in journals. So, the leaky sequence of liquid ammonia is very serious. This paper puts forward to not only important information to prevent ammonia leakage and to control and disposal accident, but also emergency succor plan.

2 Gauss Leakage Model

(1)Leakage Mechanism. There are some fire, explosion and person toxic accidents in chemical industries due

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to person mistake behaviors, which include operation mistake, neglect danger and warn, equipment danger condition, which are unreliable equipment, inferior material, no safety devices, and mistake management, in which man agement system and safe operation regulations have not been constituted, or workers do not comply with them, as managers do not trictly administer superintendence system. Ammonia, for instance, probably happens to leak during the course of production, storage, transportation, loading and discharging ammonia. Then, ammonia leakage and diffusion which are related to not only ammonia characteristic but also geometry shape of leakage gape, as well as local weather and local environment, are so complexity that some hypothesis is put forward in quantity analysis leakage model. This hypothesis is as follows:①Leakage distribution submits to Gauss model.② Damage area is defined poison concentration excess death concentration.③ Leakage velocity is constant during the course of ammonia leakage.

(2) Leakage Damage Area of Calculation Model. There are lots of mathematics models which depict leakage diffuseness. Based on different leakage mediator diffuse characteristic, models are divided into middle cloud model and heavy cloud model. Middle cloud model depicts leakage gas whose density is nearly the same as that of atmosphere, while heavy cloud model depicts leakage gas whose density is heavier than that of atmosphere. Gauss model belongs to middle cloud model. This paper introduces Gauss model because ammonia leakage model belongs to middle cloud model.

Based on Gauss model[1], distribution of ammonia concentration is as follows:

$$C(x,y,z)=V_g \times exp[-0.5(y^2/\lambda_y^2+z^2/\lambda_z^2)] \div (\pi \times \mu \times t \times \lambda_y \times \lambda_z) \quad (1)$$

Where: $C(x,y,z)$–concentration /g·m^{-3}; Vg–evaporation volume of ammonia /m^3;

μ–wind of velocity /m·s^{-1}; t–time of leakage/s;

x, y, z–propitious wind, crosswind, perpendicularity distance.

Pervasion parameter can be calculated by formula[2,3]:

$$\lambda_y=a_y x^{\beta_y} \qquad \lambda_z= a_z x^{\beta_z} \quad (2)$$

Where: a_y, a_z, β_y, β_z–related to weather stability. Gifford had put forward their parameters.

V_g can be determined as follows: The quality of leakage ammonia in the tank is W(kg). The temperature of ammonia in tank before the tank broken is T(℃). The pressure of ammonia in tank before the tank broken is P(MPa). The boiling point of ammonia is t_0(t_0=−33℃)[4] and boiloff hot of ammonia is Q (Q=1.37 × 10^{3}kj/kg)[4].The average specific heat of ammonia is C(C=4.6kj*kg^{-1}·℃$^{-1}$)[4]. The molecular weight of ammonia is M (M=17). V_g can be can be calculated by formula[4]:

$$V_g = [22.4 \times W \times C \times (T-t_0) \times (273+ t_0)] \div [273 \times M \times Q] \quad (3)$$

Ammonia concentration of level ground can be calculated by formula(1) (z=0):

$$C(x,y)=V_g \times exp[-0.5 \times (y_2/\lambda_y^2)] \div (\pi \times \mu \times t \times \lambda_y \times \lambda_z) \quad (4)$$

Based on formula(2) and (4), it can be calculated by formula:

$$C(x,y)=V_g \times exp[-0.5 \times (y^2/\lambda_y^2)] \div (\pi \times \mu \times t \times k \times x^n) \quad (5)$$

where: $k=a_y \times a_z$, $n=\beta_y + \beta_z$.

Ammonia concentration in damage area exceeds LC_{50} according to hypothesis. Namely $C(x,y) \geqslant LC_{50}$.

Ammonia concentration equals to LC_{50} at propitious winds. It can be calculated with the formula:

$$x_c=[V_g \div (\pi \mu t k \; LC_{50})]^{1/n} \quad (6)$$

Based on formula (5) and(6), supposing $C(x,y)=LC_{50}$, it can be calculated by formula:

$$y=(2n)^{1/n}\lambda_y x^{\beta_y}[\ln(x_c/x)]^{1/2} \quad (7)$$

Damage area of ammonia can be calculated by the formula:

$$A=2\int_0^{xc} y dy$$

$$\text{Namely:} A=(2\pi \times n)^{1/2} \times a_y \times x_c^{\beta_y+1} \div (\beta_y+1)^{1.5} \quad (8)$$

Where: A–the damage area

(3) Damage Area Calculation. There are five ammonia storage tanks which is full volume of 60.9 m^3 in a metallurgy

chemical limit company. Due to some reason, if all of the ammonia which is 9653 kg in the tank, happens to leak on the sunny day, how can the ammonia poison area be calculated? Ammonia is poison gas. When ammonia concentration is 3500~7000 mg/m^3 [5] in the atmosphere, human will immediately die without breathing apparatus. Let us suppose that wind velocity is 1m/s (μ=1m/s) ,time of leakage is 224 (t=224 s), temperature of ammonia in tank before the tank broken is 25℃ (T=25℃), LC_{50}=3500 mg/m^3. According to Gifford putting forward diffuse parameter, they can be calculated with formulas[2,3]:

$$\lambda_y=a_y x^{\beta_y}=0.2818x^{0.914} \qquad \lambda_z= a_z x^{\beta_z}=0.127x^{0.964} \tag{9}$$

The damage area of 9653kg leaky ammonia can be calculated as follow:

$$V_g=[22.4 \times W\times C\times(T-t_0) \times (273+ t_0)]/273 \times M\times Q]=$$
$$[22.4 \times 9653 \times 4.6 \times (25+33) \times (273-33)]/(273 \times 17 \times 1.37 \times 10^3)= 2177.62\ \mathrm{m}^3 \tag{10}$$

$$x_c=[V_g \div (\pi\mu t k\ LC_{50})]^{1/n}=$$
$$[2177.62 \div (3.14 \times 1 \times 224 \times 0.2818 \times 0.127 \times 3500 \times 10^{-6})]^{1/(0.914+0.964)}= 218.36\ \mathrm{m} \tag{11}$$

$$A=(2\pi\times n)^{1/2} \times a_y\times x_c^{\beta y+1} \div (\beta_y+1)^{1.5}=$$
$$[2 \times 3.14 \times (0.914+0.964)]^{1/2} \times 0.2818 \times 218.360.914+1 \div (0.914+1)^{1.5}= 10964.92\ \mathrm{m}^2 \tag{12}$$

When all of the ammonia which is 9653 kg in the tank, happens to leak on the sunny day, the perpendicularity distance is 218.36 m, and damage area is 10964.92m^2, where most of persons without protection facility will die.

3 Toxic Estimation Model

This hypothesis is that the leakage ammonia, which is in the tank, diffuses on the ground by half-ball, then the toxic estimation radius can be calculated with formula as follows[4]:

$$R=[V_g /(0.5 \times 4/3 \times \pi\times C_e)]^{1/3}=[V_g /(2.0944\ C_e)]^{1/3} \tag{13}$$

Where: R–ammonia gas radius /m; V_g–evaporation volume of ammonia /m^3, by the formula (14);

Ce–death of ammonia concentration(%); (Ce =0.5%[5])

Then the leakage ammonia diffuses on the ground by half-ball, the toxic estimation area can be calculated with formulas follow:

$$S=\pi\times R^2=\pi \times [V_g/(2.0944\ \mathrm{Ce})]^{2/3} \tag{14}$$

Where: S–the toxic estimation area

The damage radius and area of 9653 kg ammonia can be calculated respectively as follow: Based on formula (14), V_g=2177.62 m^3

$$R= [V_g/(2.0944\ \mathrm{Ce})]^{1/3}=[2177.62 \div (2.0944 \times 0.5\%)]^{1/3}=59.24\ \mathrm{m}$$

$$S=\pi\times R^2=\pi \times [V_g/(2.0944\ \mathrm{Ce})]^{2/3}=\pi\times 59.242^2=11021.26\ \mathrm{m}^2$$

The calculation damage area (A)of 9653 kg leakage ammonia, which is 10964.92 m^2 by Gauss leakage model, almost is equal to the toxic estimation area(S), which is 11021.26 m^{2}on the basis of the toxic estimation model. This indicates that Gauss leakage model and the toxic estimation model are not only correct, but also rational.

4 Comparisons with Other Models

When ammonia was charged from the ammonia storage tank which was full volume of 20 m^3 to the other ammonia storage tank which was volume of 18.2m^3 in a chemical fertilizer limit company in Shandong, the ammonia was leaking from the flexible pipe which was broken[6]. For another example, assuming the leaky tank had liquefied ammonia 50t, the pressure and the temperature were 2.5 MPa and 25 ℃ respectively, the radius was calculated[7] by different model as follow:

Table 1　Comparisons of Ammonia Leakage　T=25℃

Quality of Leaky Ammonia /kg	Gauss Leakage Model				Toxic Estimation Model		Other Model	
	μ /m·s^{-1}	t /s	x_c /m	A /m^2	R /m	S /m^2	r /m	s /m^2
9653	1	224	218.36	10964.92	59.24	11021.26		
11102	2	115	231.95	12308.58	62.07	12098.29		141982.6[6]
50000	1	390	390.00	33309.52	102.51	32994.11	108[7]	

From the Table 1, the

calculation number of poison radius and area, where most of person will die, by Gauss leakage mode and the toxic estimation model respectively, are nearly equal to that by other models. The results once again indicate that these models are not only correct, but also rational.

5 Emergency Succor Plan

The calculation severe hazard radius and area of the leaky ammonia provide theoretically basis for working out emergency succor plan. Because of some reason all measures do not prevent accident. So, we should do our best to prevent accident from magnification, reduce human injury and object damage by the emergency help plan.

It is very important to protect project safety by safe measures, which include the essence safety which is considered the best method by technology and design measure, and management measure. Lots of responsibility system and safe management organization should be constituted, and workers must comply with them. All level workers should take part in safe education and training. Management measure of dynamic embodiment is supervise and examination. As so do, they can ensure effectively ammonia not to leak. Not only the ammonia tank but also loaded and unloaded place should be inspected to find hidden trouble and be taken measures in order to prevent ammonia leakage.

If it is misfortune to happen ammonia in tank leakage, the project will send out sound and light signal by inspected equipment, and turn on automation spray water. The corresponding technical measures are taken and prevented accident spread by emergency help plan.

6 Conclusion

Leakage ammonia from broken tank or pipe is major danger diathesis in ammonia storage tanks. The damage area and radius of leakage ammonia, in which persons will die when he breaths ammonia in 5–10 min, can be calculated by Gauss leakage model and the toxic estimation model, which are not only correct, but also rational. The leaky consequence of liquid ammonia is very serious. It is necessary to take preventive measures during the course of production, storage, transportation and using of ammonia. Person mistake behavior, equipment danger condition and mistake management are major causes for ammonia tank of leakage and broken tank. Safety measures are put forward to preventing accidents. Emergency help plan is a system engineering, which need be sustained and cooperated by all levels workers. All of the employer and employees should understand "safety primacy, prevention priority" guideline and execute it in employment.

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