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Mobile LPG cylinders at WUI fires: an alternative to avoid accidents

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Abstract

Wildland fires are frequent events worldwide, particularly in the European-Mediterranean region, USA, and Australia. These fires have been more frequent and intense in recent years due to climate changes and may cause significant damage, especially when reaching theWildland-Urban Interface (WUI) areas. The presence of liquefied petroleum gas (LPG) cylinders may cause severe events in WUI areas, as occurred in Portugal during the large wildfires of 2017, which could have been avoided if the cylinders were protected. Devices for protecting the parts of houses under WUI fire were previously presented, but a protective device for cylinders was not. In this work, a protective device for LPG cylinders made with a thin fabric with an aluminum coating on the external face was tested in laboratory and field conditions. The cylinder and the fabric were equipped with thermocouples and heat flux sensors attached to their surfaces. The tests showed that the device gave effective protection to the cylinder, decreasing the radiative heat flux that reaches it and keeping it in a safe condition when exposed to a fire; consequently preventing extreme behavior such as an explosion.

1. Introduction

Wildfires cause huge socio-economic damages, particularly when they occur in Wildland-Urban Interface (WUI) areas. These fires are becoming more frequent and severe in recent years due to climate change (Barbosa et al., 2022; Oliveira et al., 2020; Pastor et al., 2020; D. X. Viegas et al., 2021). Liquefied petroleum gas (LPG) cylinders are widely used in many countries for different domestic purposes, such as cooking, heating water, and keeping homes warm (Heymes et al., 2013; Scarponi et al., 2020) . Given the fact that the majority of rural WUI areas do not have a gas distribution network, the presence of mobile gas cylinders near each house is common. When a wildfire occurs nearby, the cylinders become a relevant hazard for the people and structures because of the enormous amount of energy stored.

Accidents related to LPG cylinders have been registered in Portugal during at least five large fires and in other countries (Table 1). Regarding the effects caused by an LPG cylinder's explosion, experimental tests with an LPG cylinder were carried out by other authors (Stawczyk, 2003; Tschirschwitz et al., 2017): the flying projectiles could reach up to 300 meters from the initial position; the overpressure presented high values at distances shorter than 10 meters from the explosion. These effects may jeopardize the safety of persons and structures in the surroundings.

Table 1: Summary of events related to LPG stored at WUI

id	Place	Type	Year	Event	Reference
1	Quinta do Colaço, Portugal	Cylinder	2015	BLEVE	(Almeida, 2015)
2	Funchal, Madeira, Portugal (2 cases)	Cylinder	2016	BLEVE	(Barbosa et al., 2022; Caballero et al., 2019; Scarponi et al., 2020)
3	Calabassas, California, USA	Domestic tank	2016	Jet fire	(Scarponi et al., 2020;Bartholomew, 2016)
4	Benitatxell, Spain (2 cases)	Domestic tank	2016	Jet fire	(Scarponi et al., 2020; Caballero et al., 2019)
5	Louriceira, Portugal	Cylinder	2017	BLEVE	(Viegas et al., 2017)

6	Oliveira do Hospital, Portugal (2 cases)	Cylinder	2017	BLEVE	(Barbosa et al., 2022; Viegas et al., 2019)
7	Vale do Laço, Portugal	Cylinder	2017	BLEVE	(Viegas et al., 2019)
8	Balsa, Portugal	Cylinder	2017	BLEVE	(Viegas et al., 2017)
9	Mati, Greece (2 cases)	Domestic tank	2018	Jet fire	(Scarponi et al., 2020)
10	Llutxent, Spain	Cylinder	2018	Jet Fire	(Caballero et al., 2019)

Protective devices were presented to protect house walls and roofs in a WUI fire case (Barbosa et al., 2022; Takahashi, 2019; C. Viegas et al., 2021) . However, the LPG cylinders are commonly placed outside of the houses as a safety recommendation. Thus, cylinders should also be protected to avoid accidents.

To fill the gap related to the LPG cylinder's protection, this study presents a light and cheap protection for LPG cylinders capable of keeping them in a safe condition when exposed to WUI fires (Barbosa et al., 2022; Takahashi, 2019; C. Viegas et al., 2021).

2. Materials and Methods

2.1. The protective device

The protective device (PD1) was manufactured with two main parts. The first and most external one is made with a fabric manufactured with fiberglass with an aluminum coating on the external face to decrease the radiative heat flux. The fabric is classified "A" (non-combustible) according to the European fire classification for construction products (EN 13501). The second one is a structure made with a square metal tube, with geometry the same as a cube, with opened faces and a handle on top used for moving. On one face, near the bottom, there is a small vent square of 15 x 15 cm to pass the gas tube. This tube was wrapped in the fabric. The goal of the protection device is to reduce the heat flux that reaches the cylinder and prevent the LPG stored in the cylinder from getting warm. It is an alternative system for people living in rural areas without access to an industrialized or commercial protection system; it is easy to be built, cheap, light, mobile, and ergonomic. The protective device was built for cylinders of 11 kg of propane or 13 kg of butane and manufactured in accordance with European codes (EN 12245:2009+A1; EN 1442). It has the following dimensions: 65 cm in height and 45 cm in length and width. The cost of the protection was 56 Euros, and the total system weight was 6.4 kg.

2.2. Laboratory tests

Seventeen tests were carried out (Table 2), sixteen at the laboratory and one in the field. The laboratory tests were performed in the Forest Fire Research Laboratory (LEIF) in Lousã, Portugal, at four different flame distances, to evaluate the protection efficiency related to the heat flux at flame distances similar to those found in fires near rural houses. The field test was aimed at evaluating the cylinder protection in a real fire scenario and validating the laboratory tests.

Table 2: Summary of the tests

Test	Reference	Distance (m)	Content Moisture (%)	Room Temperature (ºC)
1	F25-1	0.25	16	24.3
2	F25-2	0.25	11.5	19.7
3	F25-3	0.25	11.5	19.5
4	F50-1	0.5	14.3	15.1
5	F50-2	0.5	11.5	19.7
6	F50-3	0.5	11.5	19.7
7	F75-1	0.75	16	25.6
8	F75-2	0.75	11.5	19.7
9	F75-3	0.75	11.5	19.7
10	F100-1	1	16	22.5
11	F100-2	1	10	20
12	F100-3	1	10	19.8
13	Ref25	0.25	16	11.9
14	Ref50	0.5	16	12

15	Ref75	0.75	16	11.6
16	Ref100	1	16	11.8
17	PSS	surrounded	40	21

The cylinders were placed at four different distances ”D”. These distances from the flames used were 0.25, 0.5, 0.75, and 1 meter. For each test were used 10 kg of shrubs. Shrubs were used according to previous studies placed (Pinto et al., 2017; Rodrigues et al., 2019; D. X. Vegas et al., 2021; Viegas et al., 2006), and it is the same fuel present in the field test. This fuel was in a basket with a volume of 1 m^3. Reference tests with the cylinder and without protection were performed to obtain the heat flux and temperature on the cylinder’s surface.

The cylinders were equipped with the temperature and heat flux sensor IHF01 Hukseflux attached to the external surface (FI 1, TI 1) halfway up the cylinder’s height; the same was attached to the external surface of the fabric (FI 2, TI 2) (Figure 1). Two thermocouple type K were used; the first thermocouple was attached to the floor at 10 cm from the fuel basket (TI 3); and the second was attached to a wall surface, far from the influence of the flame (TI 4). The flux sensors were connected to the model 9211 (±80 mV) from National Instruments (NI), and it was plugged into the chassis 9174, also from NI. These instruments allow for the continuous measurement of the signal from the sensor with a frequency of 1 Hz, being able to load and process the data directly to a computer. The thermocouples were connected to a model 9213 from NI.

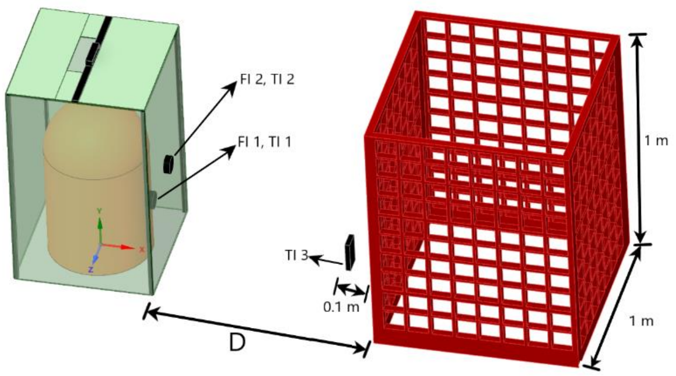


Figure 1- Schematic drawing of laboratory test: protective device at the four distances “D” from the fuel basket, and the instrument’s position on the cylinder’s surface (FI 1, TI 1), fabric’s surface (FI 2,TI 2), and thermocouple 3 – credit Barbosa et al. (2022).

2.3. Field Test

In the field test, the instrumental apparatus used was the same as in the laboratory tests. The field test was performed on a slope of 30% covered by shrubs with less than 50 cm in height and an average moisture content of 40%. The LPG cylinder was covered by the protective device and surrounded by shrubs. The ignition was made on the bottom of the hill (Figure 2 b).

(a) (b)

Figure 2- (a) Laboratory teste, and (b) field test

3. Results and discussion

3.1. Laboratory tests

A significant difference was found (Figure 3) related to the heat flux that reached the cylinder´s surface and the fabric´s surface, showing that the high level of heat flux decreased, and this factor is decisive in keeping the conditions safe in a fire scenario. If there is no high heat flux reaching the vessel, the fluid pressure and temperature will not be high enough to produce an explosion.

The flux sensor attached to the surface cylinder showed values with no significant changes. For the test at 0.25 m from the flames, the difference related to the heat flux that reaches the cylinder´s surface and the fabric´s surface was up to 10 kW· m^{-2} (87%), which shows that the protection device works even at a short distance from the flames. The heat flux registered in the reference tests (Ref) without protection, and the flux on the cylinder´s surface under protection (Cylinder), show a significant difference in the flux that reaches the cylinder.

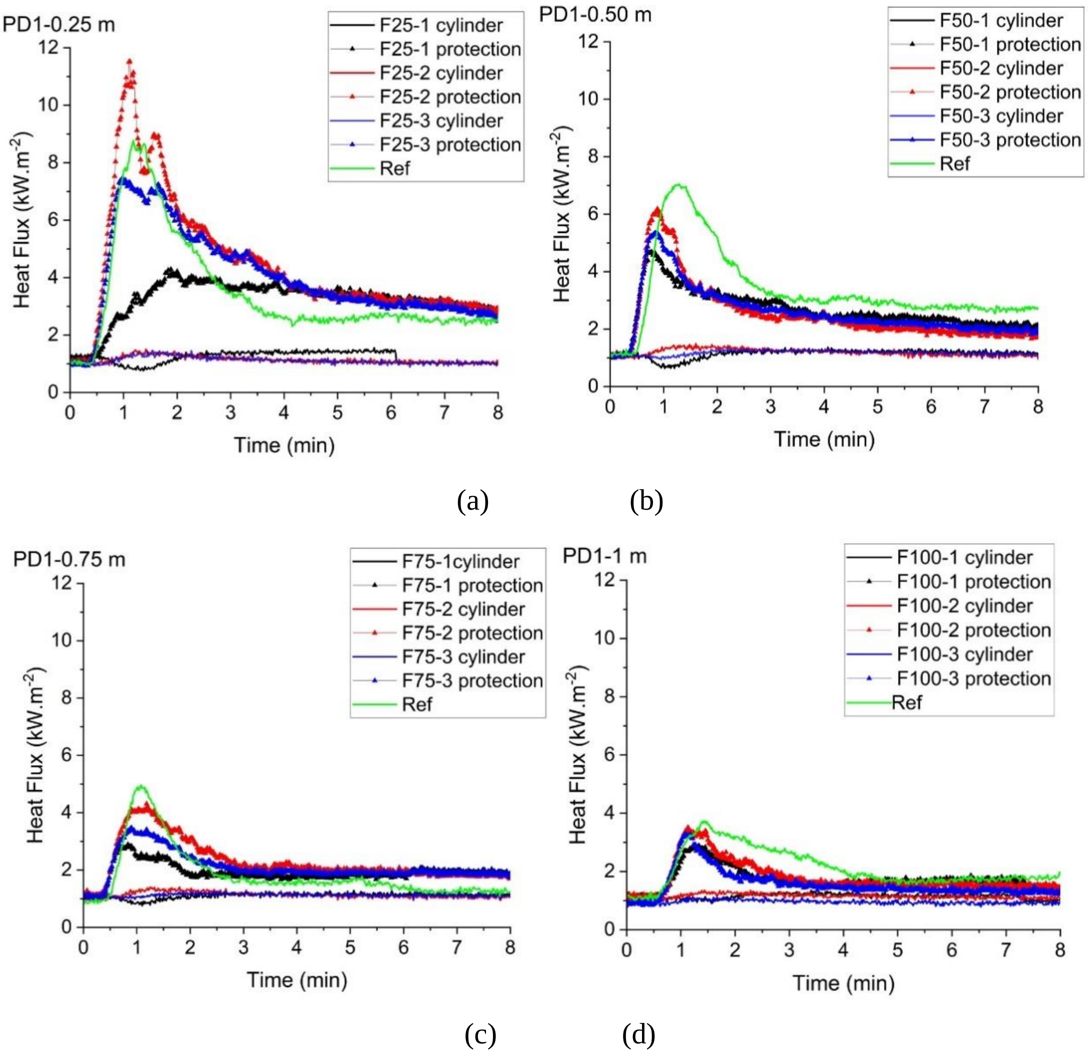
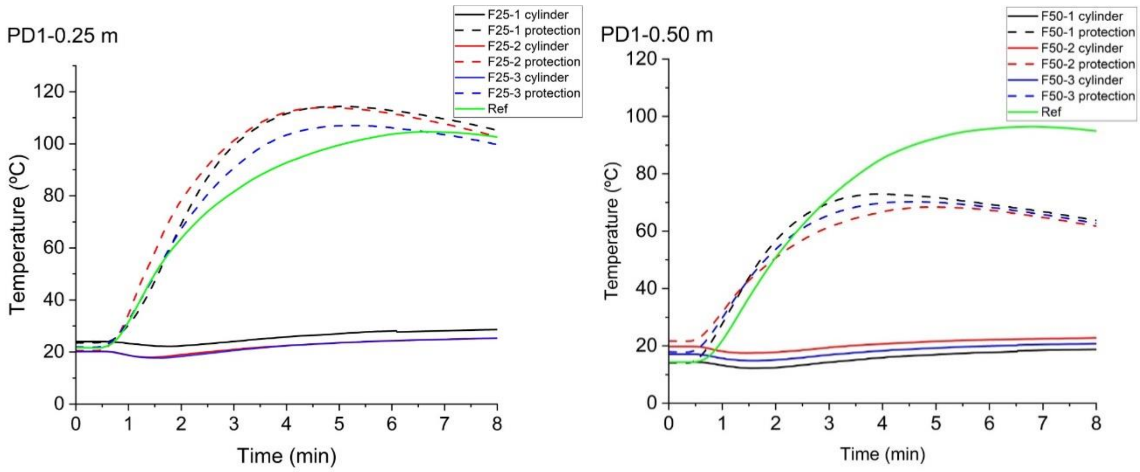


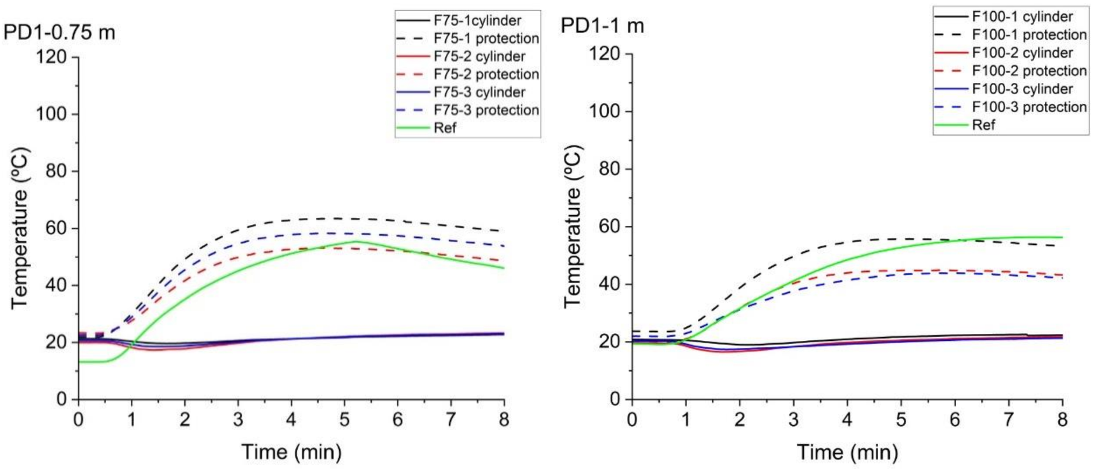
Figure 3- Heat flux on the protection, cylinder, and reference tests at (a) 0.25, (b) 0.50), (c) 0.75, and (d) 1 m from the basket fuel

In all tests with the protective device and during the time of fire exposure, the cylinder surface temperature remained close to the laboratory environmental temperature (Figure 4). Thus, the LPG cylinder was not heated and stayed under safe conditions, even when the fabric was reached by the intense heat flux of up to 12 kW· m^{-2} .

Figure 4 shows the temperature on the cylinder´s surface (Cylinder) and the temperature on the fabric´s surface (Protection). There is a great difference between the cylinder and fabric surfaces, reaching 80 °C. The cylinder´s surface temperature was kept at safe values, close to the laboratory temperature, and below the temperature needed to cause high pressure and open a pressure relief valve (26 bar). The temperature registered in the reference tests (Ref) without protection and the temperature on the cylinder´s surface under protection (Cylinder) shows a significant difference in the cylinder´s temperature, up to 80 °C (Figure 4).



(a) (b)



(c) (d)

Figure 4- Temperature profile in the laboratory, on protection, cylinder, and reference tests at (a) 0.25, (b) 0.50), (c) 0.75, and (d) 1 m from the basket fuel

3.2. Field Test

In the field test, the behavior of the cylinder and protection was similar to the laboratory tests. There was a large difference between the temperatures of the cylinder´s surface and the fabric’s surface, and the same occurred for the heat flux (Figure 5). On the outer face of the protection, the thermal radiation peak was 7 $kW \cdot m^{-2}$ and the peak temperature was 174 °C; on the face of the cylinder, the radiation peaked at 2.5 $kW \cdot m^{-2}$, and the surface temperature had a maximum of 51 °C.

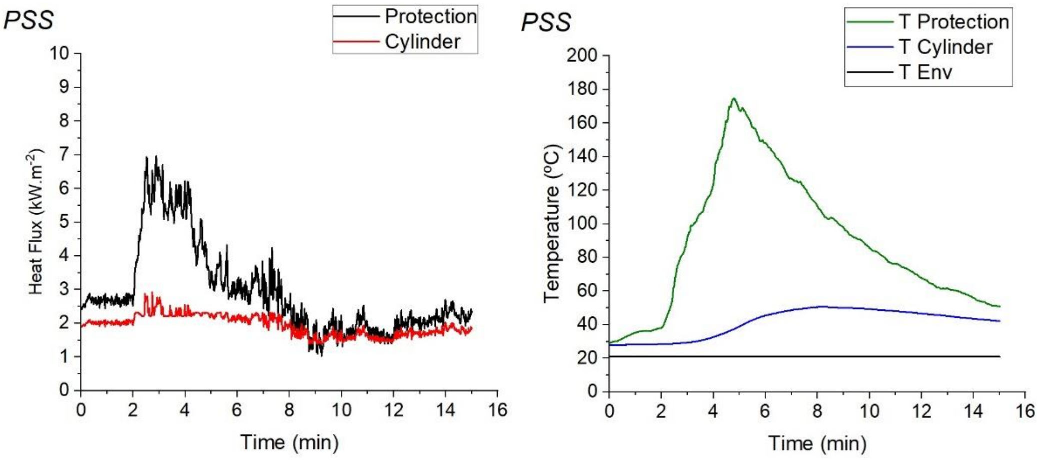


Figure 5- Field test (PSS): (a) Heat Flux and (b) temperatures on the surfaces of the protection and cylinder

4. Conclusion

WUI fires are frequent events, and they may cause accidents related to LPG stored. In this work, the efficiency of a protective device manufactured in an insulating fabric with a reflective external surface to cover an LPG cylinder and block the heat flux when a WUI fire occurs was assessed.

Laboratory and field tests were carried out with the protective device at different distances from the fire to find the block rate of the heat flux and determine if the protective device works in a real fire event.

The protective device could block up to 87% of the heat flux and keep the cylinder's temperature close to room temperature even under high heat flux and at a short distance from the flame.

Regarding the accidents mentioned, the protective device tested in this work could have avoided these burst vessel cases. It shows the importance of a protection system and how positive its use can be in avoiding the heating of the fluid, and hence the material rupture, decreasing the probability of extreme events, such as a BLEVE. The proposed protective device is an alternative to prevent accidents related to LPG cylinders in WUI fires.

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