SAFETY ASPECT IN CARRIAGE OF DANGEROUS GOODS BY RAILWAY TRANSPORT

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Abstract. Safety in transportation of dangerous goods is an important issue in transport processes. The impact of transport damage on the level of safety is very high and therefore becomes a very important issue in transport. The number of breakdowns in railway transport is becoming more and more advanced with deterioration of wagon condition due to aging. Thanks to the analysis of these data, it was possible to approximate the problem of transport failures and their impact on the safety of people involved in this transport process. In addition, the simulation in ALOHA program has been carried out that allows to illustrate the effects of the hazardous substance release from the transport rail tank. This event may result from derailment of the wagon or breakage of the wagon component. The simulation shows the extent of the threat during the incident. The conducted researches and their analysis have shown the problems of railway transport safety on various levels and different planes.

Keywords: railway transport, dangerous goods, threats, defects of railway transport, advantages of railway transport

INTRODUCTION

Railway transport is one of the transportation branches. The development of this branch is connected with the development of railway lines, targeted with increasing pressure from the European authorities to protect the environment. Data in the literature of the subject indicates that emission of pollutants emitted by the railway are much lower than those emitted by road transport, which generates as much as 80% of pollution caused by all modes of transport (Tomaszewski and Wojciechowska, 2011).

Road transport is the leader in the volume of transport performed in the European Union. The railway carries about 11% of freight transport (Badyda, 2010). Railway transport is environmentally friendly, emitting less greenhouse gases, pollutants and noise to environment than other transport modes. It significantly reduces road congestion and road traffic accidents. Routing, coverage, and deployment are often tailored to the location of production regions, making this branch of transport easy to use. An important aspect in the carriage of goods is combined transport, which allows the connection of rail transport with road or water. This branch is also full of flaws. The main problem is the poor condition of the railway infrastructure and the long transit time.

The development of the rail freight market is a derivative of the dynamics of commodity markets that benefit from this kind of transport service. In Poland, it is primarily the market of coal, aggregates, coke and refined petroleum products, chemical products and goods transported in containers.

According to Eurostat, currently the most developing commodity trading market is the market of oil and chemical products. Continuous increase in consumption of these goods forecasts the development of their transport. Currently, transport for the chemical sector accounts for 6% of the total volume of goods transported by rail (Eurostat). Carriage of these loads increases the risk of hazards that may occur. The biggest problem in railway transport is the condition of the means of transport in Poland, connected with the continuous growth of the average age of wagons.

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According to GUS, the average age of the operated freight wagons is 25 years, which is in line with their efficiency and hence the safety maintaining. Considering these aspects, there is a safety issue in transport. It is the most important element of the transport process. In particular, when it concerns the carriage of dangerous goods, the significance of this problem is greater. Railway transport is not the most used transport sector in Poland, but in regards to the transport of dangerous goods by rail, it is Poland in this field, second in Europe. 22 million tons of goods are transported annually in Poland (GUS, 2016).

RISKS AND HAZARDS IN THE TRANSPORT OF DANGEROUS GOODS BY RAIL

The transport of dangerous goods is governed by codes and regulations. Rail transport is governed by the rules contained in the Regulations for the International Carriage of Dangerous Goods by Rail (RID). It is annex C to the Convention on International Carriage by Rail (COTIF), which Poland is a signatory to (COTIF, 1980). The application of the RID Rules is also based on Directive 2008/68/ EC of the European Parliament and of the Council on the inland transport of dangerous goods that has been implemented in the Polish legal system by the law act on the carriage of dangerous goods. There are also many non-compulsory regulations that facilitate the process of transporting goods by rail.

Such documents are, for example, the General Contract of Use for Wagons (GCU) or "The Manual of maintenance of freight wagons" created by the Vereinigung der Privatgüterwagen Interessenten (VPI). The rail traffic safety problem is widely developed and elaborated by the European Railway Agency (ERA).

More and more solutions are being applied to both railway infrastructure and transport modes.

The RID Regulation defines the rules governing the carriage of such goods by rail (RID, 2015). There are defined in it the obligations of participants in the carriage, classifies the groups of goods being transported, and detailed provisions of each class of goods. There are also indicated the ways of using various types of transport containers, requirements for their construction and research. Besides, the regulations contain provisions on transhipment operations. In addition, there are discussed the procedures for protecting and dealing with various hazards and accidents. An important aspect of the RID provisions is the appropriate labeling of transport units carrying hazardous materials. In order to ensure safety during transport, rail transport vehicles should be marked in such a way as to allow identification of the transported goods by train drivers or train composition controllers.

Major hazards in railway transport are hazards as follows (Kowalski and Wróblewska, 2004): fire, explosion, chemical-ecological, toxic, breakdowns and terrorist threats.

The majority of these hazards are caused by the presence of flammable liquids, aerosols of flammable liquids and flammable solids. In companies handling flammable substances transported in wagons, the easiest way to prevent fire is to minimize the occurrence of the source of ignition. The source of ignition in transport and handling operations are: hot surfaces, mechanical sparks, electrical appliances, static electricity, lightning.

Hot surfaces are surfaces whose temperature exceeds 2/3 of the ignition temperature of the substance. The ability to ignite through hot surfaces increases as the temperature and surface increase.

Mechanical sparks are generated by friction, impact or abrasion in which separation of high temperature particles the so-called sparks can occur. They can trigger an explosion. In order to avoid this phenomenon, no work is carried out which is accompanied by the formation of sparks during the loading or unloading of petroleum substances (Getka, 2015).

Electrical appliances might create a threat in the presence of mechanical sparks and hot surfaces. Even low voltage below 50V, used to protect people against electric shock, is able to initiate an explosion. Explosion-proof devices are used for explosion protection.

Electrostatic discharges can cause an explosion of any flammable mixture. The phenomenon of static electricity may occur in the case of loading the wagon when the substance is splashed inside the tank during filling. To avoid this type of situation, intelligent loading arms are becoming increasingly common. They are recessed into the wagon so as to minimize the occurrence of static electricity (Kowalski and Wróblewska, 2004).

Chemical and ecological hazards are related to the emission of hazardous substances to water, air or soil, which can cause a major accident. The toxicity of petroleum products depends on their composition and on the sensitivity of the tested organisms. The time at which toxic conditions persist depends on the size of the leak and the presence of organisms capable of degrading petroleum products, as well as the possibility of the conditions necessary to carry out such a process (Gronowicz, 2004).
Accidents are an important source of danger in railway transport. During transport the most dangerous breakdowns that can occur is the leakage of petroleum products, which can occur due to unsealing the installation (installation leaks). Any type of failure can result from: design error, manufacturing defect, material defect, malfunction, wear and exceptional environmental conditions (Getka, 2015).

EXPERIMENTAL PART

The research concerned breakdowns, in terms of the causes and consequences of the emergence, as one of the dangers arising from the transport of dangerous goods by rail.

Table 1.
Criteria of mechanical failures in the selected rail tank wagons

The total number of damage in year	71		**1. Wagon failure rate:**	25.36%
Number of wagons	280			
Number of damage to the spring	9		**2. Spring failure rate:**	12.68%
The total number of damage in year	71			
Number of damage to the discharge devices	9		**3. Discharge devices failure rate:**	12.68%
The total number of damage in year	71			
Number of damage to the wheelset	16		**4. Wheelset failure rate:**	22.54%
The total number of damage in year	71			
Number of damage to the buffer system	2		**5. Buffer system failure rate:**	2.82%
The total number of damage in year	71			
Number of damage to the heating fittings	7		**6. Heating fittings failure rate:**	9.86%
The total number of damage in year	71			
Number of damage to the bogies	0		**7. Bogies failure rate:**	0.00%
The total number of damage in year	71			
Number of damage to the brake system	23		**8. Brake system failure rate:**	32.39%
The total number of damage in year	71			
Number of damage wagons at customer		**The total number of wagons at customer**	**9. Wagons at customer failure rate:**	
Customer 1	24	75		32.00%
Customer 2	3	29		10.34%
Customer 3	9	20		45.00%
Customer 4	13	90		14.44%
Customer 5	22	32		68.75%
Customer 6	0	20		0.00%
Customer 7	0	14		0.00%
Mileage of one-type wagons	**Number of wagons**	**Mileage [km]**	**10. Mileage wagons failure rate:**	
DE-0L	5	23472		0.97%
DE-5L	2	10624		0.44%
DE-7Ld	1	151954		6.29%
DE-7Lk	1	76486		3.17%
DE-8Ld	1	161604		6.69%
DE-8Lk	1	80208		3.32%
DE-9G	7	193426		8.01%
DE-9-Gz	2	113358		4.70%
FR-6G	12	41430		1.72%
FR-7L	1	114204		4.73%
FR-8L	2	91404		3.79%
FR-9L	2	5800		0.24%
PO-0G	1	65484		2.71%
PO-6Lk	7	210038		8.70%
PO-6Lk	2	32655		1.35%
PO-7L	11	215876		8.94%
PO-8G	8	214521		8.89%
PO-8Ld	4	554878		22.99%
PO-9G	1	56484		2.34%
SUMA	71	2 413 906		100.00%
średnia		33 999		5.26%
Number of repairs carried out	25		**11. Repairs carried out failure rate:**	100.00%
Number of planned repairs	25			

Source: own elaboration.

The breakdowns were divided into several categories; the main focus is on the separation of the chassis failure from the tank failure. Chassis failures were subdivided into the following categories: spring breakage, failures of the tractive-collision device, wheel sets breakdowns, truck breakdowns and brake failures. In this way, all possible parts of the chassis that can be damaged have been classified into one of the categories above.

Failure of the tank was divided into two categories, i.e. failure of the drain system or breakage of the tank's jacket. There is also an "other" category where there are failures that cannot be classified as chassis failures or tank failures. Examples of such failures may be invisible inscriptions on the wagon.

Table 1 shows the breakdowns rates of the tested tank wagons.

In order to check the time after the revision was damage happened, the data presented in Table 2 was compiled.

Table 2.
Division of breakdowns over the year

Revision of chassis	Number of failures related to chassis							**Revision of tank**	Number of failures related to tank			
Years	springs	buffer system	wheelsets	Bogies	brake system	other		**Years**	discharge device	heating fittings	other	
0-1	0	0	0	0	2	0	2	**0-1**	0	1	0	1
1-2	3	1	13	0	8	3	28	**1-2**	4	3	1	8
2-3	4	1	2	0	9	0	16	**2-3**	2	1	0	3
3-4	0	0	0	0	2	0	2	**3-4**	3	2	1	6
4-5	2	0	1	0	1	0	4	**4-5**	0	0	0	0
5 and more	0	0	0	0	1	0	1	**5-6**	0	0	0	0
SUM	9	2	16	0	23	3	**53**	SUM	9	7	2	**18**

Source: own elaboration.

For the purpose of presenting the consequences of breakdowns that is the unsealing of the rail tanks causing the release of the substance into the environment, simulation in the ALOHA program was performed concerning the effects of cavity defect.

The ALOHA program is a computer application designed specifically for people involved in chemical release modeling as well as for those planning and training emergency response services for the removal and neutralizing the effects of a sudden occurrence with the use of chemicals. This application was created jointly by the US National Oceanic and Atmospheric Administration (NOAA) and the US Environmental Protection Agency (EPA).

Key ALOHA models, such as hazards – toxicity, flammability, heat radiation and hypertension – involve the release of a chemical substance that can cause gas dispersion, ignition or explosions. ALOHA models distinguish three categories of danger: gas dispersion, ignition and explosion. The ALOHA application uses several different models, including the airborne diffusion model of the Green Book, which is used to estimate the movement and dispersion of a chemical gas cloud. Based on the air diffusion model, ALOHA program can estimate toxic gas dispersion, overpressure values from vapor cloud explosions, or flammable vapor cloud areas. ALOHA uses additional models to estimate the risks associated with ignition and explosion.

There are two separate dispersion models in ALOHA program: the Gauss model and the heavy gas model (Kopczewski and Pająk, 2011). For the simulation purpose, information such as the name of the substance, the weather conditions, the area of the accident site, the type of explosion, the size of the rail tank, the degree of filling, the size and location of the cavity defect were needed.

The above information makes it possible to visualize the effects of the disaster and to realize how much of a danger poses the transport of dangerous substances.

Assumptions for the task were as follows: transported product: Ammonia anhydrous UN 1005 at ambient temperature, location known, wind speed: 20m/s from the east, measured at 3m above the ground, clear sky, air temperature: 20°C, relative humidity: 50%, rail tank dimensions: length: 12.57m, bottom diameter: 3.34m, capacity: 95m^3, dimensions of damage: damage in the shell plating, 21cm in diameter, 35cm from the bottom of the rail tank, the tank contains 59.9t of product, event: ignition of the product with a jet fire – This means that a flame is formed in the shape of a stream at the outlet of the gas flowing out of the pressure vessel through the small hole (Lesiak 2012).

Data entered into the program and results of the created simulation are shown, Fig. 1.

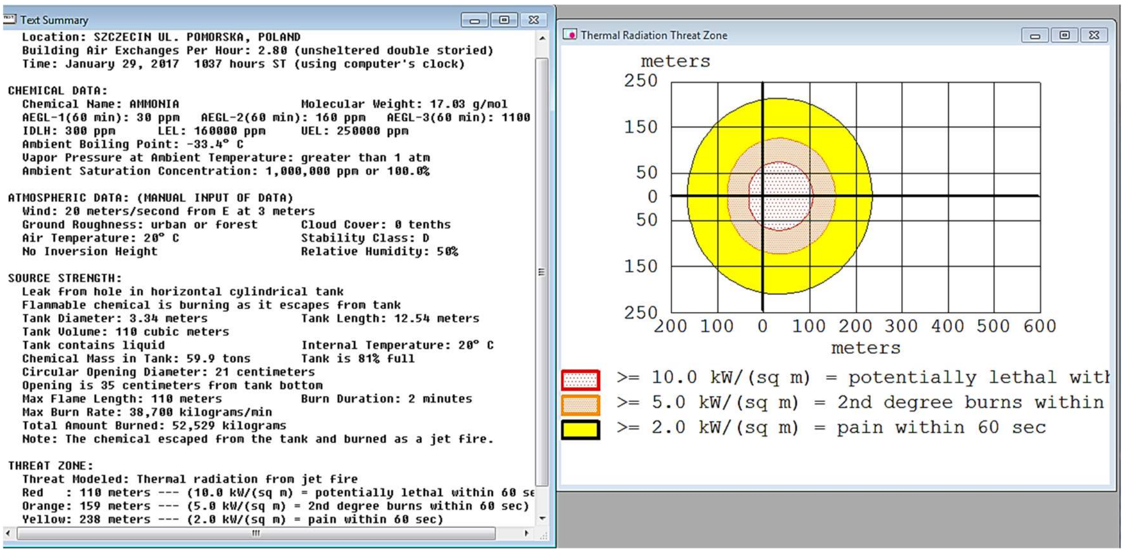

Fig. 1. Simulation in ALOHA program.

The effect grid of the event was mapped to the actual map of the event site (Fig. 2).

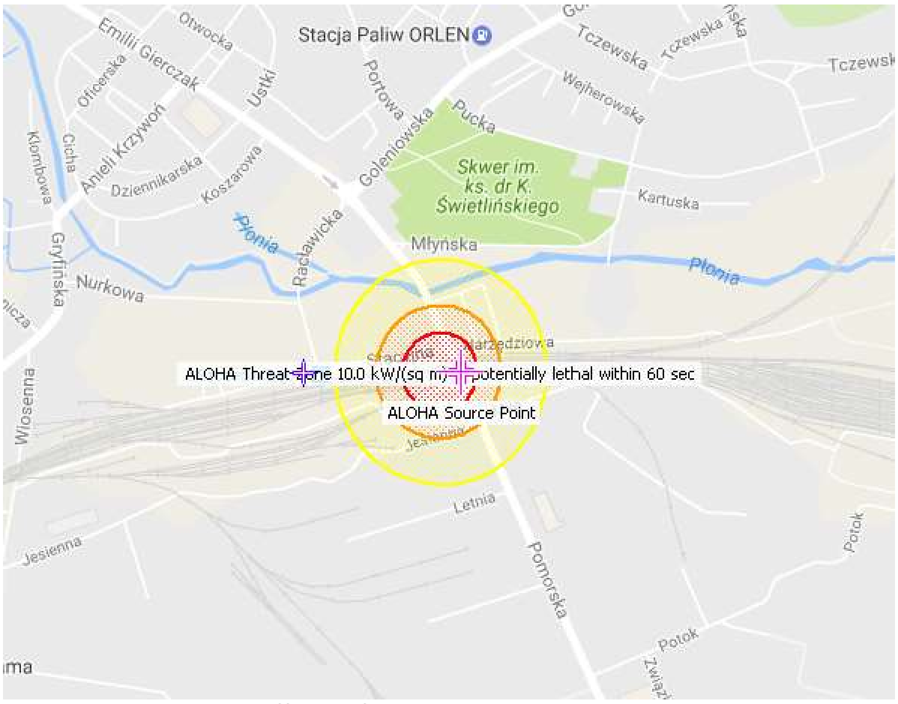

Fig. 2. Effects of leak in ammonia storage tank.

Source: own elaboration.

CONCLUSIONS

There are many legal acts that facilitate the maintaining of safety while transporting goods by railway, but they are not mandatory, which creates many difficulties, because not all countries maintain the same standards and procedures. It would be a good step to introduce the obligation of EU countries to comply with regulations such as AVV or VPI.

These are regulations that make it much easier to increase safety levels because they standardize the ways of acting.

When analyzing the results of the research, it should be noted that 25% of the entire fleet had any breakdown. The highest number of failures occurred in the braking system (over 32% of all malfunctions). Of which the largest number of breakdowns is 3-4 years after the chassis review. Another very high failure indicator is the breakage of wheel sets (over 22%). This is caused by the wear of the working parts. To reduce the value of this failure indicator there would be necessary to use wheels made of better quality material.

The analysis also shows that the greatest number of breakdowns is one to two years after the revision of the chassis or rail tank. It may result from low accuracy during repairs or revision carried out by the workshop and the age of the used wagons. In this case, the corrective action may be to find the workshops with the higher standards of repair or replacement of rolling stock to newer.

It can be concluded from the analysis that most of the wagons, in percentage distribution, were damaged at customer number 5 (over 68% of the rolling stock). Such a high failure indicator most probably results from incorrect use of wagons by the customer.

Based on the analysis of the breakdown rates, it is clear that, despite the age of the wagons, the number of faults in the overall picture is quite small. However, major corrective actions should be introduced, which should be implemented over the incoming years.

The most important of these corrective actions is the gradual replacement of the rolling stock into a more modern one, which will contribute to the increase of transport safety but will also make the company more competitive. Another the very important corrective action factor is the change in the maintenance cycle of wagons, in which wagon surveys will take place more often. This will reduce all breakdowns rates by a few percent, as parts of the wagon will in that case be more frequently controlled, reconditioned or replaced. All these activities will produce results gradually, so their success will only be assessed in a few years.

The simulation of the ammonia leakage from the rail tank in the ALOHA program allows to illustrate the size of the incident and shows how big the threat is during the transport of dangerous substances. The area around the scene is urbanized and located in the middle of a large city. The location of an event in a given place is therefore connected with the presence of people, and hence the great danger to them.

The fire resulting from the derailment of ammonia rail tanks could spread over a radius of over 200m. The greatest impact of the flames from the source would be at a distance of even 110m-10kW/m^2. Flames with a thermal energy of 5kW/m^2 would be 159m from the source, and those with energy of 2kW/m^2 would be even at 238m.

The effects of thermal radiation are very serious, for example a stream of 12.5kW/m^2 may cause melting of plastic pipes, after 10 seconds of exposure a first degree burns occur and about 1% of deaths may occur after 1 minute of exposure. A value of 2kW/m^2 is the minimum value to induce pain in human after 1 minute of exposure.

During an incident of the release of a hazardous substance from a transport tank, there might be occurred human losses, material losses related to infrastructure or environmental pollution. Events of this type are very important critical points during transport processes. There should try to eliminate these points and minimize them by elimination the causes of dangerous substance leakage into the atmosphere.

The most common cause of such events is derailment or collision of wagons. The most important role in limitation of the number of similar events is to control both the technical condition of the vehicles, the infrastructure as well as the responsibility and qualification of the staff performing the tasks.

Carrying out this type of research will allow becoming aware of the potential risks posed by the transport of dangerous goods. During training of the railway drivers and personnel who performs cargo handling operations there should be shown these types of simulators and diagrams to them as it could reduce the routine employees approach to the tasks performed and may have a direct impact on transport safety.

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