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Role of Active Fire Protection Systems in Ensuring an Acceptable Level of Safety of Rolling Stock

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Summary
The article presents issues related to active fire safety systems used in rolling stock based on water extinguishing. The approach to active methods of fire protection and extinguishing is described in detail. The article presents the current standards, regulations and requirements regulating the use of active fire protection systems for railway vehicles in the European Union. An analysis of the elements influencing the efficiency, practicality and cost-effectiveness of the extinguishing systems with the expected effectiveness of operation was carried out. The directions of development undertaken in order to develop tools for assessing the size of the threat and its prevention are presented.

Keywords: fire safety, rolling stock, requirements, active fire protection systems

1. Introduction

Fire safety of rolling stock in the European Union is governed by numerous fire safety regulations. The majority of current fire protection requirements concern issues related to passive fire protection, which involves structural solutions, materials and their selection as well as hand fire fighting equipment and its quantity depending on the type of rail vehicle. Recently, the heightened awareness and prevalence of active fire protection in rolling stock made it necessary to develop regulations at the European level to standardise active fire protection systems, which are to be used as the basis for conformity assessment when placing railway vehicles in service. The fixed firefighting system technology is currently advanced, especially in countries with many railway tunnels and in countries where fire safety issues are a priority.

Due to the lack of standards and guidelines that would define their design and operational criteria, active fire protection solutions in use vary considerably in technological and performance terms. The lack of guidelines to define the procedure for assessing active systems has a negative impact on the fire protection system of railway vehicles. Fire protection requirements in the railway sector are defined in the following documents:

- Technical specifications for interoperability (TSIs) for rolling stock and
- Infrastructure in the trans-European network (TEN) [1–2],
- series of EN 45545 standards "Railway applications. Fire protection on railway vehicles" [3–9],
- EN 50553 "Railway applications. Requirements for running capability in case of fire on board of rolling stock" [10].

However, requirements for active fire protection on railway vehicles are only defined superficially in the two documents. Most of the requirements covered in the series of EN 45545 standards are based on structural solutions and selecting materials considering smoke and flammability properties.

2. Active fire protection systems

Fixed firefighting systems are an active way of fighting fires inside railway vehicles. They are installed to improve safety of life, health and property. Compared to traditional passive fire protection measures, fire detection and extinguishing systems ensure fire fighting effectiveness. Depending on the technology in use, fire extinguishing systems vary in complexity and innovativeness. Considering the type of extinguishing agent, fire extinguishing systems used in rolling stock can be divided into:

- gas,
- water mist (low- and high-pressure water mist),
- aerosol.

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Before the considered effective, fire extinguishing systems must be tested as part of full-size fire tests. Standardisation in terms of fire protection systems at the EU level is very time-consuming, expensive and it is probable that no document defining in detail engineering guidelines for such systems in railway vehicles will be prepared in the foreseeable future. Until an official document serving to standardise the approach to assessing fire extinguishing systems is prepared, experimental full-scale fire tests must be conducted.

The lack of an official document applicable in the European Union and defining testing methods for protection systems in rolling stock led to the development of documents regulating the assessment of fire extinguishing systems in two regions. In German-speaking countries (Germany, Switzerland and Austria), ARGE guidelines were prepared [11–13], while in Italy, the UNI 11565 standard was prepared [14], which describes individual test equipment components in much detail (Fig. 1, 2).

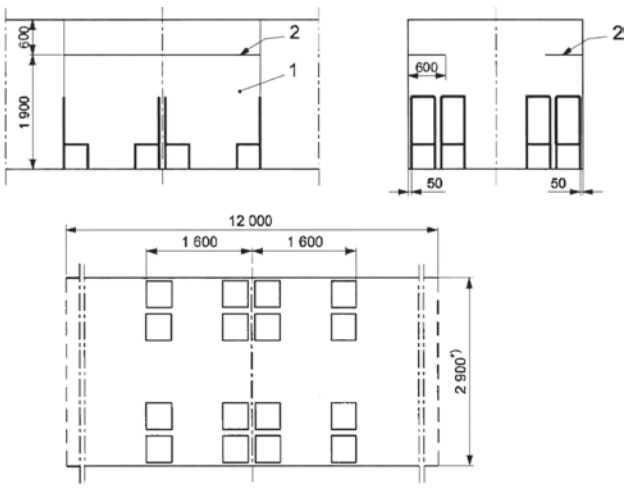

Fig. 1. Plan of the room acc. to UNI 11565 [14] used to conduct mock-up tests

The scope of the UNI 11565 [14] standard covers functional and performance requirements to be met along with criteria at the stage of designing, installing, validating and maintaining fire detection and extinguishing systems inside railway vehicles. It also defines testing guidelines considering possible ignition places due to vandalism or failure, located in the most unfavourable position for fast fire detection and possible places where passengers leave their luggage or other objects on board. Smoke sources in use include polyurethane foam blocks or a smoke generator with a coil, which is calibrated and used as required by EN 50553 [10]. Tests are made three times for every smoke source location variant.

ARGE guidelines part 2 "Fire fighting in railway vehicles" [12] focus on the assessment of fire detection and extinguishing systems in railway vehicles by defining minimum requirements. In line with the ARGE guidelines, a fire extinguishing system must be linked with a fire detection system, which automatically turns on the fire extinguishing system once a threat is detected. It is appropriate to conduct such tests, especially for water mist systems, due to the necessity to define all functions of these systems (Table. 1).

Main benefits of using water mist fire extinguishing systems include:

- no need to add any substances that improve extinguishing efficiency,
- minimum impact on the human body so that fire extinguishing can start,
- when people are yet to be evacuated from protected areas,
- high efficiency,
- no negative impact on the environment,
- no need to ensure that the protected room is tight – as opposed to
- gas fire extinguishing systems where tightness is required,
- effective cooling.

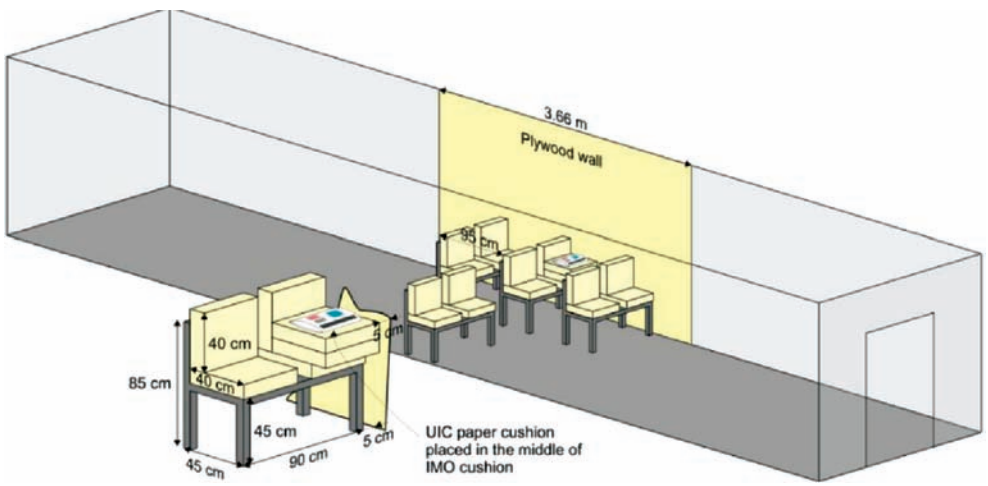

Fig. 2. View of the room acc. to ARGE – Part 2 [12] used to conduct mock-up tests

Table 1

Main advantages of water mist fire extinguishing systems

Requirement	Function	Effect
Improved evacuation conditions	• immediate cooling of the fire and the area surrounding it, • limited smoke generation – increased visibility, • binding smoke particles with droplets of water,	• it is safer for passengers to evacuate and passengers have a better chance to survive when trapped,
Better access for emergency services	• limited heat release rate (HRR), • immediate cooling of the fire and the area surrounding it, • limited smoke generation - increased visibility (SPR, TSR), • blocked thermal radiation,	• emergency services have easier access to a fire source in order to extinguish it, • much higher safety for the State Fire Service,
Prevention of fire spread	• limited heat release rate, • immediate cooling of the fire and the area surrounding it, • blocked thermal radiation,	• fire limited to the place where it broke out,
Reduced vehicle damage	• immediate cooling of the fire and the area surrounding it, • blocked thermal radiation,	• safer vehicle structure.

[Authors' own elaboration].

Water mist fire extinguishing systems in railway vehicles are a very effective form of fire protection and are completely safe for people, protected areas and the environment. With excellent extinguishing properties of water, fire can be extinguished effectively with little water, reducing the size of damage and downtime to a minimum.

3. Basic principles of the technology using high-pressure water mist

For a fire to develop freely and be maintained, the following factors must be involved (in the right proportion):

- presence of a combustible material,
- energy required to ignite, ignition source,
- oxidising agent (O_2).

To ensure effective fire extinguishing, at least one of the factors must be removed from the combustion process. Generally, the combustion process is interrupted by cooling, meaning that the energy or oxygen is reduced. Water mist extinguishes fires with droplets having a small diameter. Depending on the application, the droplet size varies from approx. 20 µm to 200 µm. The droplet size is the main parameter of water mist fire extinguishing systems, which affects heat absorption (cooling) and, as a result, water vaporisation (Fig. 3). High-pressure fire extinguishing systems are very effective and require little water to extinguish/weaken a fire.

With high-pressure water dispersion, the reaction surface used to cool down the combustion process is considerably higher. As a result, high-pressure fire extinguishing systems can reduce the energy coming from a fire quickly and effectively. With its high cooling effect, high-pressure fire extinguishing systems are effective in putting out fires, while people and equipment in the immediate vicinity are protected against thermal radiation, which, in turn, reduces the risk of spreading fires of combustible materials. The high cooling effect is mainly achieved through the disper-

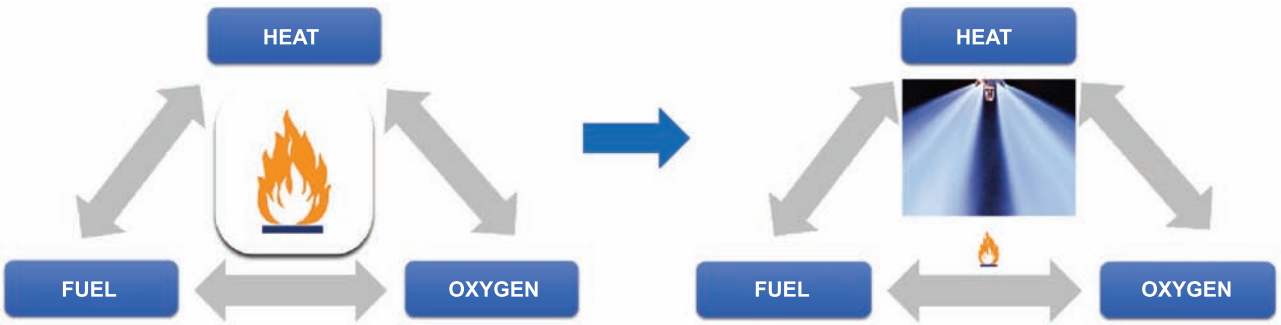

Fig. 3. Fire triangle [authors' own elaboration]

sion of water into tiny droplets, meaning that the area in which the heat energy of fire water droplets is received is many times higher. This also makes it possible for water mist to create effective barriers (water curtains) for structural and covering components etc. inside a railway vehicle. As a result of water vaporisation, water increases its volume approx. 1,620 times [18], which means that air containing oxygen, which is required to maintain a fire, is pushed out. Local inertization[2], which is limited to the place of fire. High-pressure water mist systems use very little water, so losses caused by flooding and damaging equipment are reduced, which, in turn, translates into faster train set recommissioning. The use of water in water mist systems for extinguishing purposes, i.e. the agent that is the most natural and available, is also completely safe for people and environmentally friendly (Table. 2).

Table 2

Selected physical properties of water

Water	
Specific heat of water, C_p [J/kg*K], liquid, (standard conditions)	4,181
Specific heat of water vapour C_{pv}	1,870
Enthalpy of vaporisation for water [J/kg]	2,257

[Authors' own elaboration].

In addition to the main firefighting properties of water mist systems, it should be mentioned that soot particles and water-soluble flue gases are partially flushed and bound by water droplets. This causes a considerable smoke reduction and reduces smoke toxicity, which is crucial when people have to be evacuated. Main components of a high-pressure water mist system include:

- water tank,
- low-pressure suction pipe,
- filter set,
- pump set,
- high-pressure delivery pipe,
- zone valve manifold and zone valves,
- high-pressure distribution pipes – water pipes,
- misting nozzles.

The concept of extinguishing fires in railway vehicles using active fire protection systems is usually based on two main objectives:

- complete fire extinguishing through inertisation and cooling, or
- controlling, stifling and minimising the spread of fire by reducing temperature in the place of fire in order to allow emergency services and teams to start extinguishing the fire.

4. Low-pressure water mist systems

Low-pressure water mist systems make it possible to obtain water mist with tiny water droplets (25–75 μm in diameter) using low (4 bar) or medium pressure (up to 16 bar). When dispersed, water mist at the right pressure has excellent fire extinguishing properties if the droplets are small enough and the mist is delivered at the appropriate pressure. However, if the droplets are excessively large, the mist loses its properties and water falls down. If the kinetic energy of the mist is too low, droplets will be caught by convective fire streams and removed from the fire. Low-pressure systems deliver water mist at optimum droplet size (approx. 25 μm) at a very high speed. Figure 4 shows an example of an SUGM system diagram. Main benefits of using low-pressure water mist include:

- maximum water mist effectiveness thanks to a large vaporisation area of tiny droplets,
- fast water mist thanks to optimum kinetic energy,
- no cracks in the structure, housings, steel and ceramic components caused by the system – the mist does not cause thermal shock,
- no damage caused by flooding,
- system reliability and safety thanks to low pressures.

5. Conclusions

The rapid development of railway transport, and the related new fire protection technologies, contributes to continuous improvements to safety. Active fire protection systems, in particular fire detection and extinguishing systems, belong to innovative systems introduced in railway vehicles for years and which directly contribute to human safety. As a result of financial calculations (value for money), active fire extinguishing systems in railway vehicles are increasingly required by ordering parties as an additional protection measure. Costs of fire protection systems are merely a fraction compared to the value of the entire vehicle but they bring about considerable improvements to safety.

Fire containment and control systems (FCCS) are an alternative to protecting entire passenger areas. The role of these systems is to use sensors to detect

[2] Inertization – this is a partial or complete replacement of air or a flammable atmosphere by an inert gas. It is a very effective method of preventing explosions / fires and is considered e.g. when the risk of explosion or fire cannot be eliminated by other means.

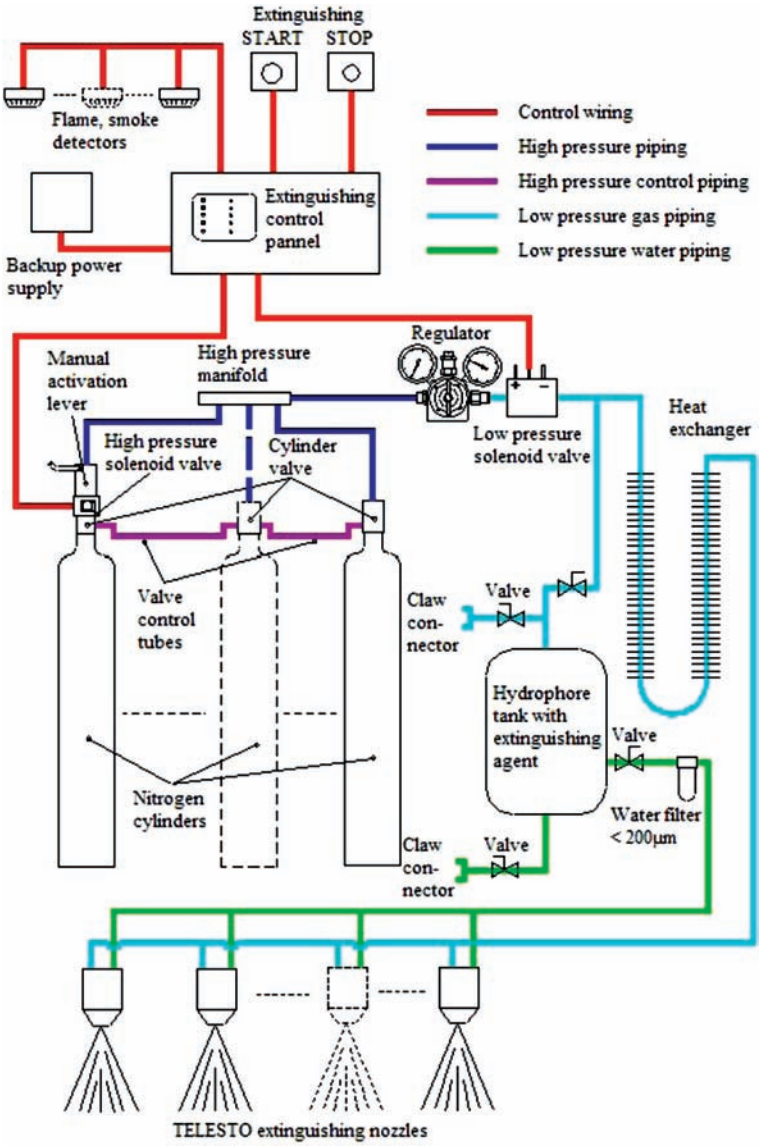

Fig. 4. Example of a diagram of an SUGM system powered from gas cylinders and a water tank [17]

a fire and limit its spread for a defined time using a system of water mist curtains whose effectiveness is comparable to fire doors. However, at present, the development of this standard resulted in the preparation of a draft technical report – CEN/TR 17532:2020 [15].

It should be remembered that the technical progress does not only mean improving existing solutions, but also adapting them to existing risks in the railway environment. To do so, works on improving testing methods should be continued so that they correspond to the current demand in rolling stock.

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