Use of Low Smoke and Halogen Free Cables for Marine Fire Safety Design

Upotreba niskodimnih bezhalogenih kabela u dizajnu protupožarne zaštite na brodu

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Summary
Safety of shipping is a growing concern. The causes of shipping casualties are various. A fire on a ship is one of the most hazardous incidents which can happen on board and a common cause of damages and accidents in ships. However, this knowledge decreases where electrical installations, whose effects are not well-understood, are involved. Because of these effects and risks, the regulations related to cables for a vessel’s electrical installations anticipate the use of special low fire propagation and fire-resistant cables made with low smoke emission and halogen-free materials. Despite these criteria, the regulations permit the use of materials such as PVC. The main purpose of this research is to identify the risks associated of the use of PVC versus Low Smoke Zero Halogen (LSOH) cables that could be present for equipment safety and people in case of fire. As a result of the implementation of the regulatory framework, test results carried out at UPC (Universitat Politècnica de Catalunya) Material testing lab from PVC and LSOH cables used in ships have been obtained. Finally, the use of LSOH cables is implemented to assess the effect of fire risk reduction measure for the enhancement of safety of shipping in coastal waters, efficiency and protection of the environment.

KEY WORDS
- fire retardant and resistant cables
- safety
- LSOH material
- marine environment

1. INTRODUCTION / Uvod
According to (Faulkner 2002), there are two main sources causing vessel loss: about 60% are due to operational causes (i.e. fire, collision, machinery damage); while the remaining 40% are characterized by design and maintenance causes (i.e. water ingress, hull breaking in two, and capsizing). Safe navigation is required to prevent accidents leading to increased risk to life, property and environment.

A review of available accident data (Lloyds List 2013; DNV 2013; EMSA 2015; MAIB 2013 and Kuehmayer 2008) shows that shipping accidents by types are quite many and their impacts on marine environment differ from one another (Akten 2006). In 2014, 3399 vessels were involved in 3025 marine casualties and incidents in and around European Union (EU) waters. The largest number of vessels involved in very serious casualty events (2011-2014) was concerned in flooding/grounding (24%), collision (22%) and around 14% in fires and explosions (European Maritime Safety Agency 2015).

Fires or explosions are quite rare but are very dangerous. A fire on a vessel is one of the most hazardous incidents which can happen on board. If the fire is detected in good time, the crew can prevent larger damages by taking immediate measures. If the fire...
### Table 1: Fire/Explosions by merchant ships type (2007-2010* / 2011-2014**)

| Fire/Explosion by ship type | 2007 | 2008 | 2009 | 2010 | 2014 |
|-----------------------------|------|------|------|------|------|
| Cargo ships                 | 29   | 26   | 30   | 17   | n/a  |
| tankers                     | 11   | 11   | 2    | 7    | n/a  |
| Container ships             | 3    | 4    | 2    | 4    | n/a  |
| Passenger ships             | 17   | 17   | 11   | 30   | n/a  |
| Fishing ships               | 16   | 14   | 9    | 15   | n/a  |
| Other vessels types         | 15   | 17   | 13   | 10   | n/a  |
| Total                       | 91   | 89   | 67   | 83   | 152  |

Source: European Maritime Safety Agency (EMSA 2010)* / (EMSA 2015)**. n/a: not available

has already spread, professional aid is needed. The most significant finding was that the numbers of fires/explosions for some ship types (see Table 1) shows great variations between 2010 and other years. In particular, the number that occurred on ferries was substantially down in comparison to the previous three years.

Conversely, the number of fires reported on cargo ships was substantially higher than the number reported in 2009. Fires on tankers were also substantially higher relatively low number in 2009. Fires on ferries was up almost 170% from the variations between 2010 and other years. Some ship types (see Table 1) shows great differences; for instance, engine room fires represent almost two thirds of all fires, second fire source is cargo spaces and finally accommodation.

Related on fires in living and service accommodation due to outfitting materials introduce serious thermal, smokeness and toxic risk (Dobrzynska 2009). Engine room fires also represent a hazard for crew members working in that area and fire fighters. The major causes of engine room fires are given in Figure 2, they are usually caused by fuel spills, overheating components or careless use of electric welding or gas brazing gear.

Application of new techniques and enhanced technologies for the early detection of fires on ships and its prevention have a major impact on the development of new sophisticated systems for fire detection (Bistrović and Tomas 2014). Moreover, ship management should therefore include a clear policy of how to avoid such incidents. Fire safety is just one part of overall safety concern, but one that is not well understood with regard to how cables materials behave under fire conditions.

### 2. Regulation / Propisi

Accidents such as the 1934 fire on the passenger ship, the Morro Castle, which had 134 casualties caused changes in the Safety of Life At Sea (SOLAS) convention (IMO 1974). This incident caused major changes in relation to fire safety on passenger ships. However, it was not until the 1996 amendments to SOLAS which introduced the mandatory Fire Test Procedures code (IMO 2010). It was made mandatory on 1st July 1998 and provides international regulations on testing of the ship. These amendments were introduced to aid companies with knowledge on the safety of products installed in ships sailing under their flag.

Statutory regulations currently in force with respect to the construction of new ships are based on SOLAS guidelines. One of the latest requirements is that ships must be equipped with automatic fire detection and automatic sprinkler systems. This is to ensure that fires are detected early and extinguished before they have an opportunity to spread widely.
of passenger ships, and of cargo ships of 500 tons and over, require compliance with The Institution of Electrical Engineers: “Regulations for the Electrical and Electronic Equipment of Ships with Recommended Practice for their Implementation” (IEE Regulations, 1993) and (IEC Regulations 2004, 2008), except in so far as they may be inconsistent with the statutory regulations. As a matter of good practice, cargo ships less than 500 tons and other small vessels should also comply. The applicable edition of the IEE Regulations depends on the date of build of the ship. Even with these safeguards and procedures fires still occur. SOLAS Maritime Rules and some of the main Classification Societies for ships (Lloyd’s Register 2013; Bureau Veritas 2013; DNV 2013 and Germanischer Lloyd 2013) establish requirement for electrical installation aboard ship, as well type and materials of cables to be used. In particular, IEC 60092-350 (IEC 2014) specifies the general construction requirements and general test recommendations for shipboard cables and includes materials for insulation, inner covering, fillers binders and outer sheath.

The main used for Insulation are:
- Thermoplastic: Polyvinyl Chloride (PVC), Poly ethylene (PE) and LSOH thermoplastic material (SHF1)
- Thermosetting: Cross Linked Poly Ethylene (XLPE), Etylene Propylene (EPR) and Hard grade ethylene propylene (HEPR).

For Inner and Outer sheath (protective coverings):
- Thermoplastic: PVC, PE and LSOH (SHF1)
- Thermosetting: Polychloroprene rubber (PCP), Chlorosulfonated polyethylene (CSPE), Chlorinated Polyethylene (CPE) and LSOH thermoset material (SHF2).

In general terms, IEC regulation requires electrical cables used in ships must be flame retardant type (IEC 2009) and must be fire retardant (Finlayson 1990), when cables are laid in bunches. Additional feature of fire resistance (IEEE 2002) emergency installations is required in accordance with IEC. Nevertheless, these requirements are not accompanied explicitly with the exigency in the use of cables with materials Low smoke zero halogen (LSOH and also LSF, LSZH, LSHF) during their combustion in the fire presence.

3. MATERIALS AND METHODS / Materijali i metode

Even if a cable can be made with flame retardant behaviour, some of the fire effects are smoke opacity, toxic hazard and corrosion damage. The main purpose of the research is to show the risks of the use of conventional materials (PVC, PCP, CSPE and CPE) compared with LSOH material, in confined spaces with large amounts of cables, in close proximity to humans or sensitive equipment. Furthermore, this paper will discuss the main benefits of LSOH cables versus conventional (especially with PVC) considering worker safety and protecting the environment.

A technology based on hydrate filled polyoylein (LSOH), an alternative material to PVC, has been utilized to develop improved technology and new materials which will not emit dense smoke that rapidly obscures visibility, and already shows a reduced flame propagation, lower toxic gas concentration and corrosion.

Ships in operation, especially cruise ships, are subject to a vast array of regulations and standards covering every aspect of ship construction and operation. A number of incidents over the years have led to improvements in safety requirements, including those relating to fire safety measures, such as escape routes and fire protections systems.

A principal advantage of LSOH cable products is reduced hazard in terms of smoke density and combustion fume toxicity. In case of reduced spaces of ships, the use of LSOH products will reduce the exposure and inhalation of smoke, toxic gases. Moreover, more time for evacuations is the vital importance, having greater visibility and therefore helps reduce disorientation and panic, allowing the visualization of signals and find emergency escape routes to ensure easy evacuation routes for crew and passengers. The smoke diffusion and the evacuee movements on three deck spaces of a passenger ship and for three different escape scenarios have been studied determining evacuation times from 7’ to 10’ (Fukuchi and Imamura 2005), when the percentage of light transmittance may be less than 20% and Carbon Monoxide (CO) emission more than 300 ppm. In evaluating the risk of fire of ceiling materials, after 10’, a substantial increase in the temperature and heat release occurs (Chung et al 2014). Since it is very important to prevent fires, if a fire still starts it is necessary to take the appropriate action to tackle it an early stage. Hlaváčová and Vondra (2016) deal with the problem of extinguishing fire on ships.

Considering protection of electrical switchgear equipment and electronic systems (for instance, control, informatics and communication), very common in any plant, (see Figure 3), damage from corrosive gases are minimized (corrosion of components, printed circuits, oxidation), due to hydrogen chloride gas, which releases the PVC when burn and combined with the moisture of water, used in extinguishing the fire, just formed vapour of hydrochloric acid (HCl) to be deposited on units and corrode over time, reaching cause much more damage than the fire itself.

Comparatively, for the same heat flux (kW/m²), PVC reaches its ignition point (burns) in less time than low emission polyethylene and, in fire conditions, for the same period, PVC has a higher loss of mass than the polyethylene, causing a higher

![Figure 3 Switchboard and control systems in ships](source: own)

*Slika 3. Kontrolna ploča i kontrolni sustavi na brodovima*
concentration of suspended particles, with a corresponding high level of smoke, opacity and toxicity.

Other hazards associated with cables is the cable layout, both horizontal and vertical (see Figure 4), especially vertical positioned cable, a chimney effect. If a cable has a content of PVC higher than 1 kg/m PVC material, once it has ignited at 450°C, measurements of the fire spread, show speeds over 20m/min speed (Alarie 2002). At temperatures of 250°C, emits black smoke.

The materials such as PVC or rubber, used as insulation or cable sheaths, can improve their properties against fire, by means of flame retardants or special fire retardant compounds. In these cases, the PVC reduces its acid emissions and improves its fire behaviour, improved PVC or PVC reduced propagation and low emission of HCl (RPLHCl), but reduces its mechanical properties. Fire retardant sheaths of both materials (PVC and rubber), contains perfluorooctane sulfonate acid (PFOS), considered hazardous materials for the EMSA (EMSA 2017).

On the other hand, main disadvantage of LSOH materials is high loading levels. LSOH jacket compounds usually have very high filler content to provide the required flame and smoke performance; as a result, most have poorer mechanical, chemical resistance, water absorption and electrical properties than non-LSOH compounds.

4. TEST AND RESULTS / Testovi i rezultati

Fire tests are consequently designed to provide information related to the “reaction-to-fire” properties of materials. Noticing the necessity of establishing suitable fire test methods, many national and local governments have developed different apparatuses in which specimens with various sizes and orientations are exposed to different fire scenarios.

The different tests, and standards, which describe the fire behaviour of insulations, inner covering, and outer sheath, such as LSOH material are:

- Halogen content IEC 60754-1
- Equivalent Acid content, IEC 60754-2: Smoke minimum pH and Maxim Smoke Conductivity
- Smoke generation, standard IEC 61034-2: Transmittance
- Determination of the Toxicity Index, standard NES 713

These tests are applied to samples of the materials. Halogen content is checked along with smoke generation and its properties (see Table 2). The fire behaviour of the whole cable is checked through the vertical-tray fire-propagation test.

In Table 2, the most significant values of the cable materials permitted by the regulations governing cables and electrical installations are shown.

As a result of the implementation of

| Test                                      | Standard        | Requirement | Material PVC | Material PVC (RPLHCl) | Material Polyrethane | Material LSOH |
|-------------------------------------------|-----------------|-------------|--------------|-----------------------|----------------------|---------------|
| Emission of Halogen Bromine and chlorine content (expressed as HCl), maximum | IEC 60754 -1    | 0.5%        | 25 - 30%     | 12 - 15%              | > 5%                 | <0.5%         |
| Corrosivity. Degree of acidity of gases evolved during combustion: | IEC 60754 -2    |             |              |                       |                      |               |
| - Minimum pH of smoke                     |                 | > 4.3       | = 1          | = 1                   | = 5.6                | = 7           |
| - Maximum conductivity of smoke (μS/mm)   |                 | < 10        | = 15         | = 15                  | = 8                  | = 1.6         |
| Smoke generation                          | IEC 61034 -2    | > 60        | = 20         | = 40                  | = 60                 | > 80          |
| - Minimum transmittance %                 |                 |             |              |                       |                      |               |
| Toxidity index is a parameter representing the total toxicity of various gases | NES 713, MIL-DTL-24643C (4.8.27) | 15          | 5.5          | 6.2                   | 0                   | 1.4           |

Source: own based on Standard Requirements (IEC 60754, IEC 61034 and Naval Engineering Standard)
the regulatory framework and the tests mentioned previously regarding cables with reduced emissions of dense, toxic and corrosive smoke, tests has been carried out by authors at UPC Material testing lab in order to obtain the fire behaviour of different materials used in cables (PVC and LSOH).

Figures 5 and 6 show the behaviour of these different cables concerning the emission of toxic and corrosive gases like HCl and CO, which can cause intoxication and poisoning as well as damage to equipment.

Figure 6 shows the level of accumulated CO gas (ppm) when a complete cable, with different combinations of insulation and outer sheath, burns for 8 minutes.

Figures 7 and 8 show the percentage of light transmittance permitted by these cables over time with respect to the emission of dense smoke.
5. CONCLUSION / Zaključak

The above research results show the low emission of toxic gases, such as CO and HCl, generated during the combustion of LSOH material in comparison with PVC, reducing the risk of intoxication or poisoning of persons due to fire in cable materials. It is also important to note the lack of Hydrochloric Acid and corresponding lack of corrosivity. This minimizes damage to electric, electronic and computer equipment.

It is seen clearly that for PVC the greatest yield of toxic gases occurs during the initial stages of fire growth. This is also when the smoke release is the greatest. Any PVC fire will always be hazardous due to the early release of hazardous combustion.

The property of low fire propagation is not in itself a guarantee of low smoke and halogen-free emission it depends on the materials which the product is made (LSOH or not). In the case of a LSOH product, the fire growth is more gradual and the toxicity of the fire gas increases as the available oxygen reduces.

Required by law or regulation to use of LSOH cables in electrical installations where the risk of fire to people and installations is significant, such as in the public spaces on a cruise ship, will greatly improve human and equipment safety in case of fire emergency.

In the market there is a wide variety of these types of cable, approved and certified by the classification societies. For this reason their general or specific use is technically possible.

The IEC 60992 cable standards for vessels should remove the materials with halogens and indicate the specific advantages of using LSOH material. Moreover, the classification societies should define those installations in which the use of this material, in both insulation and covers (inner and outer sheath), should be a priority, thereby increasing the safety of both passengers and installations on board.

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