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DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Gas cylinder accidents and incidents during Wildland Urban-Interface fires: an overview of the events

Thiago F. Barbosa*[1, 2]; Luís Reis[2]; Jorge Raposo[2]; Luís M. Ribeiro[2], Domingos Viegas[2]

[1] Univ Coimbra, ADAI, Department of Civil Engineering. Rua Luís Reis Santos, Pólo II, 3030-788 Coimbra, Portugal. {thiago.barbosa@adai.pt}
[2] Univ Coimbra, ADAI, Department of Mechanical Engineering. Rua Luís Reis Santos, Pólo II, 3030-788 Coimbra, Portugal, {luis.reis, jorge.raposo, xavier.viegas}@dem.uc.pt, {luis.mario@adai.pt}

**Corresponding author*

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Abstract

Incidents or accidents involving domestic liquefied petroleum gas (LPG) tanks have occurred at Wildland-Urban Interface (WUI) areas in Portugal, the USA, Spain and Greece, among others. The presence of LPG tanks in the WUI may cause severe events, especially when they are stored close to wildlands or artificial fuels. This work is a review aimed at presenting an overview of the cases related to accidents/incidents with LPG tanks stored during WUI fires. Fourteen recent accidents/incidents are described and lessons are taken in order to make recommendations to homeowners.

1. Introduction

Accidents and incidents related to Liquefied Petroleum Gas (LPG) stored at Wildland Urban-Interface (WUI) areas have been mentioned by authors (Barbosa et al., 2022; Caballero et al., 2019; Scarponi et al., 2020; Viegas et al., 2017, 2019). Due to the amount of energy stored, the vessel may become a hazard when a wildfire occurs.

Heating an LPG cylinder can cause severe events. For instance, it may trigger a boiling liquid expanding vapor explosion (BLEVE). The BLEVE occurs in pressurized vessels, which can cause severe damage to people and surrounding infrastructure. The main BLEVE effects are thermal radiation from a fireball (when the fluid is combustible), fragments projected and overpressure, all of which jeopardize the surroundings (Casal and Salla, 2006; B. Hemmatian et al., 2017; Behrouz Hemmatian et al., 2017; Planas-Cuchi et al., 2004). The BLEVE may be avoided if the cylinders have a PRD coupled, given the fact that the valve may prevent exacerbated pressure increment. However, in the few cases that heat dose is high, the BLEVE can still happen. If the PRD works, instead of explosion, a less dangerous event, a jet fire may occur. However, either event can trigger a domino effect.

This work is a review aimed at presenting an overview of the cases related to LPG stored at WUI fires. Fourteen accidents and incidents are described in this work as well as their effects.

2. Some recent events with gas storing occurred during WUI fires

2.1. Cases 1 and 2: Wildfire in Funchal, Portugal, August 2016

In August 2016, adverse weather conditions caused by an anticyclone in the northeast of the Iberian Peninsula and a depression in Morocco led Madeira Islands to have extreme values of temperature and relative humidity between 5 – 10th August. In the south of Madeira, the air humidity reached 10-20% and temperatures around 38ºC. On August 9th, the most extreme weather conditions were registered: the wind reached 35 km·h-1 with wind gusts of 80 km·h^{-1}; the minimum temperature registered was 29.6 ºC, which is 3.7 ºC higher than the last highest value registered in 1976 (Caballero et al., 2019; IPMA, 2016).

On August 8th, around 15:30h, an ignition occurred in forest area close to the WUI area. The local conditions of high temperatures, low humidity and strong wind, increased fire spread, namely to WUI areas, and ultimately, to urban areas. The fire spread initially up the hill through the forest zone, coming down the hill afterwards due to the prevailing wind direction. These extreme conditions exposed houses, the water treatment plant and a five-star hotel. Even on the 9th, 36 houses burned, 600 habitants were moved, the João de Almada Hospital was evacuated and three fatalities occurred.

In two houses, LPG cylinders were directly affected by the fire. Non-natural fuels and forest fuels in the surroundings of the house contributed to the cylinder´s fire impingement.

In the first house (case 1), the cylinder burst. Damages made by the BLEVE were found in the door and windows.

In the second house (case 2), four LPG cylinders were impinged by flames. The house was destroyed by the fire, but a BLEVE did not happen.

No fatalities related to LPG cylinders were registered for cases 1 and 2.

2.2. Cases 3 and 4: Pedrógão Grande Fire Complex, Portugal, June 2017

Pedrógão Grande Wildfire was a large fire in Portugal, possibly the second worst in Portuguese history. It caused 65 fatalities and around 200 injuries and 45328 hectares were burned. This large wildfire was caused by at least two different ignitions, on the same day, June 17th, at around 14:30h and 15:30h (local time), respectively in Escalos and Regadas. On June 17th, the Portuguese Institute for Sea and Atmosphere (IPMA) registered 80% of the Portuguese territory having dry conditions. The accumulated precipitation was close to the lowest in the period registered (1970-2017). The Fire Weather Index (FWI) was 26, which means a very high risk (Ribeiro et al., 2020; Tedim et al., 2020; Viegas et al., 217).

2.2.1. Case 3

In the early morning of the 18th a blind person who lived alone in a house in Balsa, did not realize that the fire had ignited an annex of the house where a gas cylinder was kept. The subsequent explosion destroyed that part of the house where the lady lived and killed her (Viegas et al., 2017).

2.2.2. Case 4

In the fire zone, near Louriceira, there was a motorhome that was used for summer vacation by an immigrant. On June 20th, the fire reached the motorhome at around 17:00h. An explosion was heard by firefighters that were nearby and they saw a dense smoke spreading upwards. A save and rescue team was sent, but they soon realized that a cylinder burst had happened. Inside the motorhome there were two mobile LPG cylinders. The first cylinder burst and became fragmented. The second one was hit by the burst that created a hole in cylinder´s surface causing LPG release and burning until the cylinder became empty (Viegas et al., 2017).

2.3. Cases 5 - 7: October Wildfire, Portugal, October 2017

Due to the long dry season, the same cited in case 3, combined with the Ophelia Hurricane (level 2-3 in the Saffir-Simphson scale), which caused powerful winds (50 $km \cdot h^{-1}$), many ignitions occurred on October 15th, leading to fast fire spread in multiple locations. October 2017 was the warmest since 1931 and the driest since 1997. In 24 hours, 220 thousand hectares were burned. On this day, 10% of moisture content of fine forest fuels was registered and in some places values close to 5% were found. The dry season, powerful winds and the low moisture content triggered a large wildfire, resulting in the largest burned area registered in Portugal. The FWI was 82 (maximum risk) and 532 ignitions were registered on October 15th. This wildfire caused 51 fatalities (Viegas et al., 2017, 2019)

Cases 5, 6 and 7 happened during the October Wildfire.

2.3.1. Case 5

In Oliveira do Hospital, a house on a hill was reached by a fire spreading very fast up the hill. The house had walls built with stone. The kitchen and its roof were totally destroyed and only the stone walls were left standing. After visiting the house ruins, a cylinder burst was suggested by the research team as the cause for the greater destruction. A fatality that happened in this house may have been related to the burst (Viegas et al., 2019).

2.3.2. Case 6

Around 16:00h, the wildfire had reached a small village called Vale do Laço. Citizens and firefighters were trying to save themselves, their houses and their belongings. A house nearby, situated on a slope and close to forest fuels, was affected by the wildfire. There were two brothers living there. It wasn't until around 20h, in the aftermath of the fire, that firefighters and habitants mentioned a previous suggestion made to the two brothers, asking them to leave and go into the town. However, the brothers had declined this advice and remained at home. They later observed smoke coming from the attic, probably caused by an ember that entered through an open window. They tried to extinguish it, but unsuccessfully which led to one fatality. On the day after, during the fire aftermath, an LPG cylinder burst destroying a large part of the house, but fortunately without causing casualties (Viegas et al., 2019).

2.3.3. Case 7

In Oliveira do Hospital, a warehouse was severely damaged by fire. 21 LPG cylinders with a volume of approximately 0.026 m^3 each were found. The cylinder´s size is usually the domestic size. It can be filled with up to 13 kg of LPG if it is butane or up to 11 kg of propane. Thus, up to 271 kg of LPG was stored, and this very large amount of energy caused great concern and damage to the surrounding structures when the various cylinders exploded. In this case, only the destruction of infrastructure was observed (Viegas et al., 2019).

2.4. Cases 8 e 9: Benitatxell Fire, Spain, September 2016

This fire is a consequence of an arsonist, on a day with a temperature of 35 ºC, relative humidity below 25% and wind gusts of 52 $km \cdot h^{-1}$. During this fire, around 1400 persons were evacuated, 470 received medical care, and 200 structures were affected by fires, but only three structures were severely damaged. The burned area was 898 hectares (Caballero et al., 2019; Rodríguez-García et al., 2022; Vacca et al., 2020).

Two LPG tanks placed nearby forest fuels were affected by the fire. In both cases jet fires were registered, being both LPG tanks equipped with PRD that were able to prevent the BLEVE (Caballero et al., 2019; Scarponi et al., 2020).

2.5. Cases 10 and 11: Mati Fire, Greece, July 2018

This wildfire is cited as the most lethal natural disaster in the history of the Modern Greek state. The wildfire broke out in the forest surroundings of the Ntaou region on Peneli Mountain, approximately 20 km northeast of Athens. On July 23rd, the temperature was nearly 40 ºC, relative air humidity was 19% and wind gusts were up to 100 $km \cdot h^{-1}$. The fire caused 100 fatalities, 200 people injured and 998 structures were destroyed (Caballero et al., 2019; Efthimiou et al., 2020; Molina-Terrén et al., 2019; Palmos et al., 2021; Tedim et al., 2020; Vacca et al., 2020).

During this fire, several explosions were reported and at least two LPG related cases were registered. The first one (case 10) is related to an LPG tank with at least 1 m3 exposed to fire. Case 11 was related to a mobile cylinder. Both vessels were found seriously damaged (Caballero et al., 2019).

2.6. Case 12: Llutxent, Spain, August 2018

This fire began on August 6th on a slope in the municipality of Llutxent. The ignition was caused by a thunderstorm and five fires were registered at the same time. The burned area was 3270 hectares, 163 persons were evacuated, 50 structures were affected and 10 houses were destroyed. The fire was completely extinguished by August 13th and no fatalities were reported (Caballero et al., 2019).

Five LPG mobile cylinders were burned during the fire and were found on a porch. BLEVE and jet fire were not reported, which may be explained by residual amount of LPG in the cylinders.

2.7. Case 13: Quinta do Colaço Fire, Portugal, August 2015

This fire occurred during the summer of 2015, in the District of Coimbra, reaching the municipalities of Almalaguês, Ceira, Semide and Rio de Vide. The burned area was 5500 hectares. 722 civil protection agents and firefighters worked to suppress the fire while they kept receiving new alert calls. The fire broke out in Quinta do Colaço around 12:42h. Unfortunately at 16:13h, the air support reported another 7 spot fires, which were suppressed by 7 fire trucks (Almeida, 2015).

A small building in a hill, probably used as a workshop and close to trees was affected by fire. Gas cylinders were placed inside the building and one of them burst. In principle, those cylinders were used to do metallurgic works using acetylene and oxygen. The cylinders were seriously damaged, and it was not possible to identify the fluid previously stored in them. The small building collapsed after the exposure to the fire and BLEVE (Almeida, 2015).

2.8. Case 14: Calabasas Fire, The USA, June 2016

During the summer of 2016 a brush fire occurred threatening thousands of homes in Calabasas. The burned area was around 208 hectares. Due to the fire, mandatory evacuations at Calabasas Highlands, Eddingham and Adamsville and voluntary evacuations in adjacent areas forced around 5000 people to leave their homes. The fast-moving wildfire swept through hills in Calabasas, it reached a preschool complex, burning outbuildings and heating a propane storage tank that caused a jet fire (Bartholomew 2016; Weber 2016; Scarponi et al. 2020).

3. Recommendation

Through the information gathered in the cases of accidents related to gas stored at WUI, we found some unsafe practices that occurred in more than one case, which should not be done. The accidents could be avoided through good practices carried out by the users, for instance: place the cylinder at a safe distance from the forest and artificial fuels; only one cylinder should be stored; and forest fuels (and other types of fuels) in the house´s surroundings should be eliminated.

Steel cylinders that are still being traded without PRD are not recommended to be used in houses that might be exposed to wildfires. For domestic applications we encourage the use of steel cylinders filled with butane and always with PRD coupled to the valve.

A protection made with a non-combustible fabric, low cost and easy to build was suggested by Barbosa et al. 2022

The users should consider the eventual jet fire direction through the PRD opening and its length before placing the cylinder. These safe practices may avoid future LPG accidents at the WUI.

4. References

Almeida, M.A. de F.B. de, 2015. Relatório resumo do Incêndio da Quinta do Colaço (Almalaguês).

Barbosa, T.F., Reis, L., Raposo, J., Viegas, D.X., 2022. A Protection for LPG Domestic Cylinders at Wildland-Urban Interface Fire. Fire 5, 63. https://doi.org/10.3390/ fire5030063

Bartholomew, D., 2016. Old Fire in Calabasas burns more than 500 acres, threatens thousands of homes [WWW Document]. Los Angeles Dly. News. URL https://www.dailynews.com/2016/06/04/old-fire-in-calabasas-burns-more-than-500-acres-threatens-thousands-of-homes/ (accessed 5.13.22).

Caballero, D., Sjöström, J., Pastor, E., 2019. Inventory of pattern scenarios. Wuiview 1–70.

Casal, J., Salla, J.M., 2006. Using liquid superheating energy for a quick estimation of overpressure in BLEVEs and similar explosions. J. Hazard. Mater. 137, 1321–1327. https://doi.org/10.1016/j.jhazmat.2006.05.001

Efthimiou, N., Psomiadis, E., Panagos, P., 2020. Fire severity and soil erosion susceptibility mapping using multi-temporal Earth Observation data: The case of Mati fatal wildfire in Eastern Attica, Greece. Catena 187, 104320. https://doi.org/10.1016/j.catena.2019.104320

Hemmatian, Behrouz, Casal, J., Planas, E., 2017. A new procedure to estimate BLEVE overpressure. Process Saf. Environ. Prot. 111, 320–325. https://doi.org/10.1016/j.psep.2017.07.016

Hemmatian, B., Planas, E., Casal, J., 2017. Comparative analysis of BLEVE mechanical energy and overpressure modeling, Process Safety and Environmental Protection.

IPMA, 2016. Análise Preliminar do Período 5 a 10 Agosto 2016 na Madeira [WWW Document]. URL https://www.ipma.pt/pt/media/noticias/news.detail.jsp?f=/pt/media/noticias/arquivo/2016/madeira-5-10-ago-2016.html (accessed 3.2.22).

Molina-Terrén, D.M., Xanthopoulos, G., Diakakis, M., Ribeiro, L., Caballero, D., Delogu, G.M., Viegas, D.X., Silva, C.A., Cardil, A., 2019. Analysis of forest fire fatalities in Southern Europe: Spain, Portugal, Greece and Sardinia (Italy). Int. J. Wildl. Fire 28, 85–98. https://doi.org/10.1071/WF18004

Palmos, D., Papavasileiou, C., Papakitsos, E.C., Vamvakeros, X., Mavrakis, A., 2021. Enhancing the environmental programmes of secondary education by using web-tools concerning precaution measures in civil protection: The case of Western Attica (Greece). Saf. Sci. 135, 105117. https://doi.org/10.1016/j.ssci.2020.105117

Planas-Cuchi, E., Salla, J.M., Casal, J., 2004. Calculating overpressure from BLEVE explosions. J. Loss Prev. Process Ind. 17, 431–436. https://doi.org/10.1016/j.jlp.2004.08.002

Ribeiro, L.M., Rodrigues, A., Lucas, D., Viegas, D.X., 2020. The impact on structures of the pedrógão grande fire complex in June 2017 (Portugal). Fire 3, 1–22. https://doi.org/10.3390/fire3040057

Rodríguez-García, E., Santana, V.M., Alloza, J.A., Ramón Vallejo, V., 2022. Predicting natural hyperdense regeneration after wildfires in Pinus halepensis (Mill.) forests using prefire site factors, forest structure and fire severity. For. Ecol. Manage. 512. https://doi.org/10.1016/j.foreco.2022.120164

Scarponi, G.E., Pastor, E., Planas, E., Cozzani, V., 2020. Analysis of the impact of wildland-urban-interface fires on LPG domestic tanks. Saf. Sci. 124. https://doi.org/10.1016/j.ssci.2019.104588

Tedim, F., Leone, V., Mcgee, T.K., 2020. Extreme Wildfire Events and Disasters. https://doi.org/10.1016/B978-0-12-815721-3.00002-3

Vacca, P., Caballero, D., Pastor, E., Planas, E., 2020. WUI fire risk mitigation in Europe: A performance-based design approach at home-owner level. J. Saf. Sci. Resil. 1, 97–105. https://doi.org/10.1016/j.jnlssr.2020.08.001

Viegas, D.X., Figueiredo Almeida, M., Ribeiro, L.M., Raposo, J., Viegas, M.T., Oliveira, R., Alves, D., Pinto, C., Jorge, H., Rodrigues, A., Lucas, D., Lopes, S., Silva, L.F., 2017. O complexo de incêndios de Pedrógão o Grande e concelhos limítrofes, Iniciado a 17 de junho de 2017.

Viegas, X., Almeida, M.F., Ribeiro, M., Almeida, M.A., Raposo, J., Viegas, M.T., Oliveira, R., Alves, D., Pinto, C., Rodrigues, A., Ribeiro, C., Lopes, S., Jorge, H., Viegas, C.X., 2019. Análise Dos Incêndios Florestais Ocorridos a 15 De Outubro De 2017 - Principais incêndios e resposta operacional.

Weber, C., 2016. Evacuations canceled near Calabasas wildfire [WWW Document]. Press Democr. URL https://www.pressdemocrat.com/article/news/evacuations-canceled-near-calabasas-wildfire/?artslide=1 (accessed 5.22.22).