6th Asia-Oceania Symposium on Fire Science and Technology
17-20, March, 2004, Daegu, Korea

Fire Risk Assessment for Ammonia Onshore Export Terminal

**Yu. N. Shebeko, I. A. Bolodian, V. P. Molchanov, Yu. I. Deshevih,
V. P. Nekrasov, I. M. Smolin, D. M. Gordienko, V. V. Strogonov**

*All Russian Scientific Research Institute for Fire Protection
VNIIPO 12, Balashiha-3, Moscow Region, 143903, Russia*

Abstract

Fire risk assessment for ammonia onshore export terminal has been carried out. Risk connected with toxic injuring by ammonia was not considered. An analysis of fire hazard of the terminal was executed, typical accidents were revealed, and event trees were constructed. Annual frequencies of hazardous events were evaluated, and impact zones for fires and explosions were calculated. Individual and social risks were evaluated both for population near the terminal and for personell of the object. It was found that the fire risk values for the population do not exceeds the values stated by standards. The fire risk values for personell do not be stated by russian standards, therefore a comparison of the calculated fire risks was made with requirements of leading oil companies. The calculated fire risks were somewhat higher than fire risks for the personell accepted by the leading oil companies, that is the additional fire safety measures are required. The propositions for determination of tolerable risk values for industrial plants have been done.

Introduction

Now large-scale ammonia onshore export terminals are constructed in various countries. Though ammonia is classified as flammable gas, it has anormously high lower flammability limit, large minimum ignition energy, low laminar burning velocity, high oxygen concentration in peak points of flammability curves, large critical quenching diameter [1, 2]. Ammonia also can not form a jet flame in air. Results of comparison of some fire hazard indexes of ammonia and propane (the typical hydrocarbon) are shown in Table 1. Differences in these fire hazard indexes are very large, therefore approaches to fire safety ensuring of large scale storages of propane and ammonia should be different.

Copyright © International Association for Fire Safety Science

Table 1. Some fire hazard indexes of ammonia and propane [1, 2]

Fire hazard index	The value of the index for	
	ammonia	propane
Flammability limits, % (vol.)		
- lower	15.0	2.3
- upper	28.0	3.4
Minimum ignition energy, mJ	680	0.25
Laminar burning velocity, m/s	0.07	0.39
Oxygen concentration in peak points of flammability curve at dilution by nitrogen, % (vol.)	16	12
Critical quenching diameter, mm	12	3

Fire risk assessment is a basis for fire safety ensuring of industrial facilities with high quantities of flammable materials [3]. On the basis of the risk assessment the key question should be solved - is it possible or not to contract that industrial object in a given space with the proposed technological equipment? Decision of this question for large -scale onshore export ammonia terminal from a viewpoint of fire safety is the main task of this study. The following tasks were considered:

- qualitative fire hazard analysis of the ammonia terminal;
- revealing of peculiarities of the ammonia terminal influencing its fire safety;
- determination of main scenarios of accidents with release of flammable gases and liquids and evaluation of annual frequencies of there original;
- calculation of hazardous factors of fires and explosions for these scenarios;
- quantitative assessment of individual and social risks of fires and explosions for the terminal;
- comparison of the calculated results with the tolerable fire risk values.

Brief description of the ammonia terminal

The ammonia export terminal has two main parts located onshore and offshore respectively. Onshore facilities are located on three places: №1 - ammonia storage, №2 - auxiliary buildings and equipment, №3 - buildings and equipment near sea. There are equipment for offloading of ammonia from railway tanks (up to 70 tanks, each of these has 43 tonne ammonia), tank for receiving of ammonia, two double - wall isotermic tanks for ammonia storaging (each tank can contain up to 30 000 tonne of product), flare system with a tube of diameter 0.6 and height 30 m, ammonia compressors, electrical power station using natural gas as a fuel, generators, storages for auxiliary substances and materials, open car park, buildings for transformers and office buildings. The place №1 has two jetties having technological equipment for loading of tankers with ammonia, diesel generators, operator building and fire pumps.

The place №2 has various auxiliary buildings and facilities including cleaning equipment, boilers and fire station.

The place №3 has diesel generators, electrical equipment buildings, transformers, water pumps, office building, boiler.

The most hazardous is the equipment containing liquid ammonia (tanks, pipelines, compressors etc.). The isothermal ammonia tanks are located in the duke of height of 2.5 m. Cooling of liquid ammonia up to the required temperature (-33^0C) is obtained by discharge of the liquid gas in the receiving tank and then immediately in the isothermal tanks. Gaseous ammonia, which is produced during this process, is cooled and then condensed in compressor station. Three compressors are installed for condensation of ammonia (2 working and 1 standby), each of these has a rate of condensation 58 tonne/hour. The compressors are driven by turbines working on natural gas (methane). Temperature of liquid ammonia in the isothermal tanks during the time period between receiving and offloading of the product is supported by removal of gaseous ammonia (which is produced by input of heat from environment) into the compressors.

A technological process of receiving, storaging and offloading of ammonia includes the following operations:

- removal of liquid ammonia from the railway tanks into the receiving tank by pressure difference produced by the compressors;
- cooling of liquid ammonia obtained from the receiving tank by two-step choking and condensation of gaseous ammonia by the compressor station;
- storaging of liquid ammonia in the isothermal tanks at temperature -33^{0}C and atmospheric pressure;
- transportation of ammonia from the isothermal tanks to a tanker by two pipelines of diameter 0.45 m;
- back-up of gaseous ammonia from the tanker to the isothermal tanks by a pipeline of diameter 0.3 m;
- supporting of the pipelines for loading and offloading of liquid ammonia in the cool state by forced circulation of the product from the isothermal tanks with removal of excess heat by the compressors.

The following systems are available on the terminal:

- flare system for utilization of accidental releases of ammonia supporting by natural gas supplying;
- standby systems for generation of electrical power for equipment of accidental operation;
- systems for removal of accidental releases of liquid ammonia;
- blowing of pipelines and equipment by nitrogen before supplying of ammonia into them.

The terminal is equipped by a fire detection system and a system for detection of accidental releases of flammable gases and vapors (gas detection system). Fire hydrants are available inside and outside the buildings. Water deluge systems are available for protection of the tanks and technological equipment from thermal radiation of a fire. Water curtains are installed for restriction of accidental vapor cloud on perimeters of the dyke around the isothermal tanks, installation for offloading of the railway tanks and on the jetty.

The following quantities of flammable and combustible substances were taken into account during calculations of fire risks:

- liquid ammonia inside the isothermal tanks (up to 30 000 tonne);
- liquid ammonia inside the railway tanks (70 railway tanks each containing 43 tonne of the product);
- liquid ammonia inside the tanker (up to 30000 tonne);
- liquid ammonia inside the pipelines;
- natural gas inside the pipelines and the equipment;
- diesel oil inside a tank of volume of 16 m^3;
- lubricant oil in the equipment (turbines, generators, pumps, compressors etc.);
- solid combustible materials inside the buildings.

Peculiarities of fire hazard of the terminal

The terminal is characterized by an availability of large quantities of flammable and combustible substances and materials. Vapour clouds can be formed at accidental release of flammable gases into atmosphere. These clouds can burn either in the regime of flash fire (ammonia-air clouds) or in the regime of vapor cloud explosion (natural gas - air clouds). Also fires with combustion of solids and liquids are possible.

Peculiarities of fire hazard of the terminal can be better understood on the basis of analysis of main typical scenarios, among which the following are the most important: release of liquid ammonia from the isothermal tanks, release of ammonia from the receiving tank and rupture of pipeline with natural gas.

In the case of the isothermal tanks the following events can take place:

- release of liquid ammonia from the tanks and its spreading inside the dyke;
- evaporation of liquid ammonia, formation and propagation of vapor cloud;
- ignition of the vapour cloud and its combustion in the regime of flash fire;
- thermal action of hot combustion products of the flash fire on technological equipment, buildings and constructions of the terminal;
- fire initiation on the technological equipment, buildings and constructions;
- action of the fire on neibouring facilities of the terminal with the following extension of the fire.

In the case of the receiving tank the following events can take place:

- formation of a hole and a release of liquid ammonia into atmosphere;
- quasi-instantaneous evaporation of some part of the released liquid;
- spreading of remaining liquid inside the dyke;
- formation and propagation of a vapour cloud;
- ignition of the vapor cloud and its combustion in a regime of a flash fire;
- thermal action of hot combustion products of the flash fire on neibouring facilities with extension of the fire.

In the case of the pipeline with natural gas the following events can take place:

- rupture of the pipeline with release of natural gas into atmosphere;
- formation and propagation of natural gas-air cloud;
- ignition of gaseous cloud and its combustion in the regimes of a flash fire or vapor cloud explosion;
- formation of flare in the place of rupture of the pipeline;
- thermal action of the flare on the technological equipment with ammonia;
- destruction of this technological equipment with release of flammable substances (ammonia, natural gas), with extension of the fire.

The typical event tree for the scenario with the accident on the receiving tank is shown in Fig. 1.

The list of possible accidents is not restricted by the proposed above scenarios, which are presented only for illustration of peculiarities of fire hazard of the terminal. The total list of the accidents was produced on the basis of analysis of studies [4-8] and design documentation.

Results and Discussion

Fire risk was evaluated using methods stated in the standard [3]. These methods combine the advantages of the best known methods for risk assessment. Frequencies of initiating events were taken from [4,8,9-12] and were critically reconsidered. Individual risk (risk contours [14]) and social risk were calculated. The following physical effects were taken into account in the calculations: flash fire (combustion of ammonia-air and natural gas – air mixtures), flare (combustion of natural gas), pool fire (combustion of diesel oil), room fire (combustion of solid materials), vapor cloud explosion (combustion of natural gas-air mixtures in rooms and congested volumes). We did not take into account explosions of ammonia – air mixtures even in congested volumes because of low laminar burning velocity of ammonia in air (see Table 1). Ammonia flares and pool fires of liquid ammonia were also not considered because of ammonia can not form stable diffusion flame in air.

Results of evaluation of the individual risk for industrial buildings are shown in Table 2 and for territory of the terminal in Fig.2. The individual risk contours and the social risk were compared with the tolerable risk values for population living near the hazardous object, which are stated in the standard [3]. These tolerable risk values are the following:

- individual risk
  a) if risk is lower then 10^{-8} year^{-1}, then the hazardous object is undoubtedly acceptable;
  b) if risk is higher then 10^{-6} year^{-1}, then risk is not acceptable;
  c) if risk is between 10^{-8} and 10^{-6}year^{-1}, then strict control of the risk is required, and all reasonable measures for reduction of risk should be executed.

Table 2. The values of the individual risk for industrial buildings

Name of building	Annual frequency of fire origin, year^{-1}	Individual risk, year^{-1}
Air compressors	$3.2\cdot10^{-6}$	$2.1\cdot10^{-6}$
Gaseous electrical power station	$1.3\cdot10^{-2}$	$9.5\cdot10^{-6}$
Ammonia compressors	$3.1\cdot10^{-2}$	$2.5\cdot10^{-4}$
Diesel generators	$1.2\cdot10^{-2}$	$8.0\cdot10^{-6}$
Office building	$1.3\cdot10^{-2}$	$1.3\cdot10^{-5}$
Storage building	$8.7\cdot10^{-2}$	$5.8\cdot10^{-5}$
Operator building	$4.9\cdot10^{-4}$	$4.9\cdot10^{-7}$

It can be seen from Fig.2 that the individual risk for the personel on the territory of the terminal is in the range $1.5\cdot10^{-4}\div8.7\cdot10^{-3}$ year^{-1}, and for the most part of the storage area the individual risk exceeds 10^{-3} year^{-1}. The main input into the individual risk value is given by the accidents on ammonia compressor units. The individual risk for the zone of the onshore facilities and the jetty does not exceed 10^{-4} year^{-1}.

The social risk for the personel calculated for whole object is equal to $8.6\cdot10^{-3}$ year^{-1}, and the value of the social risk for the personel of the storage area is equal to $8.4\cdot10^{-3}$ year^{-1} (that is the social risk is determined mainly by the storage area facilities – the compressor station).

Now in Russia the tolerable risk values for personel of hazardous plants are not regulated (regulations are available only for population living near hazardous objects). The following propositions have been done for regulations of the fire risk for personel of hazardous objects (these propositions were produced on the basis of analysis of experience and regulations of leading oil production companies) [8].

Individual risk:

- risk higher than 10^{-4}year^{-1} – unacceptable risk;
- risk lower than 10^{-6} year^{-1} – acceptable risk;
- risk is higher than 10^{-6} year^{-1}, but lower than 10^{-4} year^{-1}- this is the zone of a strict control of the risk. In this zone risk can be considered as acceptable, if all reasonable measures for risk reduction are undertaken, such as strong restriction of presence of people on the territory of the terminal, preparedness of personel to actions at emergencies etc.

For the most hazardous types of an industrial activity the maximum acceptable risk level can be increased from 10^{-4} to 10^{-3} year^{-1}.

Social risk is evaluated on injuring of more than 10 people. The tolerable values for the social risk are the following:

- risk higher than 10^{-3} year^{-1} – unacceptable risk;
- risk lower than 10^{-5} year^{-1} – acceptable risk;
- risk is higher than 10^{-5} year^{-1}, but lower than 10^{-3} year^{-1} this is zone of the strict control of the risk.

Following conclusions can be made on the basis of comparison of the results of evaluation of the individual risk with the tolerable risk values. The risks for population are acceptable without any additional protective measures. But the risks for the personel exceed the limiting values, therefore additional measures (mainly in the direction of increase of relibibility of the technological equipment) for risk reduction are needed.

One useful note should be made concerning an application of determination of the individual risk concept. According to the standard [3] an individual risk is an annual frequency of origin of fire hazardous factors in a given point of space. This value characterizes distribution of the risk and does not depend on probability of presence of people in this point. According to [14] such kind of risk is named as potential risk. This approach is reasonable for the case of population living near hazardous object, because it is very difficult to determine, how much time is spent by the people in places where they live. Another situation is for the personel of the object, for which this time can be determined rather exactly. Therefore the risk for the personel is proportional to the time spent near hazardous facilities (working time). A portion of this time in principle can be much lee than 1, and the individual risk can be much less than the potential risk. We do not take info account this factor, therefore the individual risk calculated in this study is overestimated for several times.

Conclusions

In this study a fire risk analysis for ammonia onshore export terminal has been executed. Risk related to toxic injuring by ammonia was not considered. A qualitative analysis of fire hazard of the terminal has been made, and typical scenarios of accidents with fires and explosions have been revealed. Frequencies of hazardous events initiation and impact zones sizes for various scenarios with fires and explosions were determined. An individual and a social fire risks for population living near the terminal and for personel were calculated. It was shown that the risk values for population do not exceed the limiting values stated by russian standards and fire safety codes. The fire risks for personel in Russia are now not regulated, therefore a comparison of the calculated risks has been done with values stated for personel by leading oil production companies. It was found that the calculated risks for personel are higher than mentioned above limiting risk values, that is the additional protective measures are needed.

References

1. Fire and explosion hazard of substances and materials and fire extinguishing agents. Reference book. Ed. Baratov A.N. and Korolchenko A.Ya. Moscov, Khimia, 1990, vol. 1,2 (in Russian).
2. Zakaznov V.F., Kursheva L.A., Fedina Z.I. Determination of laminar burning velocity and critical quenching diameter for ammonia-air gaseous mixtures. // Physics of Combustion and Explosion, 1987, v.14, №6, p. 22-26 (in Russian).
3. Standard GOST R 12.3.047-98. Fire safety of technological process. General requirements. Methods of control (in Russian).
4. Elokhin A.N. Risk analysis and risk control: theory and practice. Moscow, Lukoil, 2000 (in Russian).
5. Pape R.P., Nussey C.A. A basis approach for the analysis of risks from major toxic hazards.// International Chemical Symposium Series E, 1988, April, №93, p. 367-388.
6. Whittle K.LPG installation design and general risk assessment methodology employed by the gas standards office. //In Conference on Risk and Safety Management in the Gas Industry. Hong Kong, October 1993.
7. Clay G.A., Fitzpatrik R.D., Hurst N.W., Carter D.A., Grossthwaite P.J. Risk assessment for installation where liquefied petroleum gas (LPG) is stored in bulk vessels above ground.// Journal of Hazardous Materials, 1988, v.20, №1-3, p. 357-374.
8. Bolodian I.A., Molchanov V.P., Shebeko Yu.N. et al. Fire risk assessment for oil production offshore platform. // Fire Safety, 2002, №4, p. 80-88 (in Russian).
9. Standard GOST 12.1.004-91*. Fire safety. General requirements (in Russian).
10. Reliability and effectiveness in technique. Reference book. Vol. 10. Reference data on conditions of application and reliability characteristics. Moscow, 1990 (in Russian).
11. CPR 18E. Guidelines for quantitative risk assessment. Purple book. Hague, Committee for the prevention of disasters, 1999.
12. Burdakov N.I. Chernoplekov A.N. Accidents with liquefied gases. Analysis of statistics. // Problems of Safety at Emergencies, 1990, №2, p. 1-22 (in Russian).
13. Shevchuk A.P., Ivanov V.A., Kosachev A.A. Methodological recommendations on analysis and evaluation of material, individual and social fire risks for industrial buildings and rooms. Moscow, VNIIPO, 1985 (in Russian).
14. Safety Code RD 03-418-01. Methodological guidelines on risk analysis of hazardous industrial objects.// Labour Safety in Industry, 2001, №10, p. 40-50 (in Russian).