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T-Fire System: A Novel Integrated Fire Monitoring and Extinguishing System for Trucks

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Abstract

Nowadays, fires on heavy vehicles and trucks still represent a severe threat to environment and people safety, with serious consequences and injuries. In this context, fire losses can be minimized by preventing the rapid onset of fire and allowing drivers and occupants to escape safely by implementing an effective fire monitoring and extinguishing system. Commercially available fire extinguishing systems have shown multiple lacks concerning the structural implementation of the system only on specific types of heavy vehicles, the monitoring of system parameters, and the environmental toxicity of the extinguishing agents employed. Therefore, the present article proposes the early design and development of a novel integrated fire monitoring and extinguishing system for trucks and heavy vehicles called 'T-Fire System'. The proposed solution can operate in any environment (confined and not) through a close interconnection between the onboard diagnostic sensors and the plug and play fire extinguishing system which employs environmentally sustainable fluorine-free extinguishing agent. The development of the T-Fire System has started from a patented prototype, and preliminary evaluations of both the monitoring and the fire extinguishing system have shown promptness and reliability. Further research will be focused on improving and customising the solution for the pre-industrialization phase of the system.

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Keywords: Heavy Vehicle Fire; Truck Fires; Fire Extinguishing System; Continous Fire Monitoring; Onboard Diagnostic System; Compressed Air Foam (CAF)

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1. Introduction

Heavy vehicles like trucks, trailers and buses are important company assets and a fire incident could lead to a great economic and life losses. The likelihood that a particular heavy vehicle will catch fire during its lifetime is very low. However, the population of heavy vehicles is large enough, and the operating conditions of the vehicles severe enough, to result in a noticeable number of fires.

In the United States of America in 2021, vehicle fires were accounted for 15% of fires, 18% of fire deaths and 10% of fire injuries [1], that is 208,500 vehicle fires caused 680 deaths and 1,500 injuries, with $2.1 billion in direct property damage (14%). Among all the vehicle fires, 20,620 were associated to large truck fires, causing an average of 53 deaths (14%), 156 injuries (11%), and $415 million in direct property damage (24%) [2,3]. 42% of the large truck fires (5,300) were caused by a failure of the equipment or by a heat source with $108 million in direct property damage (39%) [3]. As regards the fire-starting area, 55% of the large truck fires (6,900) were generated in the engine area, running gear, or wheel area, while among the major causal factors, 59% of the large truck fires (7,400) were caused by mechanical failure or malfunction, and 13% (1,700) by electrical failure or malfunction [3]. Regarding fires involving large trucks, the most frequently items firstly ignited were the tyres (30%), flammable or combustible liquid, gas filter or piping (16%), or electrical wire of cable insulation (15%) [3]. In Italy in 2021, 250,000 rescue operations carried out by the firefighters were associated to the category ‘fires and explosions’, with an increase of 9.3% from 2020 to 2021 [4]. Among these interventions, 7.5% were associated to vehicles (18,750), with 1% (2,500) associated to trucks.

Due to the criticalities associated to vehicle fires in terms of deaths, injuries, economic losses and the real hazard of secondary fires or explosions, the causes, characteristics, and consequences of a vehicle fire have been largely analysed. Some researchers focused their work on places where vehicle fires have occurred, like highway tunnels, where the characteristics of these locations (ventilation, narrow passages and dimensions) have highly contributed to the development of combustion episodes [5], and brought to higher chances of catastrophic consequences [6]. Other researchers studied the development of vehicle fires in underground parking lots, where high density of parked cars and scarce ventilation can enhance the spread of fires and increase the difficulty to rescue people [7]. In general, most of scientific contributions focus on vehicle fires that have broken out in confined environments such as highway tunnels [5,8], underground roads and railway tunnels [7,9,10], underground car parks [11], Ro-Ro spaces [12]. These cases have involved mainly civilian or military vehicles [13], or coaches and buses [14] despite almost ∼20000 fires have occurred on trucks and heavy vehicles every year, and the death rate related to these fires (2.7 deaths per 1,000 fires) is 36% higher than the death rate relating to fires on all types of vehicles (2 deaths per 1,000 fires) [3].

Therefore, the prevention and extinguishing of vehicle fires is still an issue of great importance and concern nowadays, as regards safety and economic consequences. For these reasons, this paper presents the early design and development of an innovative system allowing the monitoring of potential ignition points of trucks and heavy vehicle and the extinction of fires to reduce as much as possible damages to people, as well as economic losses. The present paper is aimed at describing a novel system to continuously monitor specific physical parameters of trucks and heavy vehicles to avoid an ignition fire and a plug and play module to extinguish possible fires on trucks and heavy vehicles.

The remaining of the paper is organized as follows: in Section 2, the state of the art on available solutions for ignition fire suppression extinguishing systems adopted for heavy vehicles are described; in Section 3, types and standard on firefighting foams are discussed; in Section 4, the T-Fire system detailed; conclusion and future development of this work are in Section 5.

2. State of the art on fire extinguishing systems for heavy vehicles

In the last years, multiple companies developed fire extinguishing systems for heavy vehicles; some of these systems directly act on the engine, while others act on the engine through sensitive detectors placed on specific fire extinguishing points along the heavy vehicle. In the following paragraph a brief description of the main fire extinguishing systems which have been recently developed worldwide are described.

2.1. Commercially available fire extinguishing systems

The U.S. company AFEX [15] developed an active extinguishing system for engine compartment and hydraulic systems consisting of a stainless-steel distribution system equipped with conical discharge nozzle. Nozzles are intended for the distribution of a dry chemical agent and allows the maximisation of the area covered by the device (total flooding). Its automatic detection system adopts a switch automatically activated when a thermal sensor reaches a pre-set temperature, while its monitoring panel promptly warn the operator on the condition of the system through acoustic/visual alarms.

The GS-Bus Protection System by Green Safety [16] is another fire detection/extinguishing system that can be used in the engine and/or preheater compartment of a bus. It is a fully automatic system that activates the extinguishing agent without the need for human intervention. The GS-Bus Protection System consists of an electronic unit which manages the thermal sensors, analyses the signals sent by the sensors, and automatically controls the extinguishing system.

Domino Technology's Safety Automotive System [17] can be used for the suppression of fire in confined compartments on all types of vehicles, such as buses, trucks, construction equipment and boats, and allows the driver to promptly intervene avoiding damage to the vehicle and preserving passengers. In addition, it includes a health monitoring system and an interface which allows the driver to promptly detect any anomalies in real time and act quickly.

Another system for the fire extinguishing is the Fogmaker [18]. It is a fire-fighting system for engine compartments. It does not require the presence of an operator or even electricity. The automatic system allows the suppression of a fire by spraying water at high pressure in the engine compartment of the vehicle. The system consists of a hydro-pneumatic detection circuit, made with thermosensitive material pipes. The circuit is directly connected to the fire extinguisher, which is in turn connected to the extinguishing distribution system composed of stainless-steel tubes and spray nozzles.

Firecom Automotive's AK0746 [19] is another fire extinguishing system intended for buses. Once the fire has been detected in the engine compartment and/or in the preheater compartment, the system sends a signal to the command/control unit that automatically activates the supply of the extinguishing agent. Many functions are self-controlled by electronics, including the functionality and integrity of dispensers, whose anomalies are reported to the control panel. The system therefore does not require any maintenance.

Another commercially available system on the market is the Falcon Fire Extinguishing System [20] : it is a smart, economical and effective solution for protecting equipment against fire. The system can be adopted in different applications (e.g., for electrical equipment, cabinet rack, machine tools, trains, buses, and boilers). It guarantees protection and preservation of the equipment, limiting the damage to the source of ignition of the flame, avoiding its spread.

The Firetrace Automatic Fire Suppression Systems [21] comprises heat- and flame-sensitive heat detector pipes that act simultaneously as detection and suppressant devices on heavy vehicles. During a fire, the part of the pipe that heats up the most, is subject to a break, and consequently acts like a nozzle. Due to the pressure of the system, the extinguishing agents of the cylinder are quickly expelled through the nozzle to effectively suppress the fire.

The P-Mark SPCR183 and P-Mark SPCR199 certified vehicle fire extinguishing systems of Reacton [22], are designed and tested to meet the hardest driving conditions. It is available for a wide range of heavy vehicles and the fire protection solutions are designed to deal with all classes of fires. These fire extinguishing systems are intended for confined space use and can be fitted to any vehicle including heavy equipment, buses and coaches.

FirePro's VELEX [23] has been developed for both fire detection and fire extinction and can be either self- or manual-actuated for the protection of various types of vehicles. It can detect fire in the engine compartment and extinguishes the fire using a unique and environmentally friendly dual extinguishing (hybrid) technology. The system operates through a piston, consisting of a cylindrical tank, containing a premixed liquid extinguishing agent, and a condensed aerosol generator that activates, if necessary, the dispensing of the liquid agent.

The main features of the fire extinguishing systems described in this paragraph are briefly summarised in Table 1. It can be noticed that most of the systems listed therein operate mainly on buses, with major structural modifications of the vehicle system, with more than half employing environmentally toxic extinguishing agents.

Therefore, this analysis further supports the need of designing and developing a novel fire extinguishing system for trucks and heavy vehicles which can fill the gaps of its implementation on most heavy vehicles and extinguishing agent's environmental toxicity. In the following section the requirements needed for a novel firefighting system for trucks and heavy vehicles are described.

Table 1. Main features of commercially available fire extinguishing systems

Product	Type of vehicle	Structural modifications to the vehicle (Minor/Major) *	Parameters monitoring system included	Extinguishing Agent (Typology)	Type Of Extinguishing class (UNI EN 2:2005)	Agent's Environmental Toxicity
AFEX [15]	Tractor, Truck	Major	Yes	Dry and liquid (CAF)	A, B, C	Yes
GS-BUS PROTECTION SYSTEM [16]	Bus	Major	Yes	Aerosol and Powder (/)	/	No
SAFETY AUTOMOTIVE SYSTEM [17]	Bus	Minor	Yes	Aerosol (CAF)	A, B, C, E	No
FOGMAKER [18]	Bus, Tractor, Truck	Major	N.A.	Water mist (Hydro-pneumatic)	/	No
FIRECOM AUTOMOTIVE [19]	Bus	Minor	N.A.	Aerosol (Condensed aerosol)	A, B, C	No
FALCON [20]	Train, Harvester	Major	N.A.	Dust, Gas, Water (ILP)	A, B, C, D	Yes
FIRETRACE [21]	Bus, Train	Minor	N.A.	CO2 (ILP/DLP)	A, B, C	No
REACTON [22]	Bus	Major	N.A.	Dry and liquid (CAF)	A, B, C	Yes
VELEX [23]	Bus, Truck	Major	Yes	Aerosol (FPC®)	A, B, C, F	No

Abbreviations: CAF (Compressed Air Foam), ILP (Indirect system Low Pressure), DLP (Direct system Low Pressure), FPC® (Fire Pro Compound).
All the systems listed above operate in an automatic mode; no technical data are available regarding their extinguishing ability in terms of time, except FIRETRACE (4 seconds).
* Type of structural modifications on the heavy vehicle to install the Fire Extinguishing System; Minor: minimal drilling, gluing, injectors fixing on restricted areas of the vehicle - Major: substantial splicing, welding, important cutting of key vehicle components.

2.2 Requirements for a novel firefighting system for trucks and heavy vehicles

From the description of the systems above and from the analysis of the scientific literature, multiple lacks have been identified in currently available extinguishing systems. Most of the authors focus on vehicle fires that break out in confined environments (e.g., highway and railway tunnels, underground parks and roads, Ro-Ro spaces) since the current existing systems are not specifically suitable to work in unconfined spaces.

Moreover, most of the systems available nowadays are specifically designed for passenger transport vehicles (buses, coaches), and have significant different design from trucks: in case of trucks, if a fire outbreaks in the engine compartment or at one of the trailer axes, it can lead to the involvement of the entire load (payload) at very different times. Particularly, if combustible material is transported, it is necessary to counteract the fire principle before it involves the payload. Usually, the tyres of the truck trailer are very close to the fuel tanks and the payload. This is of extreme interest since the most frequently items firstly ignited in trucks were the tyres (30%), compared to flammable or combustible liquid, gas filter or piping (16%) [3]. However, although most of the current systems use sensors to monitor temperature at most frequently ignition points, these data are not used for preventive maintenance purposes.

The 'T-Fire' system has been developed to meet the technical requirements that fill the identified gaps. Main features of the system are listed in Table 2.

Table 2. Main features of the T-Fire system

Product	Type of vehicle	Structural modifications to the vehicle	Parameters monitoring system included	Extinguishing Agent (Typology)	Type Of Extinguishing class (UNI EN 2:2005)	Agent's Environmental Toxicity
T-FIRE SYSTEM	Truck, heavy vehicle	None (Plug and play)	Yes	Water-synthetic hydrocarbon mixture (CAF)	A, B	No

Abbreviations: CAF (Compressed Air Foam).

The T-Fire system can be easily implemented on most of trucks and heavy vehicles with no substantial structural modifications of the vehicle *via* a plug and play system. Moreover, compared to the commercially available solutions, the T-Fire system includes a parameter monitoring process for ignition fire diagnostics. The system can operate also in unconfined environments and employs an environmentally sustainable extinguishing agent whose typology (Compressed Air Foam [CAF]) is the most reliable one for unconfined spaces [13]. Since both the extinguishing agent and typology are the most important specifications for the correct fire extinction on a vehicle, in the following section, an overview of available commercial firefighting foams is described.

3. Firefighting foams: types and standard

Foams are gas-filled bubbles often adopted in firefighting systems due to their suppression capacity and their low water content (especially in case of high expansion foam). For any type of fire extinguishing system, fire extinguishing solutions should be appropriately chosen to suppress the fire promptly with minor risks for the humans and environment [24].

Basing on their expansion factor, fire extinguishing foams can be divided into three types: Low-expansion foams (expansion ratio lower than 20, low viscosity, cover quickly large areas (e.g., Aqueous Film-Forming Foams)), Medium-expansion foams (expansion ratio in the range 20-100), High-expansion foams (expansion ratio greater than 200-1000, suitable for enclosed spaces).

Moreover, basing on how the foams react to carbon, two types of fire extinguishing foams are commonly available: class A and class B. As a carbon-attracting solution, class A foam soaks into solid and combustible materials by breaking down the surface tension of the water. It helps the water to penetrate the burning material to quickly suppress the fire and prevent rekindles. Class B foam, on the other hand, repels carbon; when mixed with water, it forms a film that hovers over a burning liquid, sealing the flammable vapours. In case of a spill, a class B foam blanket prevents vapor production and ignition, or, in case of a fire, suppresses the blaze and prevents it from spreading or reigniting. Class B foams have two main subtypes: synthetic foams and protein foams. Synthetic foams are based on synthetic surfactants: they provide better flow and diffusion on the surface of hydrocarbon-based liquids for faster abatement of flames; on the other hand, synthetic foams are toxic groundwater contaminants, such as fluoro-surfactants, and have limited post-fire safety. Protein foams contain natural proteins as foaming agents: unlike synthetic foams, protein foams are biodegradable; they flow and spread more slowly but provide a foam blanket that is more heat-resistant and more durable, and contains fluoric components, such as fluoro-protein.

Techniques for applying class A and class B foam (UNI EN 2:2005) vary greatly. Generally, class A foam application techniques are typically straightforward – attacking with direct or indirect methods. On the other hand, class B methods require strategic stream placement to "blanket" the flaming liquid and prevent dangerous vapours from escaping. Depending on the circumstances, the flow may be directed by a wall or other nearby structure located in front of the fire to envelop or 'cover' the fuel. Indeed, the firefighting foam should be appropriately chosen to meet site-specific needs, in terms of risks and existing foam equipment.

The current legislation provides that foaming liquids can be synthetic, certified according to the UNI EN 1568:2018 standards for class B fires (flammable liquids such as gasoline, diesel, alcohols, solvents, paints, mineral oils, greases, ethers, etc.) and comply with the NFPA 18:2017 standard of wetting type for class A fires (solid materials whose combustion generates embers such as wood, coal, paper, fabrics, shavings, leather, rubber and derivatives, etc.).

According to the UNI EN 1568:2018 standard, it will no longer be possible to use protein and fluoro-protein foaming liquids, and stocks must be disposed of according to current law. The use of synthetic foaming agents instead of fluoro-protein ones must be preceded by an operability check consisting of a careful remediation of the mixers and systems that might have contact with the previous foaming liquids. The general characteristics of synthetic foaming agents recommended by UNI EN 1568:2018 allow the use of foaming liquids with seawater. Directive 2006/122/EC of 12/12/2006 bans the use of PFOS (perfluorooctanyl sulfonate) in fluorinated surfactants and requires that all foamers containing PFOS must be disposed of in the incinerator.

3.1. T-Fire System foaming agent

Several solutions of commercially available synthetic foaming agents have been analysed, and the chosen one for the T-Fire System is a commercially available foam concentrate including synthetic hydrocarbon foaming agents and stabilizers, including a patented foaming agent and, 2-(2-butoxyethoxy)ethanol, ethane-1,2-diol, 1-dodecanol, 1-tetradecanol. The selected solution allows to give a foam with high expansion capacity and good water retention power, also in case of large volumes. According to the manufacturer [25], this foam has been designed for those circumstances where the environmental impact must be minimized, as well as performances must be ensured through adequate tools. Indeed, the non-fluorinated surfactants are combined with a foaming agent base to produce a vapor sealing foam blanket providing a quick control and extinguishing.

The chosen solution is composed by class B foaming liquids that do not contain fluorinated compounds, in accordance with the UNI EN 1568, and the NFPA 18:2017 wetting agent standard. Moreover, the foam used in the solution has an expansion ratio greater than 10 and is suitable for fire types A and B (i.e., ordinary solid combustibles [paper, wood, cloth and some plastics], and flammable liquids [alcohol, ether, oil, gasoline and grease]). Minimum stocks, low-cost storage, long life and low levels of use characterise this solution, and high expansion is guaranteed when it is discharged through a special high expansion generator. In addition, the synthetic hydrocarbons used are biodegradable in the soil and readily biodegradable in water, with minimal bio accumulative potential, according to the corresponding technical sheet. This set of crucial physical-chemical characteristics supported the choice of this foaming agent for the T-Fire system.

Overall, based on the scouting analysis of currently available fire extinguishing systems, fire extinguishing foams and legislation, the T-Fire System has been designed and developed to constitute the first system that integrates IoT solutions which continuously monitor the vehicle status based on physical sensors on the truck, and an innovative fire extinguishing system that can be used in a plug and play manner to increase the readiness of the fire suppression.

4. T-Fire System design and development

In the present section the design of the T-Fire System will be described. The T-Fire System is an integrated fire monitoring and extinguishing system that operates through a close interconnection between the onboard diagnostic system and the plug-ang-play fire extinguishing system.

4.1. Onboard Diagnostic System

The onboard diagnostic system is composed by two blocks: detection block and monitoring block. The detection block is composed by selective Temperature Pressure Monitoring System (TPMS) wireless sensors placed on the tyres, while temperature sensors located on engine compartment and, if available, on the refrigeration unit (Fig. 1). To increase safety, the skid group is provided with a system arm command including a series of indicator lights which show to the operator if the extinguishing T-Fire system is ready to use or needs to be loaded. Moreover, a hose reel file is available to be used for extinguishing a possible fire (Fig. 1).

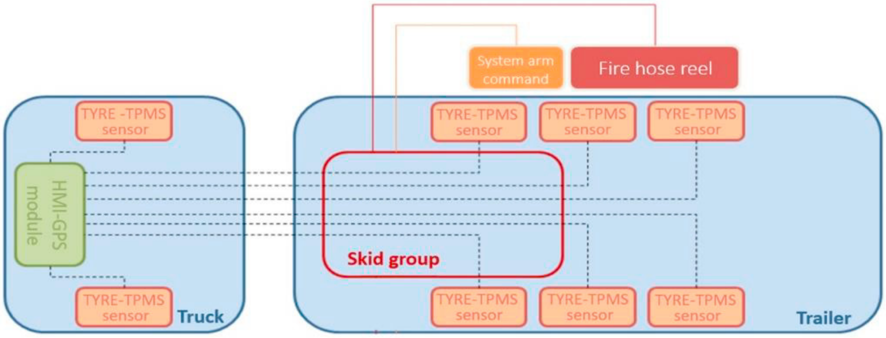

Fig. 1. T-Fire System on-board diagnostic

The monitoring block is composed by a central operating system useful to collect and send data via Bluetooth technology from all the tyre linked TPMS sensors to a tablet or a PC with a specific software and permanent connection to the central operating system which analyses the data from the detection block, process them and makes the results available to the operator (driver or passenger).

In addition, the system's platform uses intelligent algorithms to collect the data about the working conditions of the heavy vehicle and monitor, in real time, its status. Through the intelligent control platform on cloud, the safety status of the heavy vehicle can be continuously monitored in real-time, thereby improving the efficiency of predictive maintenance of tyres and helping the traffic safety department to limit dangerous or illegal vehicle behaviours.

The monitoring system consists of smart tyre pressure sensors, intelligent vehicle terminal and smart cloud tyre management platform. The smart tyre pressure sensors placed on the inner part of the tyre (Fig. 2, left) allows the measurement of the temperature, pressure and acceleration of the tyres, as well as evaluate the wear status and load of the tyre; moreover, smart tyre pressure sensors send collected data to the intelligent vehicle terminal (Fig. 2, right), which is a component installed in the cabin to alert the driver about undesirable conditions such as over-temperature, over-pressure, damage and overloading. The terminal finally sends the real-time status of the tyres, driving status and vehicle trajectory to the intelligent tyre management platform on cloud *via* the 4G network.

This smart management of tyres on cloud receives the monitoring data uploaded from all smart tyre sensors and intelligent vehicle terminals and makes decisions through big data analysis, optimises tyre utilisation strategies, improves safety factors and reduces utilisation costs.

The user, authenticated within the information system, manages the routes and the hardware components of the vehicle. In case of abnormal values of the physical parameters of the tyres, the information system alerts the vehicle through the tablet on board or the PC of the central operating system (Fig. 3).

Additionally, this alert can be sent to specific control stations which can be appropriately installed at the entrance of road galleries and be part of an online network of supervision in order to prevent the uprise of possible fires on heavy vehicles.

Fig. 2. Pressure sensors for intelligent tyres (left); Intelligent vehicle terminal (right)

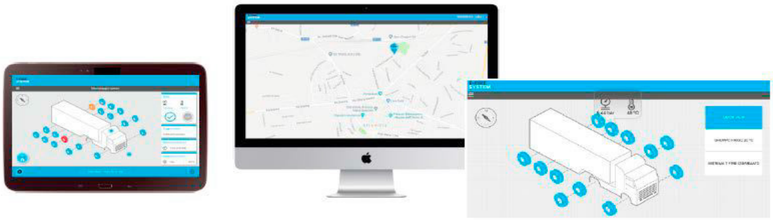

Fig. 3. T-Fire System monitoring block IoT platform

In particular, the T-Fire web application uses a set of measurable and detectable data (such as driver behaviour, driving speed, number of accelerations and breakings, tyre status, brake status, vehicle weight, trend of tyres' temperature and pressure, and geolocation information of the heavy vehicle) to perform different data analytics (descriptive, predictive, prescriptive) via specific Artificial Intelligence models. The data collected on the truck are sent to the central operating system (on cloud), and cryptographed through univocal codes. Subsequently, a system of Business Intelligence (BI) uses a set of technologies, processes, and methodologies, including well-structured algorithms, to allow the transformation of the data acquired into useful information for both the driver and the central processing unit to generate specific warning scores and make appropriate decisions to prevent dangerous circumstances while driving (e.g., excessive payload, low tire pressure, high engine temperature).

4.2. Fire Extinguishing System

The design of the T-Fire extinguishing system proceeded with different steps. The first prototype is composed of two blocks: a pressurization block (A in Fig. 4, left) and a mixing block (B in Fig. 4, left). The first is contained within a special steel containment box installed on the vehicle through major modifications on the trailer frame; it includes a control device which enables and arms the pressurisation block to pressurise the mixing block through flexible pipes. The second includes a toroidal tank with a mixing chamber (where the extinguishing mixture is created (water and CAF)), two hose boxes, and a personal protective equipment for the operator.

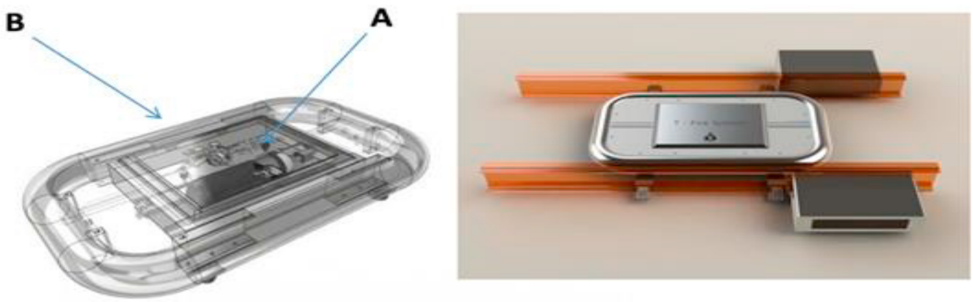

Fig. 4. First prototype of the T-Fire extinguishing system (left); toroidal position in the heavy vehicle trailer frame (right)

The extinguishing mixture is generated through the interaction of these two blocks. The fire-fighting mixture is then forced through the fire hose, which acts as a nozzle to increase the ejection speed of the foaming agent and thus reaching a final landing range of 15-20 meters. This distance ensures the driver which extinguishes the fire ignition on the heavy vehicle to be safely enough far from the fire.

Subsequently, a deep market analysis was carried out on the applicability of the first T-Fire system prototype on heavy vehicles. The analysis highlighted some critical issues: although the prototype is compatible with about 30% of trucks and heavy vehicles (especially for trailers and semi-trailers with isothermal / refrigerated equipment), it may not be applied on a large scale. In fact, the first prototype of the T-Fire system was too heavy, with excessive size that compromises the ease of installation on heavy vehicles.

Following this analysis, a second early-designed integrated solution has been created. In this paper, the early design of this second solution of extinguishing system is only moderately detailed since it is patent pending.

The entire T-Fire System has been redesigned so that human-assisted intervention can quickly extinguish the possible ignition fire that may develop on the heavy vehicle itself and/or on other vehicles involved in accidents.

Fig. 5. T-Fire extinguishing system (left) and its location on the vehicle (right)

The entire system has been positioned inside a toolbox commonly installed on board of heavy vehicles in a plug and play manner, which makes the system extremely versatile and easy to use. Fig. 5 depicts the early design of the T-Fire System, as well as its location on the vehicle.

The reconfiguration of the T-Fire allows a rapid replacement of the skid containing the pressurisation block for periodic maintenance and/or replacement of the pressurisation block for disfunctions. Routine maintenance and inspections should be carried out periodically based on the number of kilometres travelled by the heavy vehicle.

In case of an ignition fire on heavy vehicle provided with the T-fire system, the driver should stop in a safe place, without creating obstruction to traffic, and promptly activate the T-Fire system to extinguish any fire. Once the fire has been extinguished, the driver can deactivate the system.

5. Conclusions and further research

Fires that generate on heavy vehicles and trucks represent a severe threat to environment safety and human life, with devastating consequences and injuries. The nature of these vehicles, as well as the rapid spread of heat, flames and smoke generated by the fire make the safe scape difficult for individuals; moreover, risks and dangers may increase if pedestrian or other drivers are nearby, leading to further human casualties and injuries. In addition, economic implications following heavy vehicle fires cannot be neglected. The replacement cost of heavy vehicles and trucks, and the economic losses due to the irreparably damaged mean of transport, lead to important economic repercussions.

To mitigate dangers and economic consequences of fires on heavy vehicles and trucks, multiple measures may be taken. A regular vehicle maintenance and inspection can help to identify potential fire hazards. On the other hand, in case of fire, if heavy vehicles and trucks are equipped with an effective fire extinguishing system, consequences and losses due to fire can be minimized by preventing the escalation of the fire and allowing drivers and occupants to escape safely.

Therefore, due to the crucial role in enhancing safety and mitigating fire potential damages, the present article described the early design and development of a novel integrated fire monitoring and extinguishing system called 'T-Fire System'. Differently from most of the commercially available fire extinguishing systems, the proposed solution can be easily implemented on most of types of truck and heavy vehicles with no substantial structural modifications of the vehicle via a plug and play system. Moreover, the system can operate in unconfined environments, employs an environmentally sustainable extinguishing agent, and is equipped with a parameter monitoring process for ignition fire diagnostics.

The T-Fire system is structured on three levels of intervention: firstly, vehicle temperature monitoring through wireless sensors placed on tyres, engine compartment and refrigeration unit where ; secondly, automatic intervention for extinguishing on-board fires, and finally, manual intervention by the driver.

Preliminary evaluations of the first prototype have shown its reliability and readiness. In particular, the TPMS sensors on tyres have shown valuable sensibility and speed (less than 3 seconds) on detecting dangerous increases of temperatures and pressure of tyres (more than 5%); in addition, other preliminary analyses on the extinguishing solutions used to suppress an artificial ignition fire generated in an experimental setting showed successful effectiveness, resulting in an expansion factor of around 10 and in covering sufficiently large areas.

A current limitation of the present solution is due to the intervention of the driver, whose promptness is related to carry out correctly the training phase in the use of such a system. Moreover, the volume of the system containing the foaming agent does not vary according to the size of the vehicle or the size and type of payload (e.g., fuel or flammable liquids transported). Consequently, one aspect to be improved in the current system is the use of an additional tank in case highly flammable loads transported on the truck/heavy vehicle. Further experimental tests and research will be carried out to test and customise the solution to draw the development of the T-Fire System to a close and open to possible pre-industrial interactions with companies producing heavy vehicles.

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