Project concepts for combined fire-extinguishing systems

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Abstract. Based on the analysis of the functioning of the sprinkler fire-extinguishing system and the chemical reaction of the interaction of ammonia with water, the article considers the formation of an integrated fire extinguishing system to ensure the safety of processes and production plants where ammonia is used in the main and auxiliary processes. Analysis of the functioning of the system allows creating a project for a unified combined fire-extinguishing system based on an automatic sprinkler system and including the function of reacting and responding to the presence of ammonia vapors in the air of the production rooms. The paper proposes a supplement by the method of aggregation of automatic sprinkler systems with ammonia sensors, which, while maintaining the basic fire extinguishing function, can suppress emergency ammonia releases. As an example, the paper describes the formation of the project of a combined automatic sprinkler fire-extinguishing system with ammonia sensors and implements an additional function to ensure production safety in case of a possible ammonia emergency release.

1. Introduction
The problem of ensuring environmental and industrial safety of processes is the most important in terms of ensuring quality and competitiveness indicators. Taking into account the specifics of the implementation of the processes, safety issues, issues for minimizing the impact of these processes on the environment and humans are mainly resolved through the creation of various protection systems [1-5].

Therefore, fire-extinguishing systems are among the mandatory for the activities of all industrial plants. Among them, automatic sprinkler fire-extinguishing systems (ASFES) are widely used, which provide fire suppression by creating a water cloud.

2. Relevance and Scientific Importance
Currently numerous works are devoted to improving the environmental and industrial safety of technological processes, to improving the quality indices this processes, improvement of indices characterizing their impact on the environment and humans [6-14].

Of particular danger to the production staff and the population are facilities with the presence of hazardous chemicals (HC). Chemical protection measures are taken at such facilities, which are aimed at eliminating or mitigating the effects of HC on the population and production staff of these facilities, and reducing the scale of the consequences of chemical accidents [15,16]. The most important factor determining the course of protective measures is the short duration of chemical accidents. Protective
measures are most effective in cases of early detection of a chemical accident, especially at the stage of the pre-conditions or triggering [17].

The emergency protection systems at such facilities make it possible to timely detect an emergency situation, shut-down the equipment, but not eliminate the consequences of the release of HC.

Therefore, the paper aimed at modernizing the existing systems for protecting facilities containing toxic substances, namely automatic fire-extinguishing systems, and widening the possibilities of their use by adapting to other functions and thus increasing the safety of these facilities for production staff and the population, is relevant.

3. Statement of the problem
In this paper, the task is to widen the possibilities of using automatic sprinkler fire-extinguishing systems by adapting them to perform other additional functions. One of such important additional functions is the minimization of accidental toxic releases of a number of production plants.

4. Theory Section

4.1. The industrial use of ammonia
Ammonia is one of the most important products of the chemical industry, on which the production of nitrogen fertilizers and nitrogen compounds is fully based. More than 80 countries produce ammonia. World ammonia production is about 173 million tons per year (2017). Today, Russia has capacities for more than 19 million tons per year (more than 10% of world ammonia production) and is among the world leaders, second only to China [18].

Ammonia is the main reagent for industrial chemistry, construction industry, machinery manufacturing, defense industry, agriculture and a number of other industries, which are listed below:

- Production of acrylonitrile by oxidative ammonolysis of propylene (propylene + ammonia + air + catalyst), ethane and propane to acetonitrile and acrylonitrile (olefin + ammonia + air + catalyst) [19];
- Production of hydrocyanic acid according to the Andrussov method (methane + ammonia + air + catalyst);
- Ammonolysis of aldehydes to nitriles (aldehyde + ammonia + catalyst);
- Ammonolysis of alcohols to nitriles (ethanol + ammonia + catalyst), (methanol + ammonia + catalyst);
- Ammonolysis of alkylhalides to alkylamines (rocket fuel);
- Gas nitriding of parts with ammonia to harden them [20];
- Oxidation of ammonia to nitrogen oxides as the first stage of nitric acid production (figure 1).

![Figure 1. Nitric acid synthesis scheme.](image)

Currently, in densely populated urban areas there are a number of facilities that at the first glance do not pose an obvious threat. This refers to the plants of the food industry (meat cutting plants, dairy
plants, trading bases, breweries, etc.) operating industrial refrigeration units, the working fluid in which is ammonia in most cases.

The advantages of ammonia as a refrigerant lie in its thermodynamic and thermophysical characteristics, allowing having a high efficiency factor (EF) in refrigeration units. Ammonia is chemically neutral to structural materials (except for copper and its alloys), has a low cost and is available on the market [21].

The potential danger of the above production plants, including the production of ammonia and refrigeration units, is the possibility of emergency situations. Ammonia has a high toxicity (maximum permissible concentration (MPC) in working areas is of 20 mg/cubic meter), and it is explosive. Ammonia vapors cause excessive lacrimation, eye pain, chemical burns of the conjunctiva and cornea, and vision loss.

4.2. The automatic sprinkler fire-extinguishing system

The popularity of automatic water-based fire-extinguishing systems at many sites is due to their low cost and the following chemical and physical characteristics of water, which make it an irreplaceable means to eliminate fires [22]:

- Large heat capacity provides temperature reduction even in hard-to-reach places;
- Chemical neutrality to many materials allows using water fire-extinguishing in places with some flammable substances;
- Being sprayed water prevents the access of oxygen to the fire;
- In combination with special foaming additives, water quickly and effectively eliminates fire even in large areas.

Among water fire-extinguishing systems, ASFESs that create water fog are widespread. Sprinklers have a special thermal lock that responds to changes in ambient temperature. The principle of operation is as follows: water is pre-pumped into the fire-extinguishing system and stored under pressure, its output is through a hole in the sprinkler blocked with a lock. When a fire occurs and the temperature rises in the protected rooms, a sensitive element (thermal lock) is triggered, which leads to the automatic opening of the sprinkler head and the beginning of sprinkling of the flame with water.

Another advantage of ASFES is that it is triggered only in the area where a critical change in temperature was detected (fire is identified). Accordingly, a fire is extinguished locally, which avoids property damage in other areas of the facility and the consequences of flooding during false operation of the system.

5. Adaptation of an automatic sprinkler fire-extinguishing system to suppress toxic ammonia releases into the air of production plants

An analysis of the characteristics of sprinkler systems justifies the possibility of adapting these systems to the function of reducing the damage of ammonia accidental releases in addition to their basic purpose of fire-extinguishing. This can be achieved by equipping the automatic sprinkler fire-extinguishing system with ammonia sensors, which ensure that the system responds with a water fog that effectively absorbs ammonia. It is known that the solubility of ammonia in water is very high (the solubility of about 700 volumes of gas in one liter of water at 20 °C), which confirms the advisability of using water spray against ammonia vapor.

To date, several dozen sensors (gas analyzers) have been developed of stationary, mobile and removable types for the detection of ammonia in the air of residential and industrial rooms. When developing a project for adaptation of a sprinkler system, one of the defining characteristics is the speed of its response, determined by the sensor quality. For example, the removable modular gas analyzer Senson-SM-9001 is capable to detect an ammonia concentration of 0.02 mg/cubic meter with a response time of less than 5 minutes [23].

Figure 2 shows a scheme of a combined automatic sprinkler fire-extinguishing system, complemented by a function to response to the presence of ammonia vapors in a production room.
Figure 2. Scheme of a combined automatic sprinkler fire-extinguishing system: (I) water-filled system; (II) air-filled system; 1 – water pipes; 2 – hydraulic pneumatic tank; 3 – control block; 4 – supply pipeline; 5 – feed pipeline; 6 – distribution pipeline; 7 – main pump; 8 – standby pump; 9 – compressor; 10 – water gate valve; 11 – water check valve; 12 – air gate valve; 13 – air check valve; 14 – electric-contact pressure gage; 15 – control unit; 16 – signaling device; 17 – ammonia sensor (gas analyzer); 18 – sprinkler head; (a) water; (b) air; (c) signaling and control circuits.

Combined sprinkler system in the function of suppressing the ammonia release operates as follows. From water pipes (1), pump (7) supplies water to a piping system. If there is no signal on the excess of ammonia concentration, water gate valves (10) open and part of the water enters the hydraulic pneumatic tank (2), and the other part goes directly to the piping system. If gas analyzer detects ammonia, several sprinkler heads (18) open, sprinkling the zone with the formed ammonia cloud. In this case, gas analyzer (17) transfers the impulse to the control block (3). Sensors (modular gas analyzers) are combined into a common circuit and connected to a control block, in which, when the gas analyzer responds, that is, when the concentration of ammonia in the air in any area of the production rooms exceeds a predetermined threshold, a control signal is generated. The control signal actuates the pump, which supplies water to the sprinkler system from the water supply pipe. Thus, the neutralization of ammonia vapor is performed with sprayed water.

The required amount of water is determined by the physicochemical process of the interaction of a chemically hazardous substance with water. Water consumption is determined by the rate of evaporation of a chemically hazardous substance from the entire spill area. At the same time, the specific water consumption for neutralizing a hazardous chemical (for ammonia it is 1.9 L/kg), the
dispersion of water jets, water temperature and the concentration of vapor of a hazardous chemical in the cloud are taken into account.

Therefore, the proposed supplement to the automatic sprinkler fire-extinguishing system with sensors for ammonia detection allows suppressing accidental releases of toxic ammonia while maintaining the basic fire-extinguishing function. The proposed method can also be used to neutralize accidental releases of other water-soluble toxic substances, for example, nitrogen oxides in the production of nitric acid.

A wide range of production plants using ammonia suggests the possibility of forming the combined sprinkler systems, proposed in this article, which are related to ceiling systems. Their disadvantage lies in the relatively late response to the floor area, where the staff is located. Accordingly, if an accidental release of toxic gases start in a technical system close to the floor area, the risk of poisoning the staff increases.

MSTU “STANKIN” developed a combined fire-extinguishing system based on the location of fire sensors and ammonia sensors in the floor area and the automatic system for creating water fog based on the actuation of high-speed floor water systems [24].

6. Conclusion

- The paper solves the problem of increasing the capabilities to use automatic sprinkler fire-extinguishing systems by adapting them to perform a supplemental function, namely, minimizing accidental ammonia releases.
- The proposed solution of the problem allows to improving the environmental and industrial safety of technological processes.
- In the paper, a project was developed for a combined automatic sprinkler fire-extinguishing system with ammonia sensors, which implements a supplemental function to ensure production safety in case of a possible ammonia accidental release to the production room.
- Studies have shown that the aggregation of technical systems is an effective creative method to widen their functionality. Therefore, the aggregation of well-known automatic technical systems by introducing sensors for the characteristics of other objects to implement the possibility to perform supplemental functions is promising for solving production problems without significantly increasing economic costs.

References

[1] Shvartsburg L E, Butrimova E V and Yagolnitser O V 2017 Quantitative evaluation of the effectiveness of best available technologies of form-shaping MATEC Web of Conferences 129 01027

[2] Gvozdikova S I and Shvartsburg L E 2017 Analysis of sources and methods for reducing noise by minimizing vibrations of engineering technological processes Procedia Engineering 206 958–964

[3] Shvartsburg L E and Vikharev A S 2017 Performance management of local air purification systems Ecology and Industry of Russia 21(1) 4–7

[4] Ivanova N A, Ryabov S A and Shvartsburg L E 2016 The role of information technology in rotor balancing Russian Engineering Research 36(3) 235–238

[5] Egorov S B, Kapitanov A V, Mitrofanov V G, Shvartsburg L E, Ivanova N A and Ryabov S A 2016 Modern digital manufacturing technical support centers Mathematics Education 11(7) 2213–25

[6] Shvartsburg L E, Yagolnitser O V and Butrimova E V 2018 Integrated approach to providing for environmental friendliness and safety of the technological processes MATEC Web of Conferences 224 01090

[7] Shvartsburg L E, Butrimova E V and Yagolnitser O V 2017 Energy efficiency and ecological safety of shaping technological processes Procedia Engineering 206 1009–14
[8] Rodriguez P E, Shvartsburg L E and Artemyeva M S 2017 Methodological design and commissioning of an experimental stand for the study of the spread of harmful substances in the air of work areas during the processing of metals in industry Procedia Engineering 206 588–593

[9] Egorov S B, Kapitanov A V, Mitrofanov V G, Shvartsburg L E, Ivanova N A and Ryabov S A 2016 Formation of the integral ecological quality index of the technological processes in machine building based on their energy efficiency International Journal of Environmental and Science Education 11(11) 4065–78

[10] Shvartsburg L E 2015 Ecoenergetics of cutting manufacturing processes Ecology and Industry of Russia 3(19) 4–9

[11] Zaborowski T, Shvartsburg L E and Konov S G 2016 Tracking navigation system based on photogrammetry principles Materials Science Forum 876 69–836

[12] Kapitanov A V 2016 Special characteristics of the multi-product manufacturing Procedia Engineering 150 832–836

[13] Hudoshina M Y and Butrimova O V 2015 A complex criterion for the evaluation of ecologically substantiated selection of LCAs and systems for their application Ecology and Industry of Russia 5(19) 46–49

[14] Zaborowski T, Shvartsburg L E, Ivanova N A and Ryabov S A 2018 Ecoenergetic cutting techniques Management and Production Engineering Review 9(4) 70–75

[15] Golubkov Y U, Ermolaeva N V and Shvartsburg L E 2016 Nitrogen-bearing organic components of industrial oils Chemistry and Technology of Fuels and Oils 52(1) 90–94

[16] Shvartsburg L E, Ivanova N A, Ryabov S A and Zaborowski T 2014 Chemical contaminations in a process of polishing with an implementation of liquid LCTS Life Science Journal 11(10S), 40 228–230

[17] Ryabov S A, Ivanova N A and Shvartsburg L E 2014 Assessment, analysis and managing occupational risks in the industry Chief mechanical engineer 12 21–26

[18] Russian Statistical Yearbook 2018 RF Rosstat (Moscow). https://www.gks.ru/storage/mediabank/year18.pdf. Accessed 15 Nov 2019

[19] Movsumzade E M, Dumayeva I V, Rasulbekova T I, Mamedyarova K B and Rekuta Sh.F. 2004 Analysis of acrylonitrile synthesis methods Chemistry and Chemical Technology 47(10) 3–10.

[20] Goryachev A B 1999 Nitriding of structural steels by an ammonia pulsating supply Abstract of Ph.D. thesis in Engineering Science (Moscow)

[21] Belozerov G A, Mednikova N M, Lapshin V A and Pytchenko V P 2005 Current trends in the use and safety of ammonia refrigeration units at Russian plants, ed Belozerov G A, Scientific Support for the Refrigeration Industry (Moscow) pp 219–227

[22] Mikhailov L A 2014 Fire safety of buildings and structures, DEAN (Moscow)

[23] Zubkov I L 2007 Optical chemical sensor for monitoring the concentration of ammonia in the air, Abstract of Ph.D. thesis in Engineering Science (Nizhny Novgorod)

[24] Bukeikhanov N R, Jumagaliyeva E M, Nikishechkin A P and Chmyr’ I M 2013 A device for the neutralization of accidental releases of highly toxic ammonia RF Patent for utility model 131629 MPK A62C 2/6 25 Sep 2013