Bus fire safety – state of the art and new challenges

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ABSTRACT

Several bus fires with many fatalities are reported in the world each year and in Sweden 1% of buses burn annually. At the same time the fire requirements for buses are lower than for trains, ships, and aircrafts. Stricter regulations have been implemented the last decade but there are still great potential for improvement of the fire safety of buses. This paper summarizes the most important fire regulations for buses in Europe and presents some selected recent activities for further improvement of fire safety. Finally areas are pointed out where more research and/or regulations are desirable.

KEYWORDS: Bus fire safety, UN ECE Regulation No. 107, UN ECE Regulation No. 118, Fire test methods, Fire suppression, Fire detection

INTRODUCTION

Buses have lower requirements on fire safety than other public transports such as rail vehicles, shipping, and aviation [1, 2] with e.g. no requirements on heat release, smoke density, or smoke toxicity for materials on buses, while there are for trains, ships, and aircrafts [3]. Buses also have a relatively high frequency of fires. In Sweden fires are reported for 1% of buses annually, and 10% of all buses are involved in a fire during their service life [4]. Similar statistics from Germany shows that 0.5-1% of buses burn annually [1]. Though losses of lives caused by bus fires are relatively uncommon there are examples of disastrous bus fires in recent years such as

- Veracruz, Mexico 2014 (36 fatalities)
- Nagari Tanjung Lolo, Indonesia 2014 (7 fatalities)
- Karnataka, India 2014 (6 fatalities)
- Fundacion, Colombia 2014 (32 fatalities)
- Northern California, USA 2014 (10 fatalities)
- Qum, Iran 2013 (44 fatalities)
- Kothokota, India 2013 (44 fatalities)
- Lwengo, Uganda 2012 (30 fatalities)
- Yobe, Nigeria 2011 (18 fatalities)
- Wuxi, China, 2010 (24 fatalities)
- Uttar Pradesh, India, 2008 (63 fatalities)
- Hannover, Germany, 2008 (20 fatalities)
- Wilmer, USA, 2005 (23 fatalities)

Statistics indicate that the frequency might have increased due to tighter standards on emission and noise, which make the thermal environment in the engine compartment more challenging from a fire safety point of view [5, 6]. Although incident reports and statistics are not always exhaustive, literature indicates that, very approximately, 60% of the fires start in the engine compartment, 20% in the wheel well, and 20% in other areas such as the passenger or luggage compartment for example [5, 6].

Whereas the fire frequency of buses has been high historically, the positive side is that actions to reduce the problem have shown significant results. For instance information from Swedish insurance companies [7] shows that before 2004 there were approximately six to seven complete burnouts of buses each year in Sweden due to fires that started in the engine compartment . In 2004 the insurance companies requested all buses to be equipped with automatic fire suppression system in the engine compartment. During the following six years no complete burnout occurred as a consequence of such fires. More recent data from Germany [8] shows similar positive effects. The scope of this paper is to summarize the most important fire regulations for buses in Europe and to present some selected recent activities for further improvement of fire safety, as well as pointing out areas where more research and/or regulations are desirable. In this paper the word bus comprehend buses and coaches.

CURRENT REGULATIONS

The requirements on fire safety for buses are mainly defined in the UN ECE Regulations No. 107 and 118.

UN ECE Regulation No. 107

Regulation No. 107 [9] covers a wide range topics for buses, many of them related to fire safety. The regulation is based on the European bus directive 2001/85/EC which basically was a mix of the now obsolete Regulation No. 36 [10] and the British Disability Discrimination Act. The main fire related requirements are:

- No flammable or liquid-absorbing sound-proofing materials in engine compartment are allowed.
- Heat-resistant partitioning between engine compartment (or any heat source) and rest of the bus.
- Safe construction and installation of cables.
- Fusing.
- Isolating switch for circuits with a voltage exceeding 100 V.
- Safe and accessible installation of the battery.
- Space provided for fire extinguishers and first-aid kits.
- No flammable materials within 10 cm of any potential heat source, such as exhaust systems or high voltage equipment for example.

Two important amendments related to fire safety have been issued for Regulation No. 107 the last years.

As of 2012-12-31 it is prescribed that the engine compartment, and each compartment where a combustion heater is located, shall be equipped with an alarm system detecting excess temperatures. This requirement is only valid if the engine compartment is located rear of the driver's compartment. The alarm system shall be operational whenever the engine start is operated.

The most recent addendum stipulates that as of July 2014 an alarm system detecting either smoke or excess temperature shall be installed in toilet compartments, driver's sleeping compartments, and other separate compartments. The alarm system shall be operational whenever the engine start is operated.

UN ECE Regulation No. 118

This regulation [11] has replaced the European directive 95/28/EC and originally covered fire performance of materials in the interior compartments of buses, which is defined as any compartment intended for passengers, drivers and crew. The regulation is designed for coaches carrying more than 22 passengers, and not for buses designed for standing passengers and/or city buses. In 2010 an amendment was issued with a test method and performance requirement for assessment of the capability of insulation materials (e.g. sound-proofing materials) to repel fuels or lubricants. In the same amendment a test method and performance requirement was prescribed for electric cables. This amendment was a step meant to develop the fire prescriptions in Regulation No. 107 more quantitative.

In 2012 an amendment was issued regarding the fire performance of interior materials. Until then three test methods were employed for interior materials:

- Test to determine the melting behaviour of materials
- Test to determine the horizontal burning rate of materials
- Test to determine the vertical burning rate of curtains and blinds

The test to determine melting behaviour of materials is now required for materials installed above 500 mm from the seat cushion, i.e. including the roof, and for materials installed in the engine compartment and any other separate heating compartment.

The test to determine the horizontal burning rate, see Figure 1, was mandatory until 2012 for combustible materials in the interior compartments, with some exceptions. The test is similar to the test standards ISO 3795 [12] or FMVSS 302 [13]. This method has received arduous critics [14-18] for being too lenient based on the fact that test specimens are oriented horizontally, whereas much fire spread in a real bus fire occurs on vertically oriented products, and also based on the fact that the test is a small scale method not suited for bus fires induced by for example fire in the engine compartment or fire in a tire. In the aftermath of the disastrous bus fire in Hanover in 2008 it was decided by the GRSG (Working Party on General Safety Provisions) of UN ECE that the test for horizontal burning rate should no longer be applicable to vertically oriented materials. Therefore, in the latest revision of Regulation No. 118, the horizontal burning rate test is only valid for horizontally oriented materials in the interior compartment and in the engine compartment and any other heating compartment.

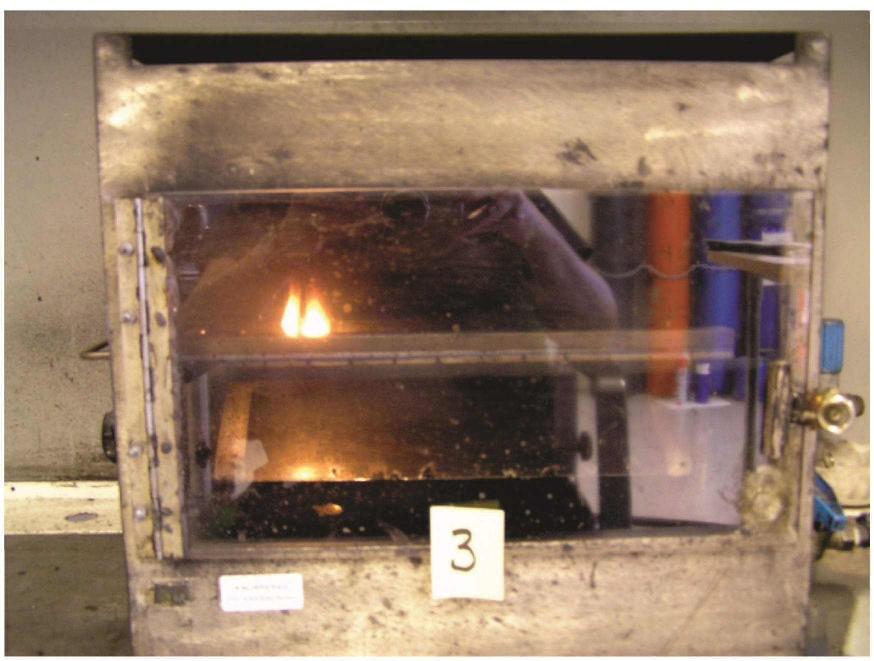

Figure 1 Test to determine the horizontal burning rate according to Regulation No. 118.

The test to determine the vertical burning rate, see Figure 2, is similar to the standard test ISO 6941 [19] and was originally only applicable for curtains and blinds. However, since this method was already implemented in the regulation it was deemed reasonable to use this as a replacement for the horizontal burning rate test for materials that are oriented vertically. Some modifications of the test method were implemented in order to make it suitable for stiffer and thicker materials than curtains and blinds. This change of test method constitutes a significant sharpening of the fire requirements on interior materials since vertical burning rate typically is faster than horizontal burning rate (the performance limit, not more than 100 mm/minute burning rate, is the same for the horizontal and vertical burning rate tests).

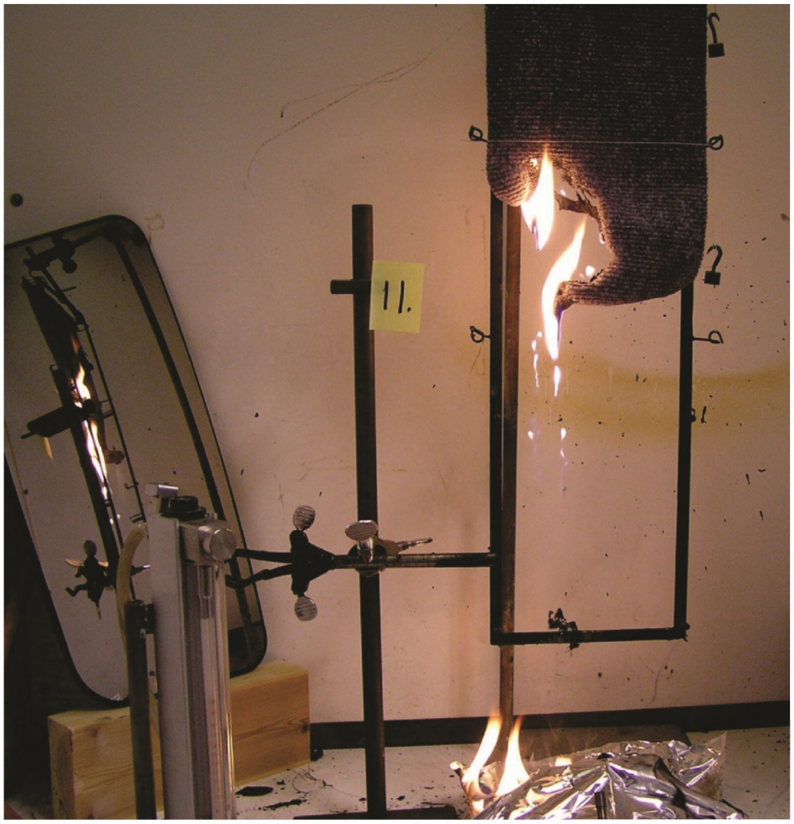

Figure 2 Test to determine the vertical burning rate according to Regulation No. 118.

Materials that fulfil the requirements for the vertical burning rate test are considered to also fulfil the requirements for the horizontal burning rate test. This means that materials that are mounted both horizontally and vertically only have to pass the vertical burning rate test.

As a mean of approaching the bus requirements with the more elaborate prescriptions for trains and ships the latest revision of Regulation No. 118 allows the use of the test method ISO 5658-2, lateral spread on building and transport products in vertical configuration [20], see Figure 3. Materials that are approved by this test are considered to also fulfil the requirements for both the vertical burning rate test and the melting test, provided no burning drops are observed.

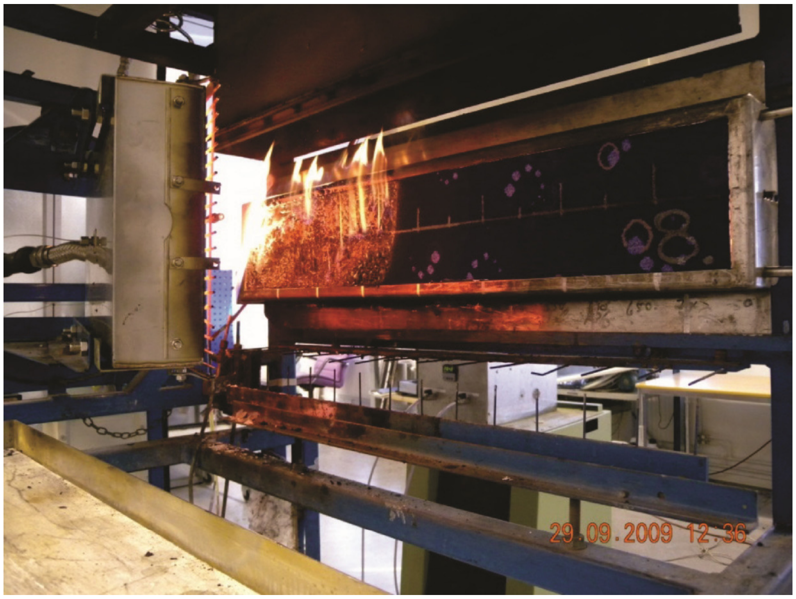

Figure 3 Test according to ISO 5658-2 which is implemented in the latest revision of Regulation No. 118. A successful test renders unnecessary both the melting test and the vertical burning rate test.

Other UN ECE Regulations

There are other regulations with requirements relevant for fire safety that are applicable to vehicles more generally, and not only to buses.

Regulation 34 specifies requirements with regard to liquid fuel tanks.

Regulation 43 contains requirement on horizontal burning rate for plastic safety glazing (measured with the same apparatus as specified in Regulation 118).

Regulation 44 contains flammability performance requirements for materials of child restraint systems. This regulation refers to Regulation 118.

Regulation 67 contains prescriptions for vehicles using LPG (liquefied petroleum gas) in their propulsion system.

Regulation 100 provides requirements concerning electric power train of vehicles, including fuel cells. Fire safety is not mentioned directly but results from e.g. limitations on hydrogen emission during battery charge operations.

Regulation 110 contains prescriptions for vehicles using CNG (compressed natural gas) and/or LNG (liquefied natural gas) in their propulsion system

Regulation 122 contains prescriptions for vehicles regarding their heating systems, in particular combustion heaters.

ONGOING ACTIVITIES

This section presents a selection of recent or ongoing activities aimed at improving bus fire safety, but which has not so far been implemented in international regulations.

Engine compartments

As most of the fires in buses commence inside the engine compartment most efforts the last years have been focused on improving fire safety in the engine compartment.

Encouraged by the statistics from the Swedish insurance companies, that indicated a significant effect of fire suppression systems in the engine compartment, SP initiated a project in 2010 with the purpose to develop a test standard for evaluating automatic fire suppression systems meant for bus engine compartments [4]. This work led to the standard SP Method 4912, Method for testing the suppression performance of fire suppression systems installed in engine compartments of buses and coaches [21, 22]. The standard includes eleven different tests in a realistic test rig, see Figure 4. The test report rates the tested suppression system based on the number of passed (extinguished) tests and the ability to protect against re-ignition. This means that manufacturers can compete with each other by improving their systems to increase the number of passed tests. It also allows e.g. purchasers to set stricter requirements, e.g. passing all tests, for buses frequently utilized in special hazard areas, such as tunnels and underground car parks for example. This standardized test is now gaining grounds within authorities, bus manufacturers, and fire suppression manufacturers. There are ongoing efforts by the Swedish Transport Agency to include parts of SP Method 4912 into Regulation No. 107. Such an amendment would be a further step in order to make the fire prescriptions in Regulation No. 107 more quantitative.

Figure 4 Fire test according to SP Method 4912. A fan is seen to the left.

Clearly the suppression performance of an automatic fire suppression system is an important factor in assessing the total quality of the system. However, it is also important that the system can function in the harsh environment of an engine compartment. Therefore SP has developed an extended testing scheme including a set of component tests [23]. The focus is laid on environmental durability testing with respect to vibration, shocks, temperature variations and corrosion, in addition to extinguishing capacity. These tests allow demonstration of the overall quality of the tested fire suppression systems for engine compartment in buses.

The changes in the regulations and the new test methods can improve the fire safety significantly. Still there are some areas that could improve the situation further. Real scale testing of fire suppression systems in bus engine compartments performed by BAM, Federal Institute for Materials Research and Testing in Germany, showed that even if the suppression system temporarily extinguished the fire, it reignited some seconds later [3]. This was mainly due to the sound-proofing insulation materials. It remains to see if the new requirements for the capability of insulation materials to repel fuels or lubricants in UN ECE Regulation No. 118 will improve this situation. The test campaign at BAM also included several tests of fire detection systems. Detection systems were found to, in general, be effective, but problems with promptness of spot thermal detectors where identified. This has also been confirmed in numerical simulations [24]. Given the obvious importance of fire detection SP initiated a project in 2013 [25] with the main objective to develop a test standard for assessing the quality of fire detection systems for the engine compartment of buses. This standard will complement SP Method 4912 and is expected to be finalized in 2015. Also, Southwest Research Institute (SwRI) in USA has developed a test fixture and test procedures for bus engine compartments where both detection and suppression systems can be tested [26].

Tire fires

The motor coach fire during the evacuation from the hurricane Rita, with 23 fatalities, in 2005 [27] is an example of the potential devastating effects of tire fires in buses. Tire fires are notoriously hard to extinguish and therefore efforts for protection and detection, rather than suppression, have been most focused on.

NIST, the National Institute of Standards and Technology, in USA performed a study [28, 29] where it was found that the fastest penetration route into the passenger compartment was that the tire fire ignites the plastic fender and glass-reinforced plastic exterior side panel which subsequently broke the windows. This route was much faster than fire penetration through the flooring or lavatory. Fire hardening experiments were therefore performed and it was shown that replacing the plastics by steel, or covering it with intumescent coating, was effective and delayed the fire penetration into the passenger compartment with 20 minutes or more.

A test method to evaluate early warning systems for wheel wells has been developed by SwRI [26]. The method evaluates sensors and algorithms used to detect a hot wheel, before a fire breaks out. The failure scenario of the test is either a dragging brake or a failed bearing.

Smoke and toxicity

Some improvements of the requirements on fire performance of interior materials have been implemented in UN ECE Regulation No. 118. Still, no requirements on smoke and toxicity apply for buses. In a recent project performed by BAM it was found that most of tested bus interior materials fail the smoke production requirements of rail vehicles according to the European train standard EN 45545-2 [30]. Furthermore all materials generated hazardous to lethal concentrations of toxic gases within a few minutes. This is also supported by material tests [15] and a full scale test of a bus fire [31] at SP. In the full scale test the fire was ignited in the rear luggage compartment and dangerous concentrations of toxic effluents were measured in the passenger compartment only 4-5 minutes after ignition. A more recent test at SP indicated high CO concentrations after only 3 minutes [32]. In another full scale experiment by NIST [28] the time from penetration of a tire fire through the window to untenable conditions due to toxic gases in the passenger compartment was approximately 10 minutes.

Fire detection in other compartments

Although bus fires commonly start in the engine compartment there are other locations where an early warning system is also desirable. This is exemplified by the bus fire in Hanover 2008 where a catastrophic fire propagation occurred after a passenger had open the door to the toilet compartment, where a well-developed fire was located. UN ECE Regulation 107 now requires thermal or smoke detectors in the toilet compartments, driver's sleeping compartments, and other separate compartments. Therefore SP performed a study [33] to provide guidelines for fire detection in these spaces. In was found that smoke detectors are significantly faster than thermal detectors and that great care must be taken to the forced air flows in these small compartments.

GAP ANALYSIS

Great progress has been made with the recent improvements in the regulations and the situation is expected to further improve as new buses according to the new regulations are set on the market. With some further effort the situation would improve even more. This section contains a non-exhaustive number of items where new international regulations or research is desirable.

UN ECE Regulation No. 107

The markedly positive statistical results from the Swedish insurance companies indicates that fire suppression systems should be mandatory in the engine compartment of buses, and their quality should be assessed using a test method such as e.g. SP Method 4912. The detection systems are an important part of the fire safety measures and therefore these should also be mandatory with clear performance criteria, once a test method for this purpose is available.

There are many well-intentioned paragraphs regarding fire safety in Regulation No. 107 but in many cases there is a lack of stringent performance criteria. For example there is a requirement on a heat-resistant partitioning between engine compartment and the rest of the bus, but there is no defined test method or performance requirement. This requirement could be put on a firm basis e.g. by using a furnace as shown in Figure 5 which is proposed in Section 9.4 of Hammarström et.al. [31].

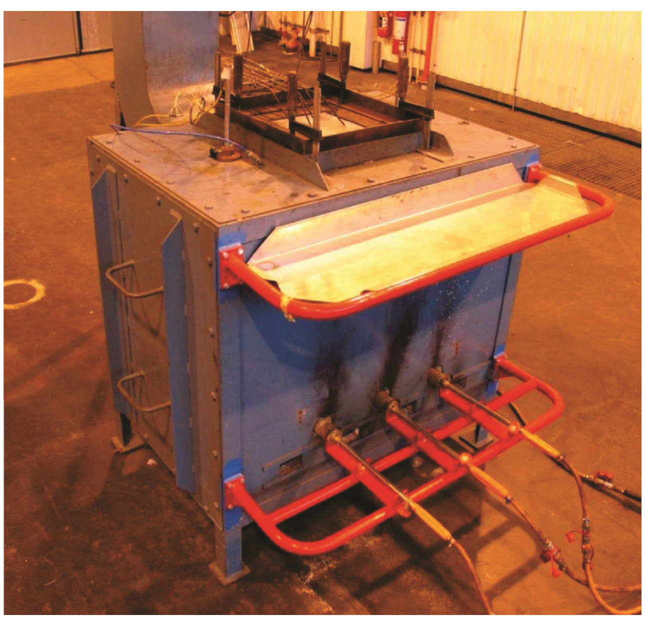

Figure 5 Furnace to assess fire resistance of partitioning as proposed by Hammarström et. al [31].

Similarly it would be of interest to require fire hardening near the wheels as studied by NIST [28, 29] and to require early warning systems as proposed by SwRI [26].

As a curiosity it can be noticed that Regulation No. 107 requires that space is provided for fire extinguishers and first-aid kits. As an alternative the presence of such items could be required, instead of space for the items.

UN ECE Regulation No. 118

Although the fundamental fire test method was recently changed from horizontal burning rate testing to vertical burning rate testing for interior materials these are both small-scale methods that were originally conceived to mimic a small ignition source such as a cigarette or a match. That type of threat was most relevant some 40 years ago when the horizontal burning rate test was defined, but today other fire sources such as fires in the engine compartment or in tires are more relevant. The fact that the ignition source is small in the test methods means that many materials extinguish by themselves or do not ignite at all. This is indeed an attractive property when the ignition source is small, but it does not reflect the outcome from a fire where the heat attack is larger or when large amounts of hot gases enter the passenger compartment via the floor (e.g. fire in the engine compartment) or via the windows or side walls (fire in a tyre). Therefore a single requirement on interior materials using a more realistic test method such as ISO 5658-2, lateral spread on building and transport products in vertical configuration [20], would be desirable.

Toxicity is still unregulated. BAM and SP have performed research that show that toxicity requirements for interior materials should be enforced for materials for buses. In this context it is interesting to notice that BAM suggests limiting toxic concentrations of single smoke gas components instead of limiting CIT values (Conventional Index of Toxicity). Since fires rarely start in the passenger compartment but are transported from other locations, e.g. the engine compartment, to the passenger compartment it would also be realistic to put toxicity requirement on all materials that are found in potential penetration routes for the fire, and not only on materials in the engine compartment and passenger compartments themselves.

Hazard levels

As pointed out in reference [3] the operating conditions for trains defines the fire requirements in the train standard EN 45545-2. In contrast buses only have one type of requirement. The requirements on buses could be differentiated based on the intended use. For example buses that will travel, and be parked, extensively in tunnels and underground constructions could have stricter requirements than buses used only above ground.

CFD

CFD (Computational Fluid Dynamics) has been considerably developed the last decade. The use of CFD for bus fire safety should be elaborated and the results should be put into practice. As an example, two independent studies [3, 31] have shown that the presence of combustible materials in the ceiling can drastically enhance the fire spread inside the bus, and that automatic opening of the roof hatches effectively reduces smoke levels in the event of a fire, thereby facilitating a safe escape. It has also been shown that CFD can be used in the design phase of detector installations on buses [33].

Statistics

In order to quantify the effects of e.g. amendments of the UN ECE Regulations, and in order to perform cost-benefit analyses with some degree of accuracy, a central database for bus fires would be helpful. Such a database should cover at least the European road net.

NEW CHALLENGES

The major new challenges within the field of bus fire safety are probably the alternative fuels that are gaining in importance, supported mainly by environmental concerns. Examples of such fuels, or energy carriers, are CNG, LNG, LPG, ethanol, methanol, RME (rapeseed methyl ether), batteries, hydrogen, and fuel cells. A striking example of the new threats was revealed when a fire broke out in a CNG-powered bus in Wassenaar in 2012 in the Netherlands [34, 35]. The gas cylinders on the roof on the bus heated up and activated the safety valves, resulting in 15-20 meters long flames shooting out during four minutes. This demonstrates the radically different fire threats with fuels such as CNG, LNG, and LPG, as compared to traditional fuels such as diesel which are liquid at ambient temperature. The risk with a fire is no longer limited to the bus and its passengers and driver, but also to the nearby environment.

Although liquid fuels will not expand in such a way as CNG upon heating, new liquid alternatives also poses new challenges due to new requirements on fire extinguishing, for ethanol and methanol, and also due to increased ignitability, for ethanol, methanol, and RME [36].

The increased number of vehicles running on alternative fuels means that the frequency of such vehicles in tunnels and other underground spaces will also increase [37]. If the CNG fire in Wassenaar would have occurred in an underground facility the effect could have been disastrous. Some countries have restrictions on the use of alternative fuels in tunnels and underground garages [38]. As an example, gas buses are not allowed in the Helsinki bus terminal [39]. Clearly, more research is needed in this field in order to obtain appropriate regulations.

CONCLUSIONS

Although the regulations on fire performance on buses have been strengthened the last decade the requirements are still considerably lacking behind other public transport means such as trains, ships, and aircrafts. The frequency of bus fires is still high and several bus fires with many fatalities are reported each year. A bus also represents a high fire load which can cause damage to the surrounding environment like in a city or in a tunnel.

Most fires start in the engine compartment and it is therefore desirable that fire detection and suppression systems are prescribed for this compartment. Tire fires are also common. Since suppression of such fires is difficult an early detection system is recommended together with fire hardening of materials near the wheel well. The requirements on materials in buses are deficient and more realistic test methods, as well including the measurement of toxic gases and heat release rate, would be advantageous.

New fuels imply new challenges for bus fire safety. More research is required in order to understand the effect of fires on the nearby environment as well as to understand the effects on ignitability and fire extinguishing. Once such data is available new mitigation strategies and regulations can be implemented.

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