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Ammonia-risk distribution by logistic subsystems and type of consequence

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ABSTRACT

Detailed quantitative analysis of results, influence of position within logistic systems and consequence of dangerous goods ammonia has been done based on a sample of 1165 workers or third persons involved in 295 accidents. Results of accidents for those involved have been classified as unhospitalized, hospitalized survived, hospitalized deceased and killed. From the logistic point of view accidents with ammonia are located in production, storage, reloading, transport and use subsystems. ammonia's consequences are systematized in the following manner: Respiratory-Toxic (RT), Cold Injury (CI), Fire and Burns (FB), and mechanical consequences after explosions (EX).

Distribution laws for unhospitalized, hospitalized, deceased and killed have been determined. The highest average number of persons involved in an accident has been determined in the production subsystem. Cold Injury by ammonia in 47.5% of accidents includes 65.23% of persons involved in accident, but the most invasive consequence of ammonia is RT.

Significantly critical fatal outcomes of accidents has been found for Respiratory-Toxic consequence of ammonia in the reloading subsystem, with extremely high average value of 0.4193 killed per accident. Based on obtained results of research certain procedures are proposed to reduce the risk of serious consequences of ammonia's dangerous influence.

1. Introduction

Symbolically, rich history of ammonia has been documented and it starts from "the father of history" Herodotus. He was the first to describe ammonia deposits in Siwa Oasis in north-western Egypt in the fifth century BC. Ammonia has been widely known in the Roman Empire as "Hammoniacus salt" in Pliny the Elder's (23–79) records. Abu Musa Jabir Ibn Hayyan (721–815) has promoted ammonia into one of the most important substances of alchemy. In 1785 French chemist Claude Louis Berthollet (1748–1822) first determined the elemental composition of the gas ammonia.

Alongside of its rich and long history ammonia is still one of the dominant expert and scientific subjects. In the last decade, only within journals with impact factor, production of papers of the numerous aspects of ammonia was sufficient enough to create thematic journal of high rank. Within the 2016 year key word "ammonia" has been searched on Science Direct

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producing 16,006 hits, while in 2017 there were 17,777 results, while 2018 year will probably have over 20,000 results. This is why it is unrealistic to have a comprehensive literature overview on the subject of ammonia.

Ammonia is one of the most researched chemical compounds. The reason for this is undisputed significance of ammonia in many branches of economy. The manufacture of ammonia is crucial for the world's agricultural industry. Estimated production for the year 2016 was nearly 140 million tons: China 46×10^6 t, Russia 12×10^6 t, India 11×10^6 t, USA with around 10×10^6 t, Indonesia 5×10^6 t, Trinidad and Tobago $4,7 \times 10^6$ t, Canada 4×10^6 t etc. The average ammonia price for 2016 was estimated to be about 270 $ per short ton. Annual economic balance of ammonia market in the world is around 40×10^9 $ [1].

Ammonia is still the dominant cooling fluid in industrial cooling systems. For equal cooling effects, ammonia based systems have smaller dimensions of pipelines, two times less filling and smaller dimensions of heat exchangers. Thanks to its thermodynamic properties it is still the best for branched pipe systems which are necessary in large capacity cooling systems. For sports ice rings it is irreplaceable. Cooling systems with ammonia contain the largest engineering know–how and experience in designing, building, usage and maintenance. Ammonia based cooling systems have the most sophisticated sensing equipment for accident prevention. Modern sensors have limits in detection of gas phase concentration at less than 1 part per million of ammonia [2–6]. In addition, should ammonia be accidentally released into the atmosphere it does not influence ozone degradation and green house effects.

In contrast to many positive aspects, ammonia also has well known unwanted consequences which are researched in a relatively new scientific area of dangerous goods, "Accidentology". Even though the following facts are well known, due to the usual protocol it should be stated that ammonia has been classified as a dangerous goods as UN1005, Class 2.3 (basic risk poisonous gas) subsection 8 (corrosive gas) because:

- Ammonia has hazardous potential for causing severe damage (injuries) due to the toxic effects based on its alkaline chemical nature. Lethal dose is $LD_{50} = 0.015$ ml/kg. Toxicity sources of ammonia are numerous [7–9].
- Inhalation can cause Laryngitis, Tracheobronchitis, Bronchiolitis, bronchopneumonia and Pulmonary edema. Patients that have survived acute phase can develop Bronchiectasis, oversensitivity of respiratory tract, Bronchiolitis obliterans, chronic obstructive lung disease, and occasionally Interstitial lung disease [10,11]. Upon inhalation of ammonia its toxic effects are inevitable.
- Ammonia can cause frostbites from the first to the third degree due to its exothermal nature (liquid ammonia has very large standard enthalpy of vaporization of 23.35 j K/mol). Frostbite injuries have severe systematic complications and can often have lethal results [12–14].
- Due to relative low self-combustion point of 651 °C specific energy 22,500 kJ/kg, at 15–28% of presence in air ammonia creates explosive mixture which is also a possible source of accidents making burns and injuries created by mechanical influence of explosion a possible consequence of the dangerous goods ammonia [15–18].

Motive to research ammonia has been initiated during research on risk distribution of dangerous goods in logistic subsystems [19]. By comparing a set of 19 different dangerous goods which make up 90% of total global production of all the dangerous goods (explosives, oxygen, methane, polyurethane, gasoline, hydrofluoric acid, methanol, liquefied petroleum gas, hydrogen, natural gas, ethanol, diesel fuel, dehydrated ammonia, ammonia, Sulphuric acid, crude oil, chlorine, nitric acid, and hydrochloric acid) by analysing 9467 accidents, ammonia has been classified in a group of relatively safe dangerous goods, taking the 14-th position with the probability of a fatal accident of $p = 0.1414$. This risk analysis of stated dangerous goods has solely qualitative character. Significant differences in risk distributions of all stated dangerous goods have been proven by logistic subsystems production, storage, reloading, transport and use subsystems. Even though risk of fatal accidents for dangerous goods ammonia has been ranked 14-th, there has been significant and singular domination of ammonia in the logistic subsystem reloading. To determine the reason it is necessary to apply quantitative analysis. Taking into consideration all the stated facts, the basic aim of this paper can be set, which refers to development of quantitative analysis for determination of risk in logistic subsystems for dangerous goods ammonia. Based on the developed model it is possible to define procedures for reducing the risk of ammonia's consequences. Apart from that it is possible to define certain measures of preventive engineering in order to reduce the percentage of unwanted effects.

After the introductory part which presents basic characteristics of ammonia as dangerous goods, as well as motives and goals of the research, the paper consists of five other sections. Second section presents comparative quantitative analysis of ammonia's risk with certain other dangerous goods. The third section presents parametric and nonparametric statistical characteristics of accidents in which ammonia is featured as dangerous goods. The fourth section determines distributions and analysis of risk for ammonia by logistic systems: production, storage, reloading, transport and use, while the fifth section analyses the consequences of accidents with ammonia. The paper ends with conclusions and possible future work.

2. Comparative analysis of ammonia's risk compared with other dangerous goods

Based on available data from database FACTS — Hazardous Materials Accidents Knowledge Base (http://www.factsonline.nl) and global production volume for the period 1980–2015, risk of accidents per produced ton (acc/t) has been calculated for dangerous goods for which the annual production volume could be determined [20]. If risk of accidents involving ammonia is adopted as a reference value, the following relations between risks for stated dangerous goods is obtained (Fig. 1).

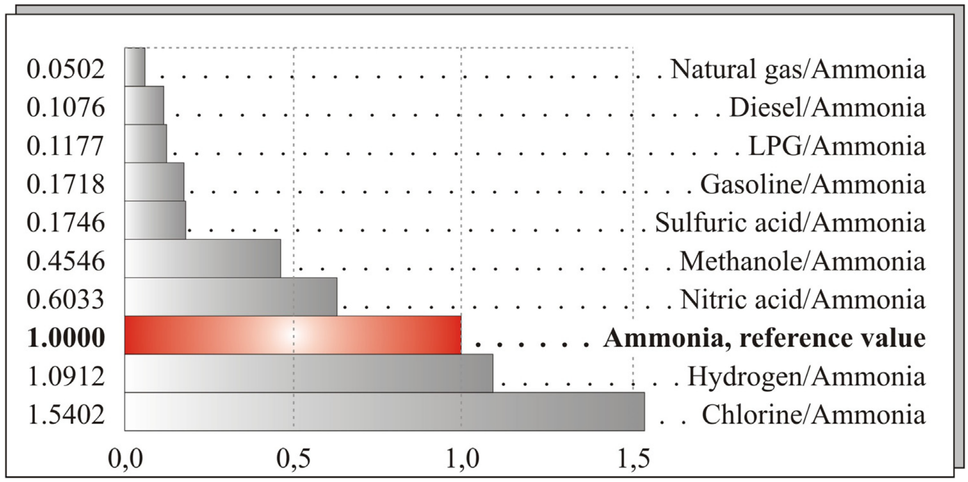

Fig. 1 – Relations between risk of ammonia and stated dangerous goods.

In global production volume of dangerous goods is dominated by energy carriers: crude oil, derivates and natural gas. Following energy carriers, two quantitatively most present chemicals in global production are Sulphuric acid with 290,000,000.00 tons/year and ammonia with around 140,000,000.00 tons/year. This is the reason why ammonia's extremely highly positioned with risk that is tens of times greater than of that of energy carriers is interesting.

Calculation of ammonia's risk is based on 259 accidents which were listed in 2016, based on available databases, officially published reports, news, etc. Countries from which data had originated in 2016 were registered and have cumulative ammonia production of $91{,}4 \times 10^6$ t (6528% of global production), which then gives quotient of risk of accident occurrence for ammonia $r = 2{,}8336 \times 10^{-6}$accident/ton. The data on accidents is mostly recorded in the developed countries where the risk is proven to be lower than in less developed countries [21]. Used data on number of accidents from China must be taken with caution. Sample misses the data from big ammonia producers such as India, Indonesia, Trinidad and Tobago, Saudi Arabia, Qatar, etc. This is why determined value of $r = 2{,}8336 \times 10^{-6}$ accident/ton can be declared as minimal estimation of risk, which for the global production volume of 140×10^6 t initiates annual occurrence of around 400 accidents involving ammonia worldwide within all the logistic subsystem.

Analysing data from OSHA database for the period 1985–2015 creates basis for quantitative comparison of risk. Analyses covers the following dangerous goods: Nitric acid, Sulphuric acid, ammonia, Gasoline and Natural gas. For ammonia the highest average number of workers and third persons has been determined in accidents — average of 4.8572, Nitric acid — 3.5217, Sulphuric acid 2.8438, Natural gas 1.8214 and Gasoline — 1.1435. However, in accidents resulting in fatalities the domination of chosen energy carriers has been noticed, especially for natural gas with average number of killed workers and third persons of average 0.5214 per accident. Apart from stated high risk of accidents for ammonia, over 50% of workers and a third of persons from accidents involving ammonia walk away without the need for hospitalization. All the other stated dangerous goods are below 50% of this ration and for natural gas it is only 7%. Surviving hospitalization after accidents involving ammonia is 95.02%, for natural gas it is 87.04% and for gasoline it is 82.16%.

3. Basic parametric and nonparametric statistical characteristics of accidents involving ammonia

Sample of 295 accidents involving ammonia has been analysed. OSHA database data has been used — United States Department of Labour — Occupational Safety and Health Administration [22] for the period between 1985 and 2015.

In the quantitative analysis of results, 55 accidents did not involve workers and third persons.

In the remaining 240 accidents there were people involved:

- 120 out of 295 accidents (40.67%) happened without endangering lives and health out of workers and third persons, without injuries or with slight injuries that demanded medical assessment but there was no need for hospitalization or injuries were taken care of in ER,
- in 127 out of 295 accidents (43.06%) health of the participants was endangered and hospitalization was obligatory,
- in 48 out of 295 accidents (16.27%) the life of workers and third persons was endangered. Fatal outcomes occurred either during hospitalization or instantly during the accident.

Obtained qualitative results from the sample of 295 accident are in accordance with qualitative analysis of results on the 533 sample from FACTS database [19] which respectively are 46.47%, 39.42% and 14.14%. Difference test between two proportions is highly in accordance for unhospitalized ($p = 0.2961$), hospitalized ($p = 0.5154$) and fatal outcomes ($p = 0.4162$). Sample can be treated as representative.

In the quantitative analysis of 240 accidents 1165 workers and third persons that were in need for health assessment after being involved in accident were analysed, of which:

- 603 workers (51.75%) after medical assessment and treatment did not have the need for hospitalization.
- 523 workers (44.90%) had the need to be hospitalized, of which 504 workers (43.26%) survived hospitalization, while 19 workers (1.64%) died during hospitalization. Information on degree of disability for survivors hadn't been available.
- 39 workers (3.35%) were killed in the accident.

In the Fig. 2. there is graphic presentation of the distribution of results. Final outcome of 240 accidents involving dangerous goods ammonia with registered participants results in 95.02% of survivors and 4.98% diseased participants of accidents.

Table 1 presents basic parameters of stated variables necessary for the analysis and the access to verification of nonparametric characteristics.

Nonparametric characteristic of statistic sets of unhospitalized, hospitalized, diseased during hospitalization and killed accident participants involving dangerous goods ammonia, even though whole number variables, mostly are verified as continuous (three of four), and only in one case as discrete variable. Parameters of all distributions are presented in the Table 2.

Change in distribution is verified only for hospitalized deceased, Bernoulli compared to Weibull distribution. This development of verification of distributions can be explained with the influence of intensive medical treatment. Due to low number in the sample (n = 19) the distribution of time interval between accident and fatal outcome during hospitalization is not verified. It should be stated that the average value of this interval was 6.56 days. Data on the length of the hospitalization period for the survivors hasn't been available.

4. Distribution and risk analysis by logistic subsystems

Distribution of 240 accidents involving ammonia with 1165 participants in these accidents by basic logistic subsystems was as following:

- In production subsystem 32 accidents (13.13%) with 286 participants (24.54%), with significantly proportional relation (p = 0.0736),
- In storage subsystem 28 accidents (11.67%) with 95 participants (8.41%), with significantly proportional relation (p = 0.2995),
- In reloading subsystem 31 accidents (12.92%) with 61 participants (5.23%), with significantly proportional relation (p = 0.0971),
- In transport subsystem 9 accidents (3.75%) with 30 participants (2.57%), with significantly proportional relation (p = 0.4385),
- In use subsystem 140 accidents (58.33%) with 692 participants (59.22%), with significantly proportional relation (p = 0.4266).

It is obvious that there is statistical domination present in the logistic subsystem of use based on occurrences of accidents within cooling systems based on ammonia (cold storages), during regular or unplanned services of cooling systems and the use of ammonia in agriculture. Significantly largest average number of workers per accident involving dangerous goods ammonia was determined within the logistic subsystem production.

By analysing variance the influence of logistic subsystem on average number of unhospoitalized, hospitalized, deceased and killed accident participants involving ammonia was examined. It was determined that there is significant influence of logistic subsystem on number of unhospitalized (p = 0.0033) and killed (p = 0.0319), while on hospitalized (p = 0.3771) and deceased (p = 0.1798) the distribution of accidents by logistic

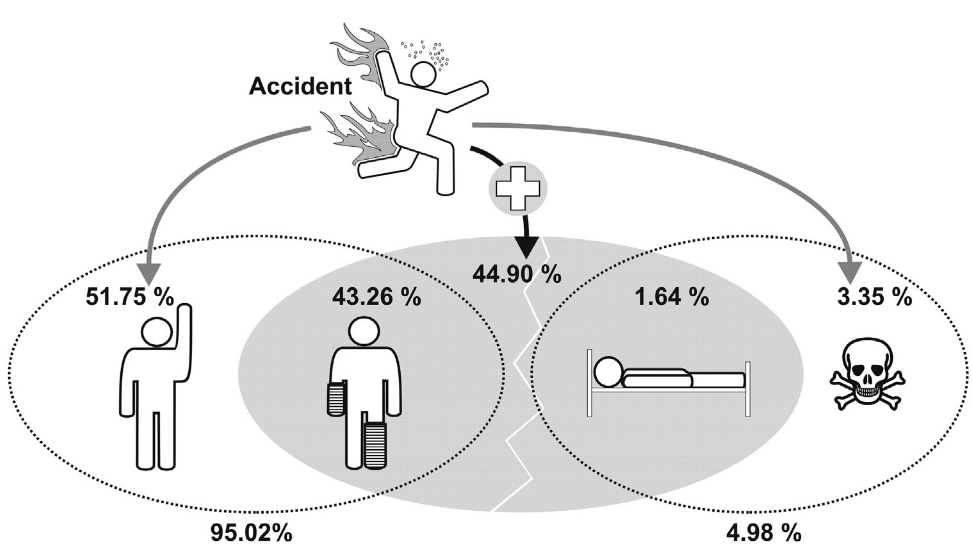

Fig. 2 – Graphic presentation of distribution for hospitalized, hospitalized survived, hospitalized diseased and killed participants in accidents involving dangerous goods ammonia.

Table 1 – Basic parameters and distribution for 1165 workers in 240 accidents for dangerous goods ammonia.

Parameter	Unhospitalized	Hospitalized		Killed
		Survived	Deceased	
Average value	2.5125	2.2100	0.0791	0.1625
Standard deviation	5.5304	4.0887	0.2856	0.4782
Median	0	1	0	0
Mode	0	0	0	0
Mode frequency	126	102	222	209
Minimum	0	0	0	0
Maximum	41	29	2	4
Asymmetry	3.9065	3.3512	3.6674	3.9084
Excess	18.4304	13.5579	13.6263	20.4454

Table 2 – Distributions, parameters of distribution and verifications of distributions for accidents involving ammonia as dangerous goods.

Weibull	a	b	μ	σ	χ^2	df.	p
Unhospitalized	0.42	0.83	2.4219	7.021	30.2225	38	$p > 0.70$
Hospitalized survived	0.43	0.74	2.0916	5.8624	36.5864	26	$p > 0.05$
Killed	0.67	0.20	0.2489	0.4348	2.1571	1	$p > 0.10$
Bernoulli	**p**	**(1–p)**	**μ**	**σ**	**χ**	**Df.**	**P**
Hospitalized deceased	**0.0750**	**0.9250**	**0.0750**	**0.2633**	**1.05882**	**1**	**$p > 0.10$**

subsystems had no influence. The results are graphically presented in the Fig. 3.

Fig. 3 shows obvious influence on increased number of unhospitalized in logistic subsystem production and increased number of killed in the reloading subsystem. Detailed quantitative analysis was performed using Duncan test for variance analysis. Duncan test was chosen due to the tolerance towards statistical error of the first kind and possibility for simultaneous comparison of average values by chosen factor of the logistic subsystem.

The average number of unhospitalized workers per accident involving ammonia is $\mu_u = 2.5125$ (Table 1). Duncan test for variance analysis has determined that the largest number of unhospitalized workers appears in logistic subsystem production ($\mu_{u1} = 5.4687$ workers/accident). This value however is not statistically significant comparing to the number of unhospitalized participants in logistic subsystems of transport and use, respectively: $\mu_{u4} = 2.2222$ ($p = 0.0528$) and $\mu_{u5} = 2.5212$ ($p = 0.0653$), but statistically is significantly greater than the number of unhospitalized workers in logistic subsystems storage and reloading respectively: $\mu_{u2} = 1.6786$ ($p = 0.0276$) and $\mu_{u3} = 0.1936$ ($p = 0.0276$).

Average value of the number of hospitalized workers per accident involving ammonia is $\mu = 2.2100$ (Table 1). Number of unhospitalized workers per accident involving ammonia in logistic subsystems production, storage, reloading, transport and use are respectively: $\mu_{h1} = 3.0625$, $\mu_{h2} = 1.6429$, $\mu_{h3} = 1.2581$, $\mu_{h4} = 1.0000$ and $\mu_{h5} = 2.2286$. Duncan test for variance analysis didn't determine significant influence of factors of logistic subsystems on average number of hospitalized participants in accidents with ammonia.

Average value for the number of accident participants deceased during hospitalization after accidents involving ammonia is $\mu_d = 0.0791$ (Table 1). Duncan test for variance analysis determined that the lowest number of deceased in accidents involving ammonia as dangerous goods appears in the logistic subsystem transport. All the cases of hospitalization of workers after incidents in transport logistic subsystem transport had the desired outcome, no deaths, $\mu_{d4} = 0.00$. This value is statistically different from the average number of deceased in the logistic subsystem production $\mu_{d1} = 0.1875$, but it can still be accepted — the average number of deceased during hospitalization "0" in case of transport doesn't have variance. Remaining average values for storage, reloading and use subsystems are respectively: $\mu_{d2} = 0.0714$, $\mu_{d3} = 0.0967$ and $\mu_{d5} = 0.0571$. Stated average values aren't significantly different from the average number of deceased from accidents involving ammonia in logistic subsystem production $\mu_{d1} = 0.1875$.

Average value for the number of accident participants killed after accidents involving ammonia is $\mu_k = 0{,}1625$ (Table 1). Duncan test for variance analysis determined significant negative influence of factors within the logistic subsystem reloading. Average value of number of workers killed in an accident is $\mu_{k3} = 0.4193$. This value is significantly greater than in all the remaining average values of other logistic subsystems: killed in production $\mu_{k1} = 0.1526$ ($p = 0.0585$), killed in storage $\mu_{k2} = 0.1071$ ($p = 0.0436$), killed in storage $\mu_{k4} = 0.1111$ ($p = 0.0413$) and killed in storage $\mu_{k5} = 0.1214$ ($p = 0.0416$). This negative domination of reloading subsystem is qualitative confirmation of indications on critical risk of accidents for the dangerous goods ammonia in the logistic subsystem reloading.

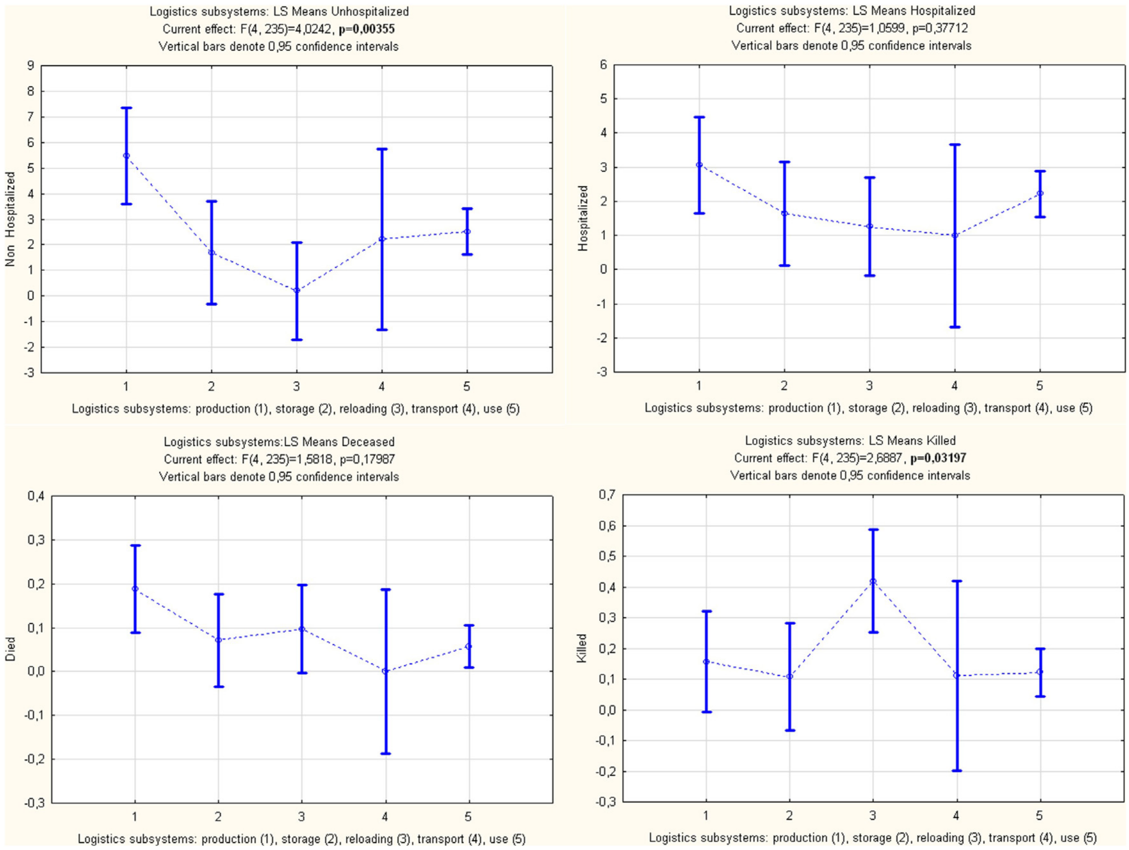

Fig. 3 – Graphic presentation of variance analysis of logistic subsystem influence on unhospitalized, hospitalized, deceased and killed accident participants involving ammonia.

5. Analysis based on consequences of accidents ammonia

Out of 240 accidents with workers, according to the consequence of contact with the dangerous goods ammonia the following has been determined:

- 112 or 46.67% accidents with respiratory and toxic effects (RT),
- 114 or 47.50% accidents with Cold Injury (CI),
- 8 or 3.33% accidents with Fire and Burns (FB),
- 6 or 2.50% accidents with injuries from explosions (EX).

Distributions of unhospitalized, hospitalized, deceased during hospitalization and killed accident participants according to the consequence for ammonia is presented in the Table 3.

Frequencies of workers are significantly unevenly distributed by consequences χ^2 test contingency has the value of 0.40 which results with threshold significance of $p = 0.00001 < 0.05$. The influence of the type of consequence is significant.

The highest number of workers in accidents suffered Cold Injuries, 760 workers. These 65.23% of workers has been involved in 47.50% of accidents. By using the proportion test

Table 3 – Distribution of unhospitalized, hospitalized, deceased during hospitalization and killed participants by consequence (No.) and average number (A.N.) per accident for the dangerous goods ammonia.

Ammonia consequence	Unhospitalized		Hospitalized				Killed		Σ No. 1165 (100%)
			Survived		Deceased				
	No.	A.N	No.	A.N	No.	A.N	No.	A.N	
RT (46.67%)	135	2.87	178	2.51	10	1.11	17	1.13	340 (29.18%)
CI (47.50%)	428	7.01	307	5.38	7	1.00	18	1.38	760 (65.23%)
FB (3.33%)	14	3.50	16	2.00	1	1.00	3	1.00	34 (2.91%)
EX (2.50%)	26	13.00	3	1.00	1	1.00	1	1.00	31 (2.68%)

(p = 0.0002) it can be concluded that Cold Injury is significantly most often consequence of accidents involving ammonia.

Death rate of participants (deceased and killed) for CI consequence of ammonia is 3.29%. Death rate of participants for RT consequence of ammonia is 7.49% disproportionally higher than CI consequence of ammonia (p = 0.0004). Also, death rate of participants for FB consequence of ammonia is 11.76% is also disproportionally higher than CI consequence of ammonia (p = 0.0050).

Death rates form CI and EX consequence 6.45% are proportional (p = 0.1709). Between proportions RT and FB consequences of ammonia there is no significant difference (p = 0.2206). It can be concluded that RT and FB consequences of ammonia involved accidents are significantly more invasive than complementary CI and EX consequences.

Domination of killed workers in reloading logistic subsystem was examined in detail according to consequence type (Table 3). Out of 1165 workers and third persons, 61 (5.23%) was involved in 31 accidents realized in logistic subsystem reloading. In three accidents there were unhospitalized and hospitalized deceased. In one accident hospitalized survived and hospitalized deceased while. In two accidents there were hospitalized survived and killed participants.

Distribution of participants by consequence type of ammonia and their results is presented in Table 4.

From the Table 4 it is obvious that the results in logistic subsystem reloading are far worse. There is reduction in number of unhospitalized at the account of hospitalized. Set of hospitalized consist of much greater number deceased along with increase in the number of killed. This conclusion can be statistically confirmed.

If accidents in reloading subsystem are compared with its complementary set of outcomes of accidents in all other logistic subsystems (remaining 1104 workers and third persons), differences that occur are significantly emphasized:

- compared to 6 of 61 unhospitalized or 9.83% in logistic subsystem reloading, there are 557 of 1104 unhospitalized remain or 50.45% in complementary logistic subsystems. Proportion test confirms significant difference for unhospitalized (p = 0.0000),
- compared to 42 of 61 hospitalized or 68.85% in logistic subsystem reloading, there are 481 of 1104 hospitalized remain or 43.56% in complementary logistic subsystems. Proportion test confirms significant difference for hospitalized (p = 0.0001).
- compared to 13 of 61 killed or 21.32% in logistic subsystem reloading, there are 26 of 1104 killed remain or 2.35% in complementary logistic subsystems. Proportion test confirms significant difference for killed (p = 0.0001).

Should we compare accidents by their results in reloading subsystem with consequence of ammonia in accidents realized in complementary logistic subsystems, with set of accident outcomes in all other logistic subsystems differences that occur significantly stand out:

- compared to 37 of 61 or 60.65% of RT consequence of ammonia in logistic subsystem reloading, remaining 98 (difference to 135) of 1104 or 8.87% of RT consequence of ammonia in complementary logistic subsystems. Proportion test confirms significant difference between proportions for RT consequence (p = 0.0001).
- compared to 21 of 61 or 34.42% of CI consequence of ammonia in logistic subsystem reloading, remaining 407 (difference to 428) of 1104 or 36.86% of CI consequence of ammonia in complementary logistic subsystems. Proportion test does not confirm significant difference between proportions for CI consequence (p = 0.3502).
- compared to 2 of 61 or 3.28% of FB consequence of ammonia in logistic subsystem reloading, remaining 12 (difference to 14) of 1104 or 1.08% of FB consequence of ammonia in complementary logistic subsystems. Proportion test does not confirm significant difference between proportions for FB consequence (p = 0.0619).
- compared to 1 of 61 or 1.64% of EX consequence of ammonia in logistic subsystem reloading, remaining 25 (difference to 26) of 1104 or 2.26% EX consequence of ammonia in complementary logistic subsystems. Proportion test does not confirm significant difference between proportions for EX consequence (p = 0.2435).

Proven tendency is obvious from the distribution of average number of unhospitalized, hospitalized, deceased and killed in accidents by consequence type of ammonia in logistic subsystem reloading (Table 4).

Based on elementary differentiation of proportions, it can be concluded that accidents involving ammonia in logistic subsystem reloading, dominantly, in 60.65% cases, are due to respiratory toxic (RT) consequence of ammonia. RT consequence occurs significantly more in logistic subsystem reloading than in other logistic subsystems.

Table 4 – Distributions of unhospitalized, hospitalized, deceased and killed in accidents involving ammonia by consequence type in logistic subsystem reloading. Number of accidents (No.) and average number (A.N.).

Ammonia consequence	Unhospitalized		Hospitalized				Killed	
			Survived		Deceased			
	No.	A.N.	No.	A.N.	No.	A.N.	No.	A.N.
RT (37)	3	1.50	27	2.70	1	1.00	6	1.50
CI (21)	2	1.00	10	1.66	2	1.00	7	1.66
FB (2)	1	0.00	1	1.00	0	0.00	0	0.00
EX (1)	0	0.00	1	1.00	0	0.00	0	0.00

Due to invasive RT consequence, accidents involving ammonia in logistic subsystem reloading significantly increase number of hospitalized and killed workers. It should also be mentioned that statistic influence of Consequence type on the results, in large number of incidents had participants with triage of Consequences. This is the reason why interpretation of results acquired by using ANOVA test is not transparent like proportion tests are.

Distribution of accidents and workers (and third persons) by consequences and logistic subsystems for the analyzed set of ammonia accidents, is given on Fig. 4.

6. Discussion and conclusion

From the view point of accidentology, ammonia belongs to dangerous goods with estimated risk of $r = 2.8336 \times 10^{-6}$ accident/ton. In comparison to other dangerous goods, ammonia has high risk of accident occurrence per production unit. The base of high risk are heterogeneous unwanted consequences: from poisonous, corrosive, extreme cold to fire and explosion. Apart from high risk, for accidents involving ammonia high number of affected workers or third persons is characteristic, 4.7225 in average per accident. 95.02% of those involved in accident survive it while 4.98% has a fatal outcome.

Distributions of hospitalized, unhospitalized and killed accident participants involving ammonia have homogenous laws, based on Weibull distribution. Relation between mathematical expectation and Weibull distribution variance points to occurrence of low number of accidents with large number of participants and vice versa. Unsuccessful medical sustenance of life of vitally endangered participants of accidents involving ammonia somewhat changes the distribution, hospitalized deceased participants are distributed according to binomial distribution.

The highest number of participants of accidents involving ammonia was determined in logistic subsystem production, the average is 8.8750. Of it in average 5.4687 unhospitalized, and in average 3.0625 survived hospitalization. It is obvious that the logistic subsystem production is well prepared for accidents involving ammonia (survival rate 96.47%). It was designed to taking care of safety aspects by using broad spectre sensors, use of safety equipment, accident protocols etc. Due to these reasons logistic subsystem production, which during accidents inevitably involves large number of workers, has significantly large number of unhospitalized and survived hospitalized workers. These results should make us satisfied.

Logistic subsystem storage doesn't have significant risk of accidents involving ammonia.

Critical risk for ammonia was determined in the logistic subsystem reloading. In previous research it has already been stated that ammonia is singularly the most important matter in logistics of dangerous goods. Quantitative analysis in this paper has significantly proven high risk of reloading ammonia,

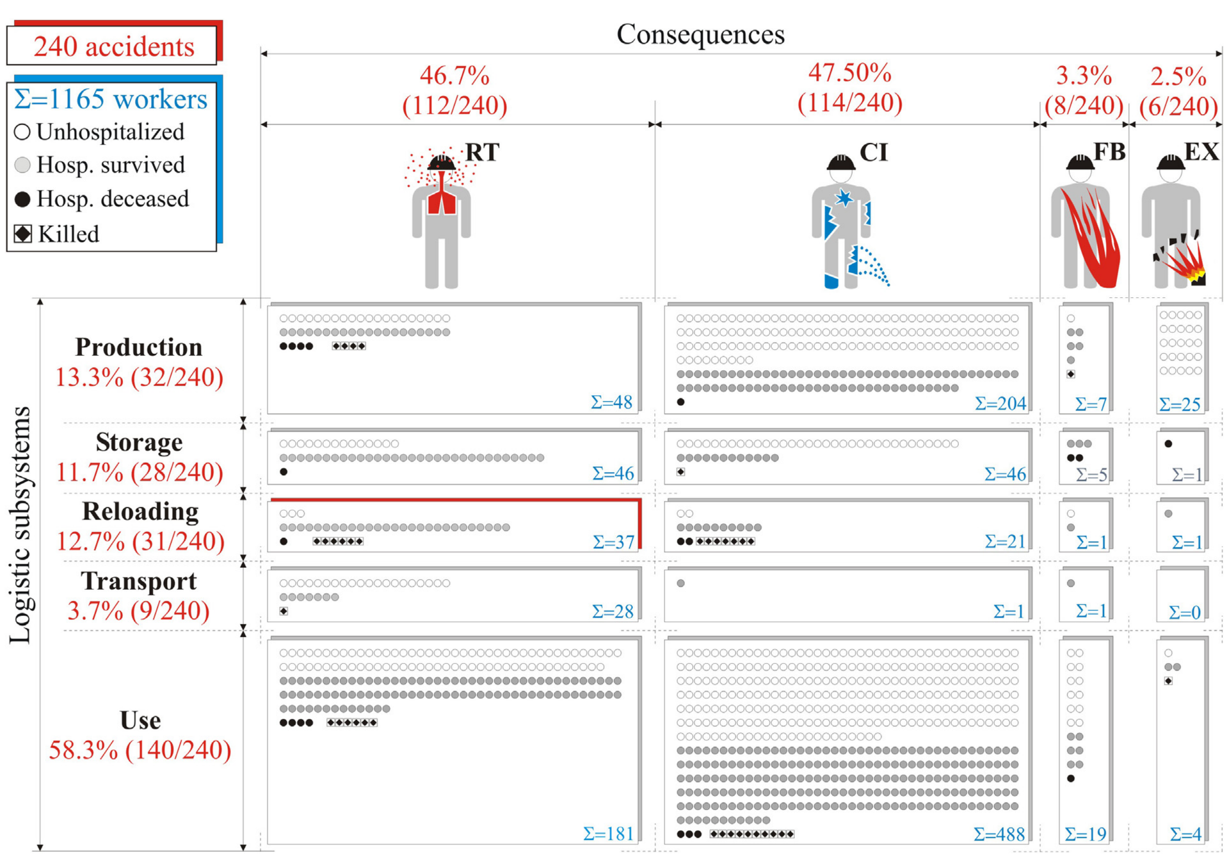

Fig. 4 – Synthetic graphic representation of ammonia accidents outcome.

especially with the result of 0.5160 (0.0967 hospitalized deceased +0.4193 killed) fatal outcomes per accident. Practically in every second accident during ammonia reloading, one deceased or killed participant is a certainty! Cause can be determined by analysing type of ammonia consequence: Respiratory–Toxic (RT) consequence is significantly emphasized as dominant. Cold injury (CI) consequence in accidents have a large but statistically unexpressed contribution in ammonia reloading.

There is no need for additional techno-chemical research to take care of this worrying result. Emphasized RT consequence points to exceeding high levels of ammonia concentration in reloading environment. Instant measures are possible to begin with: due to known ammonia enthalpy it is necessary to reduce the speed of ammonia flow during reloading, reloading stations themselves need to have intensive ventilation, and sensory equipment needs to be used on joining elements of reloading equipment along with rigorous use of safety equipment. At the same time existing reloading equipment needs to be reconstructed and new, safer, equipment should be designed.

Results for logistic subsystem transport are especially satisfying. Smallest number of accidents with ammonia have high average number of unhospitalized participants (2.2222). Subsystem transport has the smallest average number of hospitalized, deceased and killed in ammonia involved accidents. We can be especially satisfied with the results for the transport subsystem, which comes as a result of consistent use of ADR and RID.

In the distribution of accidents by logistic subsystems use is the one that dominates. It has 58.33% of accidents involving ammonia. This quantity doesn't have statistically emphasized qualitative differences in risks, either desirable or undesirable. If it is emphasized that the largest number of accidents occurred in agriculture, in open spaces, the target group of agricultural manufacturers is positioned. By additional education of agricultural manufacturers of the dangers involved with ammonia and proper methods for its use, the number of accidents could be reduced.

The most common type of ammonia's unwanted consequence is Cold Injury (CI). Even though it is the most common it, at the same time, causes lowest number of fatal outcomes. Most invasive type is Respiratory–Toxic (RT) consequence of ammonia. This is why apart from sensory prevention, extension of protocols for respiratory protection (gas filter type K) in case of ammonia surely leads to significant reduction of fatal outcomes of accidents involving ammonia.

Conflicts of Interest Statement

None.

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