Factors influencing on the environment during hazardous goods transportation by the sea

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Abstract. Some goods transported by sea can be hazardous during transport because of their chemical nature. They are classified as dangerous goods. It is estimated that more than half of packed goods and bulk cargoes transported by sea today can be regarded as dangerous, hazardous or harmful to the environment. The most significant situations during sea transportation of dangerous goods which have impact on the environment are uncontrolled release of liquid into the environment, gas emissions and waste generation. Sea transport of dangerous goods is regulated by IMO regulations, EU regulations and national legislation. It is regulated in order to prevent possible accidents and injuries, damaging goods and environment pollution. In order to ensure that such transport keeps on being profitable and environmentally friendly, emphasis is placed on the quality and condition of infrastructure, transport safety, and carefully focused supervision and control. Measures to improve the environment include detailed standards of packing, marking, labelling, documentation, stowage, quantity limitations, exceptions and notifications. This paper includes analysis of the action aimed at preventing and minimizing sea pollution caused by transportation of dangerous goods.

1. Introduction

Carriage of goods by sea is the most important form of transport in the world. In 2015, it accounted for more than 80% of global freight. The volume of transportation of goods by sea is an indicator of the global economy. Marine industry is characterized by consistent growth of port facilities and increasing transportation volume, including dangerous goods [1].

Dangerous goods transportation is growing in regard to the number of chemicals and the total volume of goods. Nowadays, the number of different dangerous goods and compounds is quoted in thousands. Maritime transport of these goods is done in bulk and in packed form [2].

International Convention for the Safety of Life at Sea, (SOLAS, 1974) defined dangerous goods as follows: “dangerous goods means substances, materials and articles covered by the International Maritime Dangerous Good Code”[3].

The term “dangerous goods” includes any empty unclean packaging such as tank – containers, receptacles, intermediate bulk containers (IBC’s), bulk packaging, portable tanks or tank vehicles which previously contained dangerous goods, (unless the packaging has been sufficiently cleaned of residue of the dangerous cargoes and purged of vapors to nullify any hazard) or has been filled with substances not classified as being dangerous.
Dangerous goods are transported on a regular basis by sea and include many widely-used commodities such as: fertilizers, paints, fuels, alcohols, perfume products, pesticides, aerosols and refrigerates gases [4].

Transport of dangerous goods is generally associated with significant levels of risk which may depend on a variety of factors. Safety is the one of the main concerns in all activities related to the transport of dangerous goods. Catastrophic consequences of a possible accident include: fatalities, injures, emergency evacuations, property damages and environmental damages [5].

Maritime safety during transport of dangerous goods depends on the factors associated technology and the organization of the transport and crew preparation for the task resulting from the specific working conditions.

Some of the dangerous chemicals are characterized by the environmental impact if released into the water or air. Dangerous goods and materials transportation may be associated with accidents causing environmental damage through the whole course of carriage such as loading, unloading and storage [6].

Potential accident effects: fires, explosions, toxic gas release, leakage of dangerous substances. Every accident is associated with several types of costs:

- social cost (deaths, wounded or lost people);
- expenses incurred from restoration of ships and equipment;
- economic losses due to interrupted or slowed down volume of transported cargo;
- losses caused by environmental pollution, including damage restoration;
- loss of reputation of shipping company.

The environmental damage accounted for more than half of the total cost [4]. The cost on the environment is the cost due to damage restoration of infrastructure and costly techniques used to recover ecosystem.

In recent years, the cost of environmental damage has increased significantly. Although various research has been conducted since the increase in trend, no analysis has definitively clarified the cause for this increase [7].

One potential reason for that is increased sea transportation of hazardous and harmful products around the world over the last decades.

The evolution of shipping transport, which was affected by new cargoes and new carriage methods, introduced new, not well-understood hazards. It may be noted that high numbers of dangerous cargoes are increasingly using containers for transport. IMO regulations determine the conditions of the transport and assists in highlighting dangerous cargoes that require special care, however, some new cargoes are not covered[8]. Therefore, a new type of environmental and economic risk appears, which presents new challenges for the maritime transport. Information is the most important factor in the carriage of dangerous goods.

The goal of this paper is to develop categories of the chemical and physical factors and processes which have impact on the environment during sea transportation of dangerous goods

2. Chemical accidents during transport of dangerous goods

2.1. Hazard identification

Dangerous goods hazard is generated by combination of dangerous goods components, properties, activities during loading and transportation and external factors (Figure1). It affects ships, packages, human and marine the environment.
Figure 1. The type of hazardous source associated with transportation of packed dangerous goods.

The effects of uncontrolled release of dangerous goods primarily depend on type, state and quantity of dangerous goods. The impact of dangerous goods on marine life is caused by either physical nature of the goods (physical contamination) or by chemical components (toxic or accumulative effect).

The basis for classification of dangerous goods are physical properties. Such categorization helps in case of spillage or accident since substances in the same property group behave in a similar way. However, there are several substances which behave in a more complex manner than to simply float, sink or dissolve.

The main causes of accidents involving dangerous goods prior to ship’s departure can be divided in some categories:

- packaging deficiencies and filling errors: pre-existing damage, corrosion, defective components or devices, overfilling, instability of the cargo, impurities;
- poor securing, bracing and blocking;
- inappropriate stowage and segregation of the goods [9].

Hazard activities covering basic operation, storage activities, loading, unloading procedure, transportation and waste treatment [10].

Another factors governing safe transportation are weather conditions and sea state: temperature, wind currents and waves. Shipping accidents have usually local impact but unfavorable state of the sea can make that dangerous good spread out quickly and create a large hazard zone.

Sea voyages are made in a variety of weather conditions which are likely to exert a combination of forces upon ship and its cargo over a prolonged period. Such force may arise from pitching, rolling, surging, heaving, swaying or combination of any two.

Due to multitude of functions carried out by people with different training, human error or negligence cause accidents to occur more often [11].

For dangerous goods that have not been correctly declared or if there is no knowledge of the presence of dangerous goods in package, safe handling, stowage and segregation becomes impossible. Among many reasons why the incidents onboard occur, one of the most common is a non-declaration of new substances. The hazard is not declared due to lack of time for testing, lack of product knowledge or false assumption that cargo is not classified as dangerous.

Undeclared dangerous goods may not be stowed or handled correctly by crew or port staff if they are unaware of the hazard and it is a safety issue for emergency response personnel [12].
2.2. Behaviour of dangerous goods in the marine environment

The chemicals transported by sea are classified into nine classes and goods in the same group show similar chemical behavior. Each of the goods has one or more hazardous properties such as: explosiveness, radioactive properties, flammability, toxicity, corrosibility, reactivity, infections substance hazard and environmental hazard.

The physical state of substances is defined by the volume of vapor pressure, density, boiled and melt temperature, solubility and viscosity.

Based on chemical and physical properties of dangerous goods and environmental conditions, the behavior after spill is predicted. Generally, dangerous goods evaporate rapidly in contact with water surface, float on the surface, dissolve rapidly in the water or sink when released into the water.

Neutralization of dangerous goods in packed form, which have spilled into the sea depends on the state of packaging and transport units (whether they are undamaged enough to identify and collect the packaging). If the packaging is damaged the clean-up is carried out as for dangerous goods transported in bulk.

Hazards to the environment are varied and impacts can be long-lasting. Discharges can lead to mortality or infertility of certain species, contamination of coastlines, and water [13].

Release of dangerous goods may disrupt functioning of the ecosystem which is significant for the whole region. Chemical pollution may have impact on commercial value of fish and in the extreme cases the bioaccumulation may stop the fishing. The use of the beaches and waters may be stopped by a contamination of these areas as well.

The irreversible effect of chemical spills and accidents is ecotoxicity, a toxic effect on the environment. Some toxic substances dissolve in the water and poison the aquatic organisms. Some of them float on the water’s surface, coat the feathers of birds and the gills of fish and physically disrupt their movements and the ability to breathe.

Furthermore, the physical state of cargo has an influence on the size of affected area. Polluted area is smaller in the case of a solid good. The evaporation of solid chemicals is usually smaller, therefore the risk for area is relatively small and the largest in case of gaseous chemicals.

Hazardous impact of dangerous goods may get worse at low temperature because the decomposition of the goods becomes lower. Viscosity of the goods may be changing in the cold environment too.

The properties of dangerous goods involved in an accident need to be recognized before the selection of the response action. Change in the properties of the goods affect also rescue operations that are possible to execute [14].

3. Methods of environment protection

3.1. Laws and regulations

In recent years, there has been an increasing focus on reducing the environmental impact of dangerous goods in packed form. Dangerous goods transport must be carried out according to regulations that are in place to reduce the potential for harm to people, property, and environment that may result from a dangerous goods release. As a response to this, International Maritime Organization establishes a mechanism for a company and ships to improve the efficiency of transportation of these cargoes.

To ensure security of operations with dangerous goods, a highly regulated unified system has been created. It is based on the UN Recommendations on the transport of dangerous goods (Model Regulations), international regulations and legislative acts of certain states.

The United Nation Economic and Social Committee of Experts on the Transport of Dangerous Goods has developed UN Recommendations on the Transport of Dangerous Goods. The Recommendations are presented in the form of “Model Regulations on the Transport of Dangerous Goods”. The Model Regulations aim at presenting a basic scheme of provisions that will allow uniform development of national and international regulations for various modes of transport.
Given the extensive global sea transport of chemicals and the need to ensure their safe use, transport and disposal, it was recognized that an international approach to classification and labelling is necessary. The Globally Harmonized System of Classification and Labelling of Chemicals concerns standardizing and classification of chemicals based on hazard criteria. In order to improve the protection of human safety and environment, GHS proposes system of data sheets and labels.

The legal acts in the area of dangerous goods transport are divided into some groups:
- legal acts regulating activities in dangerous good transport;
- legal acts ensuring security;
- rules of working with dangerous goods;
- legal acts concerning technical problems;
- rules of training and certification of personnel related to dangerous goods transport;
- legal acts applying to responsibility for violation of regulations for work with dangerous goods;
- legal acts applying to protection of environment;

The most important International Conventions related to the carriage of dangerous goods in packaged form by sea are the SOLAS 74 and MARPOL73/78 conventions. The International Convention for the Safety of Life at Sea (SOLAS Convention) is the most important international convention dealing with maritime safety. SOLAS Convention in a present version was adapted in 1974 and enforced in 1980. The provisions of Chapter VII of the Convention “Carriage of dangerous goods in packed form or in solid form in bulk” contain the main regulations concerning the transport of the dangerous goods by sea.

The International Convention for the Prevention of Pollution from Ships (MARPOL Convention), which is the main international convention covering prevention of pollution of the marine environment by ships from operational and accidental causes was adapted on 2 November 1973. The MARPOL Convention covered pollution by dangerous goods in packed form recognized as harmful substances. Annex III “Prevention of Pollution by harmful Substances Carried by sea in Packed Form” includes regulations aimed at preventing and minimizing pollution from ships carrying this type of cargo.

The International Maritime Dangerous Goods Code was developed by the International Maritime Organization, and it is a unified international code of carriage of these goods by sea. IMDG Code includes a list of several thousand substances, materials and articles of commercial importance, but is not exhaustive. This Code contains a significant number of common provisions concerning classification, packaging and tanks, which are included in the UN Model Regulations. They also include hazard communication requirements which cover packages labeling and marking, placarding containers and vehicles, and documentation. The Code lays down basic principles and recommendations for operational practice such as stowage, segregation and emergency response action. Since 1 January 2004, the IMDG Code has received a binding status by Chapter VII Transport of dangerous goods of SOLAS Convention.

Harmful substances are those cargoes which are identified as marine pollutants in the IMDG Code or meet a defined set of criteria. The regulation requires development of detailed standards on packaging, labeling, stowage and segregation for preventing or minimizing pollution by harmful substances.

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW, 1978) targets the safety of human life and goods as well as the protection of the marine environment. The Convention includes a few regulations, which refer directly to the prevention of marine pollution and focus on the required knowledge and the responsibilities during watchkeeping.

Another regulation concerning the maritime transport of dangerous goods is International Convention for Safe Containers (CSC 1772) concerning standards for design, construction, testing, inspection and maintenance of containers.

Many countries face a very serious problem of harmonizing regulations of dangerous goods in sea transport due to varied local regulations. Despite the progress made in harmonization of safety
regulation, still there are many problems for exporters due to differences between international regulations and domestic regulations.

3.2. Packaging of dangerous goods

A great variety of packaging is used for transport of dangerous goods. For maritime transport, they include: conventional packaging, intermediate bulk containers, unit loads and CTU. Many properties of packaging influence its behavior when lost at sea: packing material, volume, combination outer and inner packaging. Defective or incompatible packaging may fail and release goods at any point of the voyage. Sometimes defects are difficult to spot until the package fails.

To ensure proper selection of packaging for dangerous goods, authorized laboratories test and approve each packaging for transportation of these goods. The approved packaging should be marked according to established template.

For packing purposes, dangerous goods other than those of class 1, 2, 5.2, 6.2, 7, and other than self-reactive goods of class 4.1 are assigned to three packing groups with the degree of danger they represent.

The contents of the packaging should be given on the exterior of the packaging by Proper Shipping Name and UN number, which are essential elements used to identify the dangerous good. PSN is the standard chemical (technical) name to describe the hazard properties and the composition of dangerous goods.

To respond properly to accidents involving dangerous goods, it is crucial to recognize labels, marks, and signs on the packages. The IMDG Code contains recommendations which are valid for all types of packages on how the packaged dangerous goods should be labelled. Some goods, beside the main hazard, also exhibit subsidiary risk which should be also shown by extra labels.

Currently, containerization significantly increases the volume of the cargo and provides additional protection and simplifies handling procedures. The use of freight containers and other cargo units substantially reduces physical hazards to which cargoes are exposed. Maritime Safety Committee of IMO approved Code of Practice for Packing of Cargo Transport Units. It is essential to the safe packing of CTUs and the securing of the cargo.

Incompatible chemicals should be segregated during storage and transportation, because violent reaction may occur when these chemicals are mixed.

3.3. Training of personnel

Engineering modifications may eliminate some of the worst consequences of human error during transportation of dangerous goods but still the most important thing is people’s knowledge about the risk and the method of safe handling of these goods. It is important that in transport of dangerous goods, the concerned and storage personnel receive relevant instruction about the hazard involved and the precaution to be taken.

People involved in transport of packed dangerous goods should adhere to the rules of the IMDG Code. To follow those rules the employees should undertake training. Training should be provided for all crew members who are involved in operating the dangerous goods, and handling of it as part of their operational responsibility. The Code indicates the type of specific training for different job functions involved in the dangerous goods transport chain.

After the training the personnel should be able to:

- understand the hazard of dangerous good which is shipped;
- identify cargo details depending upon the type and classification of dangerous goods and locate them in the IMDG Code;
- understand the marking and labelling of packaging;
- apply the rules of stowage and segregation;
- react in an emergency in response to any uncontrolled release of goods [15]

The shore side operations often take place inland, many miles from the ship. The personnel loading dangerous goods may be unaware of the more extreme conditions and forces to which the content of
packaging and Cargo Transport Units (CTU’s) may be exposed during its sea voyage. The shore-based personnel engaged in the preparation of dangerous goods for sea transport must receive appropriate training with regards to the rules of the IMDG Code adequate to their responsibilities.

3.4. Special areas

MARPOL Convention defines certain sea areas as “special areas” in which, the enforcement of special mandatory methods for prevention of sea pollution is required. Furthermore, IMO selects some sea areas defined as Particularly Sensitive Sea Areas. These areas need special protection because of their significance for ecological, economic and scientific attributes. Because such attributes may be vulnerable to damage during sea transportation of goods, specific measures are used to control the activities such as routing measure, strict application of MARPOL Convention and equipment requirements for a ship.

The Baltic Sea Area is one of the world’s largest brackish water areas and ecologically unique ecosystem. It is geologically young, semi-enclosed and shallow. As one the most sensitive marine ecosystems, the Baltic Sea has been classified as Particularly Sensitive Sea Area by the Marine Environment Protection Committee of the International Maritime Organization.

The Baltic Sea Area is highly sensitive due to limits in the water exchange, which is very slow. Water remains in the Baltic Sea for about 30 years. It is important factor as chemical accidents could have serious impacts on its environment. It is particularly difficult to navigate, hence there is an increased risk when transporting dangerous goods. Furthermore, the Baltic Sea is located between temperate and subarctic climate zones and large parts of the sea are ice covered [16]. Chemical decomposition chemical substances is slower and ineffective at low temperatures.

During the last decade, shipping has steadily increased around the Baltic Sea. The Baltic Sea has some of the busiest shipping routes in the world, accounting for up to 15 % of the world’s cargo transportation [17]. Around 2,000 sizeable ships are normally at sea at any time in the Baltic, including large oil tankers, ships carrying dangerous and potentially polluting cargoes, and many large passenger ferries.

The number of different chemicals transported is counted in thousands and the volume of these goods is growing. A lot of hazardous substances transported in the Baltic Sea waters are classified as marine pollutants, thus increasing the risk of major pollutant accidents [18].

Comprehensive statistics about the chemical transportation is difficult to get as compatible data from all the Baltic Sea countries is not available. Nevertheless, the cargo which is transported in the largest volumes is oil [19].

Around 80% of all incidents and accidents are due to the human factors [14]. New legislation and technical innovation has reduced the number of large-scale chemical spills.

In 2010 the transport of the oil and oil products in the ports of the Baltic Sea has reached 290 million tons while liquid chemical products only around 11 million tons [2]. Incidents involving chemical spills are statistically much likely to occur than oils spills.

The analysis of the HELCOM accident statistics indicates that during years 1989-2010, 210 ships carrying liquid bulk cargoes were involved in the accidents in the Baltic Sea area [20]. Due to 28 accidents which occurred during this period, 3100m³ of harmful substances was spilled into the sea [2]. Based on maritime accidents databases, it can be said that no significant chemical accidents happened in the Baltic sea area during the last decade. As a result, their environmental impact has been neglected.

The biggest catastrophe in the Baltic Sea happened in the 1981. The British tanker loaded with 20,000 ton of oils was leaving the port in Klaipeda when it the pier. About 16,000 tons of the oil spilled into the sea causing an environmental disaster. The spillage was classified as a medium one [21].
4. Conclusion

The constantly increasing sea transportation of dangerous goods leads to an increase in the probability of uncontrolled release of these goods into the marine environment.

It should be recognized that improving the conditions of transportation of dangerous goods will make a valuable contribution to the reduction of environmental impact and diminish the risk of accidents. Reduction of environmental risks connected with dangerous goods transportation should be accomplished through establishment of careful and efficient procedures. It is necessary to take action to improve standards which will provide an acceptable level of control of the dangerous goods hazard to people, property and environment.

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