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Experimental investigation and CFD modelling of the internal car park environment in case of accidental LPG release

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ABSTRACT

The use of new fuels (hydrogen, LPG) in daily life and industrial sites introduces new hazards which require new safety concepts. Despite the fact that LPG is used in a large number of cars, large-scale tests of accidental LPG release in the car park have not previously been performed. The problem of LPG-powered vehicles in enclosed car parks was previously evaluated only by CFD analyses.

This paper describes full scale tests, which represent conditions that may occur in a garage in the event of accidental LPG release from a car's LPG installation. Over the course of the tests full scale LPG spillage experiments were performed to study emission time and flammable cloud formation according to the assumed hole diameter in the car's installation. On the basis of them, the characteristics of dispersion of LPG in the garage were obtained. The test results were used to create the appropriate CFD model of LPG release and dispersion in FDS code (NIST). The CFD model was used for a case study of the LPG release from the entirety of the car's tank in the full scale car park where the different effectiveness of various ventilation systems were observed and evaluated.

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1. Introduction

The most often used new hazardous fuels (hydrogen, LPG) in daily life and industrial sites introduces requirement of new safety concepts (De Rademaeker et al., 2014). LPG is the third most popular automotive fuel in the world, with approximately 16 million passenger cars powered by this fuel, representing about 3% of the total market share. Approximately half of all autogas-fuelled passenger vehicles are in the five largest markets (in descending order): Turkey, South Korea, Poland, Italy and Australia, but such cars exist in other countries as well. The biggest motivation for using LPG in cars is the price, which is about 40% lower than other fuels. In addition, LPG-powered vehicles produce fewer pollutants from their exhausts in comparison with gasoline and diesel-fuelled vehicles (Karamangil, 2007; Morgan and Ocal, 2012; Van den Schoor et al., 2013). However, many LPG car installations become recently old and in bad condition, which could be the reason for the accidental gas release. They can be dangerous, especially in underground car parks.

There is a lack of research into the risk of loss of containment within LPG installations in garages. Also, no guidance exists for designing effective detection of this gas or ventilation to ensure its removal in the case of emissions. Most countries prohibit cars with LPG installations from being parked in underground garages, but this is a very big drawback for their users. In large enclosures with pollution sources, such as car parks and tunnels, sufficient ventilation is important in order to reduce the concentration of hazardous substances (or smoke in the case of fire) to a harmless level.

Despite the fact that LPG is very often used as a fuel for cars, full scale experiments have not been previously performed and the problem of LPG-powered vehicles in enclosed car parks was evaluated only by CFD analyses (Van den Schoor et al., 2013). There are some publications which deal with the technical problems of LPG transportation, such as methods for the determination of the required safety control levels for this process (Akyuz and Celikb, 2015), hazards analysis in the LPG refuelling stations (Rajakarunakaran et al., 2015) or huge tankers (Kumar, 2013), but there are hardly any publications about problems with relatively small LPG tanks and installations, which are, very often,

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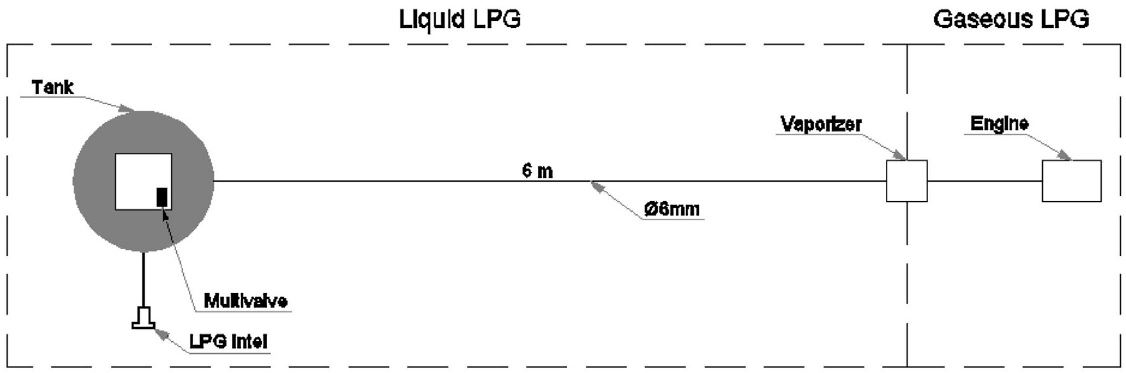

Fig. 1 – Scheme of typical LPG car installation.

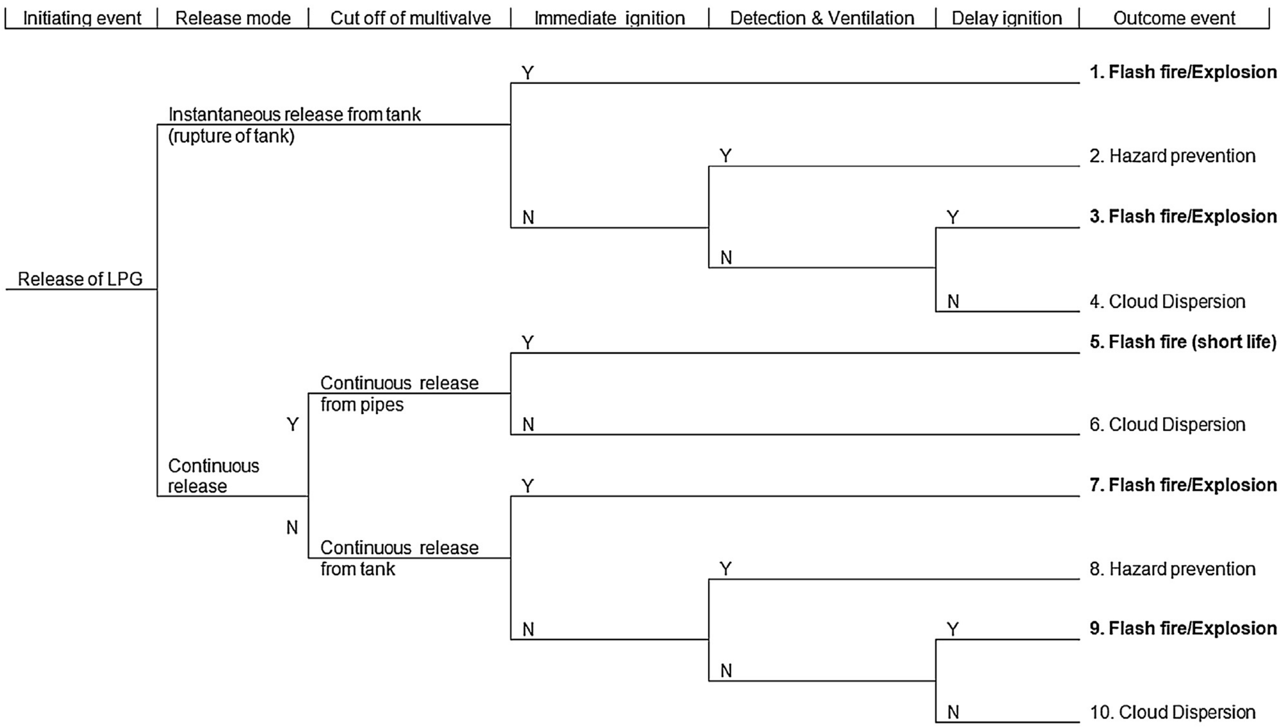

Fig. 2 – Event tree used for the derivation of possible incident scenarios. Cut off of multivalve.

in relatively small enclosures like car parks (Brzezińska and Markowski, 2016). An article by Van den Schoor et al. (2013) describes the possible scenarios of LPG leakage in car parks, but this was based only on CFD simulations.

The risk levels connected with a flammable gas release depend on the interaction with the environment and the consequent dispersion or build-up in semi-confined regions (Palazzi et al., 2013, 2014). There are hardly any statistics on the failure of LPG automotive systems either. Based on surveys carried out in vehicle control stations, it was found that unsealed tanks are practically unheard of and if a gas leak occurs, it occurs due to a leak from the installation, especially at the joints. But full tank leakage cannot be excluded from consideration. A study in Canada showed that human error was the main cause of accidents involving LPG vehicles. Information on 80 accidents was gathered by Transport Canada's investigation office and the Ontario Ministry of Consumer and Commercial Relations between August 1981 and May 1986. Among them, 47 cases were caused by the human factor, which accounts for 58% of accidents (Liu et al., 1997). However, fire incident analyses in Canada have shown that propane-fuelled vehicles do not pose a greater fire risk in underground parking areas than gasoline-fuelled vehicles (Armstrong et al., 2013); the probability of LPG release from car installation always exists and this fact highlights the necessity of equipping underground car parks with LPG detection systems along with automatically activated ventilation. Polish regulations require these installations in all underground car parks where LPG-powered vehicles are allowed (Minister of Infrastructure, 2002). The problem is that there are no specific guidelines on how these installations should be designed (Brzezinska, 2015, 2016a). In order to assess the effectiveness of LPG detection and ventilation systems, full scale tests and CFD simulations were carried out. The goal of these tests was to develop and validate tools that could be used to predict the effects of LPG gas spillage. This was done by executing full scale experiments and by developing computer models to make predictions for conditions under which tests could not be performed. The results can be used in all countries where problems with cars powered by LPG exist.

The jet fan system is a stream ventilation system, ductless, based on simultaneous action of a group of fans to transport the air from supply point(s) to exhaust point(s). Jet fans are often applied to support the ventilation process in car parks (Viegas, 2010). The jet fans are mounted under the ceiling of the enclosure to generate momentum, which causes induction of air and promotes mixing and transportation of the polluted air. Working in first gear, fans ventilate the enclosure as necessary to discharge pollutants from exhaust gases of cars circulating in the garage (daily ventilation). Second gear is used for smoke exhaust during a fire and often in the case of LPG detection. Jet fans are often used in situations where large amounts of air need to be transported with a relatively high velocity (Betta et al., 2010). However, jet fan systems were previously used only for tunnels and premature use

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