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RISK ANALYSIS OF LPG TANKS AT THE WILDLAND-URBAN INTERFACE

Volumen I

Memoria

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ABSTRACT

In areas of wildland-urban interface (WUI), especially residential developments, it is very common to see liquefied petroleum gas (LPG) tanks, particularly with a higher ratio of propane, in surface installations serving homes. The most common tanks are between 1 and 5 m^3 of capacity, but smaller ones of less than 1 m^3 are more frequent. In case of accident, installations may be subject to fires and explosions, especially in those circumstances where legal and normative requirements allow very close exposure to flames from vegetable fuel near LPG tanks.

In this project, it is intended to do a comprehensive diagnosis of the problem, addressing the compilation of information on real risk scenarios in historical fires. First, a preliminary presentation of the properties and characteristics of liquefied petroleum gas will be exposed. Its physical and chemical properties, production methodology, pressure and temperature diagrams and important considerations will be defined when using this type of substances in a storage tank of a certain volume.

Next, a review of the situation of the existence of LPG tanks in the urban forest interfaces will be exposed. In this case, the main accidents caused by problems with the storage of LPG will be analyzed taking into account the relevance of BLEVE events in this type of incidents. To do this, the main scenarios that could take place in the event of a fire will be presented.

Next, the existing legislation on the storage of LPG in these environments in some Mediterranean countries will be studied. In order to develop a comprehensive analysis, the main safety measures and distances will be considered, as well as the awareness of the possibility of vegetation material in the vicinity of LPG storage tanks, which is the main problem that will arise in a possible BLEVE scenario in case of fire. To finalize and facilitate understanding, a comparative table will be included with the aim of visualizing the main advantages and legislative deficiencies between the different countries.

Following, the state of the art in terms of modelling LPG accidents at the WUI will be reviewed. Trying to simulate and predict this type of scenarios, it will see the models normally chosen to obtain the tolerable values selected and the answers obtained in each case.

Finally, several fire scenarios will be simulated by means of a CFD tool (FDS, Fire Dynamics Simulator). In these simulations, the wind velocity and the distance of the combustible vegetal mass to the tank will be controlled in a WUI fire in which there is a tank of fixed dimensions. The temperature and the heat flow in each of the scenarios will be obtained, and the differences among the location of the sensors and the characteristics of the scenario will be analyzed.

As a conclusion, it has been observed that there is a great amount of variables that are not contemplated by the regulatory organisms and that the existing legislation does not guarantee the safety of the population in this type of environment. From the simulations results, variables as temperature should be studied for further characterizations.

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1. Preface

1.1 Master Thesis purpose

The main objective of this project is to characterize the hazards involving LPG facilities in the wildland-urban interface (WUI) through a detailed analysis of the problem.

This work intends to increase awareness of the risk that these types of interfaces have in our society as well as to make a real and deep review on the existing means and knowledge of this subject.

1.2 Scope and Purpose

In this project, a comprehensive diagnosis of the problem is made, compiling information on real risk scenarios in historical fires. A study of current technical regulations and identification of weaknesses will be done, followed by a bibliographic analysis of the state of art in this matter. Finally, the analysis of fire risk using the FDS simulation tool will be performed in order to get quantitative insights about the LPG tanks fire exposure at the WUI.

2. LPG characterization

LPG is obtained from petroleum and has two origins: approximately 60% is recovered during the extraction of natural gas and oil from the earth, and 40% is produced during the refining of crude oil [9]. The composition of the petroleum is mainly of carbon (93% – 97%), hydrogen (10% - 14%), nitrogen (0.1% - 2%), oxygen (0.1% - 1.5%) and sulphur (0.5% - 6%) with a few trace metals making up a very small percentage of the petroleum composition. The overall properties of each different petroleum source are defined by the percentage of the four main hydrocarbons found within petroleum as part of the petroleum composition. The percentages can vary greatly, giving the crude oil a quite distinct compound depending on geographic region: paraffin (15% - 60%), napthenes (30% - 60%), aromatics (3% to 30%), with asphaltics making up the remainder [21].

The main composition of LPGs are hydrocarbons containing three or four carbon atoms. LPG is defined as a mixture of butane, isobutene, propane, propylene, butylene and other hydrocarbons of low molecular weight that is refined from petroleum and depending on the source of the LPG and how it has been produced, components other than hydrocarbons may also be present. Like all fossil fuels, LPG is a non-renewable source of energy. It is a safe, clean burning, reliable and a high calorific value fuel [2], [3].

Liquefied petroleum gas is also a gas used in industry as a fuel gas for heating and it is popularly known by its abbreviation or short form which is LPG. Sometimes it is used for carburization of steel, flame heating, flame gouging, flame hardening, flame cleaning, and flame straightening [22].

The production of LPG in the world has grown at a rate of 3.3% per year accumulated during the period from 1991 to 2000, a year in which production grew by 38% compared to 1991 [11]. The domestic sector is one of the most notorious applications of LPG, with almost 45% of world demand. However, transport is one of the fastest growing sectors, accounting for almost 9% and 23.7 million tons of global consumption in 2011 [Hart et al., 2011]. As in the case of LNG (Liquefied Natural Gas), world consumption has increased significantly in recent years, the increase in 2000 compared to 1990 was 45%.

Liquid petroleum gases were discovered in 1912 when Dr. Walter Snelling realized that these gases could be changed into liquids and stored under moderate pressure. From 1912 and 1920, LP gas uses were developed, where the LPG industry began shortly before World War 1. At that time, a problem in the natural gas distribution process cropped up. Gradually facilities were built to cool and compress natural gas, and to separate the gases that could be turned into liquids (including propane and butane) [22]. Finally, LPG was sold commercially by 1920.

When gas is drawn from the earth, it is a mixture of several gases and liquids. Commercial natural gas is mainly composed of methane. However, it also contains ethane, propane and butane in accordance with the specifications for natural gas in each country in which it is distributed. Therefore, before natural gas is marketed, some LNGs, including LPG's are separated out, depending on the wetness of the gas produced: LNGs represent 1 to 10% of the unprocessed gas stream. Worldwide, gas processing is the source of approximately 60% of LPG produced.

In an oil refinery, LPG's are produced at various stages: atmospheric distillation, reforming, cracking and others. The LPG produced will be between 1 and 4% of crude oil processed. This yield will depend on the type of crude oil, the degree of sophistication of the oil refinery and the market values of propane and butane compared to other oils products. Worldwide, refining is the source of approximately 40% of LPG produced [8].

Although tied to the production of natural gas and crude oil, LPG has its own distinct advantages and can perform nearly every fuel function of the primary fuels from which it is derived. The fact that it can be easily liquefied makes LPG a highly versatile energy alternative and thanks to a wide variety of packaging and storage options, LPG has numerous fuelling applications, as it was mentioned before.

The distribution of the gas is of great importance when it comes to obtaining LPG, as it could be observed in *Figure 1*. In first place, the production of field grade LPG is the result of the treatment of LNG's. This treatment is necessary to produce oils that are suitable for transport to refineries and natural gases that correspond with commercial specifications. While crude oil is transported from the production sites to refineries by tankers or pipelines, LPG is transported to storage terminals by large LPG carriers, pipelines or train.

Butane and propane can also result from the oil refining processes. LPG storage terminals store products that are imported in large quantities. The LPG is then delivered by train, road, coastal tanker or pipeline to cylinder filling plants and intermediate-size storage areas. Cylinders are filled with butane and propane at bottling plants. LPG is generally stored in pressurized tanks (vessels or spheres) in intermediary storage centers.

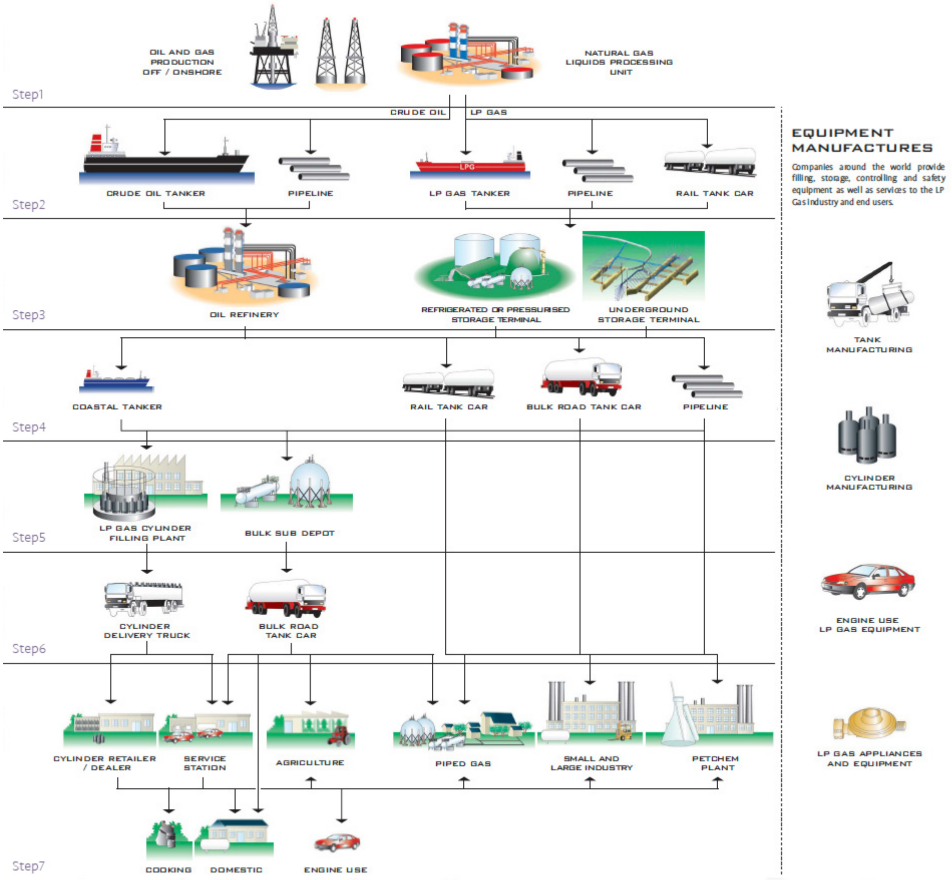

Figure 1. LPG distribution [8]

LPG can be transported virtually anywhere, either in cylinders or bulk. Trucks transport butane and propane cylinders from the bottling plant to retailers, as well as to private and professional customers. Meanwhile, small bulk trucks distribute LPG from the storage centers to various consumers. LPG is easily available to end users through cylinder sales points such as commercial stores or service stations close to their locations. Customers requiring larger volumes can purchase LPG in bulk [8].

Being more specific with regard to the properties of LPG, liquefied petroleum gas consists of light hydrocarbons with a vapor pressure exceeding 40 psia at 37.78°C and the examples of these include propane, propylene, butane (normal or isobutane), and butylene (including isomers) [3]. The most common LPG's are propane and butane and both are commercialized applying the specifications established, in Spain, by BOE number 303 of 19/12/84 and number 227 of 22/09/82 [7] where LPG's proportions could vary according de following limits shown in *Table 1*:

Table 1. LPG composition [7]

Volume %		
	Commercial Propane	**Commercial Butane**
Propane (C3)	Minimum of 80%	Maximum of 20%
Butane (C4)	Maximum of 20%	Minimum of 80%

As it was explained before, the properties of propane and normal butane (collected in *Table 2, 3 and 4*) as the main components of LPGs are very important to be established in order to maintain in the best storage conditions these flammable substances. The knowledge of these properties will allow to obtaining a greater yield:

Table 2. Properties of propane and butane [2], [3]

Property	Propane	n-Butane
Specific gravity of gas (air=1.0)	1.5	2.0
Vapor pressure at 15.56 °C, psia^{a}	105	26
Vapor pressure at 15.56 °C, psia^{a}	190	52
Boiling point, °C	-42.22	-0.56
Flash point, °C	-104.44	-60
Autoignition temperature, °C	466.11	405
LFL (%)	2.0	1.5
UFL (%)	9.5	9.0
Gross BTU/ft of gas at °F	2516	3262
IDLH	2000 ppm	
^{a}psia= pounds per square inch absolute		

LPGs are commercialized applying the specifications established, in Spain, by the normative and legislation, and the characteristic values for commercial LPG'S are summed up on *Table 3*, and for further substances characterization, CAS number of LPG is 68476-85-7 while its UN number is 1075 and CAS number for propane is 74-98-6 while CAS number for butane is 106-97-8:

Table 3. Commercial LPG characterization [12]

Value	Commercial Propane		Commercial n-Butane	
Absolute vapor pressure at 20°C	8.5 bar abs.		2.25 bar abs.	
Boiling point at atmospheric pressure	-45 °C		-0.5 °C	
Mass by volume of the gas at 20°C and atmospheric pressure (SEGADIS values)	2.095 kg/m^3		2.625 kg/m^3	
Gas density (Respect the air)	1.62		2.03	
Mass by volume of the liquid at 20 °C	506 kg/m^3		580 kg/m^3	
Liquid phase density (respect water)	0.506		0.580	
Higher calorific value	12000 kcal/kg 25140 kcal/m^3	13.95 kWh/kg 29.23 kWh/m^3	11900kcal/kg 31240 kcal/m^3	13.83 kWh/kg 36.32 kWh/m^3
Lower calorific value	10900 kcal/kg 22835 kcal/m^3	12.67 kWh/kg 26.55 kWh/m^3	10820kcal/kg 28400 kcal/m^3	12.47 kWh/kg 33.02 kWh/m^3

Related to its safety issues, LPGs do not corrode steel, copper or their alloys and do not dissolve synthetic rubbers. However, when sulfur compounds and other impurities are present in the LPG, corrosion can be a serious problem. Liquefied petroleum gas has no lubricating properties, and this fact must be taken into account when specifying LPG handling pumps, compressors, and so forth. Instead they dissolve the fats and natural rubber. LPGs are toxic and physiological disorders occur when the gas concentration in the air is high and as a consequence there is a displacement of oxygen. The LPGs are devoid of color and natural odor; therefore, in order to be able to detect by smell any leaks that may be caused, a peculiar odorant based on mercaptane is added before distribution. The odor is felt when the mixture is still in the range below the lower flammability limit [10].

As it can be check in *Table 2*, at normal temperature and atmospheric pressure, LPG is in a gaseous state. For this reason, it is very important to notify that it can be liquefied under moderate pressure or by cooling to temperatures below its atmospheric pressure boiling point but will readily vaporize upon release to normal atmospheric conditions. It is this property that permits LPG to be transported and stored in a liquid form but used in the vapor form, important fact that allows the world population grows up according energy necessities, making the transport of LPGs as a key point of worldwide population development.

Table 4. Tank pressures for LPG's [5]

Liquid Temperature (°C)	Tank Pressure (Pound per square inch gauge)	
	Propane	n-Butane
-0.56	50	0
15.56	90	11
37.78	175	37
54.44	250	65
60.00	290	80

LPG's in the liquid phase dilate by temperature more than the containers that contain them. Therefore, these must not be fully filled in order to be able to absorb the expansion differential because otherwise undesirable excess pressure would occur. The maximum filling level established (UNE-EN ISO 60250) is 85% considering the mass in volume at 20 °C. To be able to establish these storage conditions, knowing the pressure and temperature curves (*Figure 2*), as well as mass by volume if LPG (*Figure 3*) will be of crucial importance.

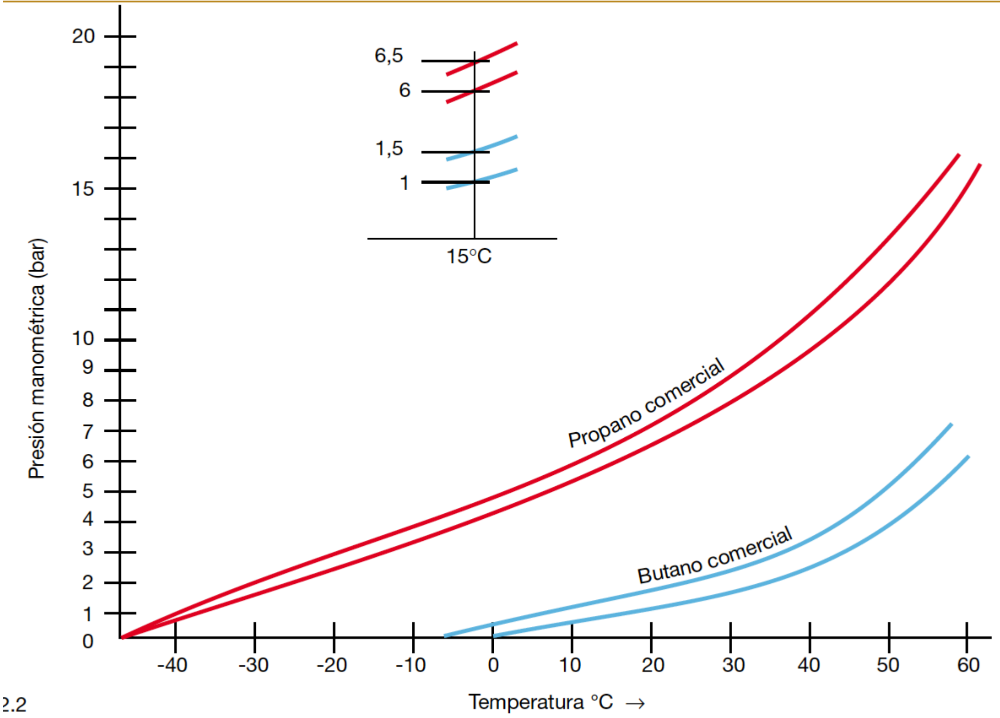

Figure 2. LPG pressure and temperature curve [10]

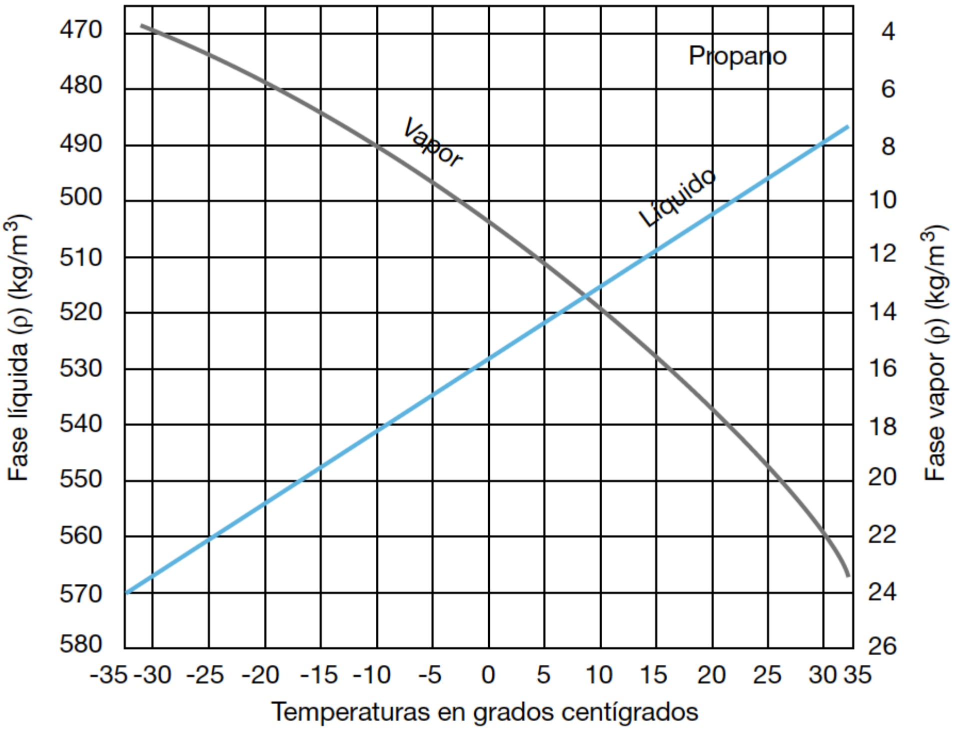

Figure 3. Mass by volume of propane (kg/m^3) [10]

Encompassing the properties seen so far, it could be pointed out that concentrated LPG vapors are heavier than air. They tend to stay close to the ground, collect in low spots and disperse less readily than lighter-than-air gases. Undiluted propane vapor is 1.5 times denser than air, and normal butane vapor is twice as dense. However, once LPG is released, it mixes with air to form a flammable mixture, and the density of the mixture becomes essentially the same as air. Natural air currents, diffusion, and dispersion will eventually dilute the mixture to below the lower flammable limit (LFL). Other characteristics of LPG include that LPG exerts a chilling effect from vaporization when released or vented to a lower pressure. This effect is known as auto-refrigeration; the liquid temperature approaches its boiling temperature at atmospheric pressure (see boiling point in *Table 2*). The density of the liquid is approximately half that of water, and thus water will settle to the bottom in LPG. Small quantities of liquid will yield large quantities of vapor. High rates of vaporization and strong turbulence will result when LPG is spilled on water or water streams are added to an LPG spill [2], [3].

Regarding its reactivity profile, LPG react with saturated aliphatic hydrocarbons, which makes it incompatible with strong oxidizing agents like nitric acid. Charring may occur followed by ignition of unreacted hydrocarbon and other nearby combustibles. The mixture of hydrocarbons is not affected by aqueous solutions of acids, alkalis, most oxidizing agents and most reducing agents. With air is highly flammable and there is not any reaction with water.

For health, its hazard effect could be measured in concentrations in air greater than 10% and cause dizziness in a few minutes. Concentrations at 1% give the same symptom in 10 min and high concentrations cause asphyxiation.

Both propane and normal butane have low boiling points. Since the boiling point of liquid propane is far below temperatures typically found in ambient conditions, propane generally does not form a liquid pool when spilled. However, liquid normal butane is more likely to remain liquid if accidentally released at low ambient or storage temperatures, due to its -0.56 °C atmospheric pressure boiling point [2].

Since LPG is stored under pressure and vaporizes readily when released, it is difficult to control leaks once they occur. The vapor cloud from a leak tends to stay close to the ground and drift downwind toward low areas. This property makes it essential that leaks be prevented, ignition sources kept at a safe distance, and vapor from leaks be dispersed before it is ignited. Wind significantly reduces the dispersion distance, that is, the size of the flammable vapor cloud, for any given leak rate.

3. LPG tanks failure events

3.1 Introduction

LPG storage tanks contain large volumes of a mixture of flammable and hazardous chemical: an apparently small accident may lead to million-dollar property loss. In last 50 years, trade organizations and engineering societies such as American Petroleum Institute (API), American Institute of Chemical Engineers (AICHE), American Society of Mechanical Engineers (ASME), and National Fire Protection Association (NFPA) have published strict engineering guidelines and standards for the construction, material selection, design and safe management of storage tanks and their accessories (AICHE, 1988; 1993; API, 1988; 1990; ASME, 2004; NFPA, 1992; UL, 1986; 1987). Most companies follow those standards and guidelines in the design, construction and operation, but tank accidents still occur [23].

When discussing the hazards of LPGs one must keep in mind the reason for using LPG in the first place. One m^3 of liquid LPG will vaporize into 245 to 275 m^3 of vapor. The heating value of LPG is 2.5 to 3 times higher than natural gas. Therefore, there is a relatively large amount of potential energy contained in a very small volume of LPG. When LPG is transported in 114 m^3 rail tank cars or stored in containers up to 680 m^3, the amount of energy available for destruction is tremendous if precautions are not taken to prevent the release of the material.

Taking the importance of using LPG in the first place as a fuel, it has to be taken into account that LPG is usually stored out of the house in pressurized cylindrical tanks of medium capacity (1 or 2 m^3) in WUI. These tanks are not protected by passive protection layer against fire but are prevented from excessive pressure by a relief valve. However, when such a tank is exposed to external fire, there is a chance that the tank will fail despite the action of the pressure relief valve. If the failure mode is catastrophic then this could lead to a boiling liquid expanding vapor explosion (BLEVE). Because LPG is flammable, a fireball is possible with the associated hazards of fire engulfment and thermal radiation. If the LPG is not ignited immediately, delayed ignition may lead to widespread fires or in some cases explosions [16].

Determining whether a heated LPG tank will entail a BLEVE is not an easy task. Variables as the liquid level and pressure inside will determine the rupture of the tank and the predictability of these accidents.

3.2 Types of incidents

The potential hazards of a LPG leakage vary depending on several factors: the size of the spill, the storage conditions, the environmental conditions and the characteristics of the site where the spill occurs.

One of the most dangerous aspects of an LPG leak is the formation of flammable clouds, which can produce an explosion and, simultaneously, a fire. Another possibility is that after the flames return to the point of origin of the leak, a pool fire, a jet fire or even a BLEVE if the flames affect the tank, can occur.

Consequence analysis in these type of situations depends on various parameters. The dominant variables such as released volume, release rate, release direction, probability of ignition, time of ignition, and events associated with ignitions are considered. A typical example of accident scenarios for LPG storage bullet catastrophic failure and various outcomes are analyzed using an event tree structure (*Figure 4)*:

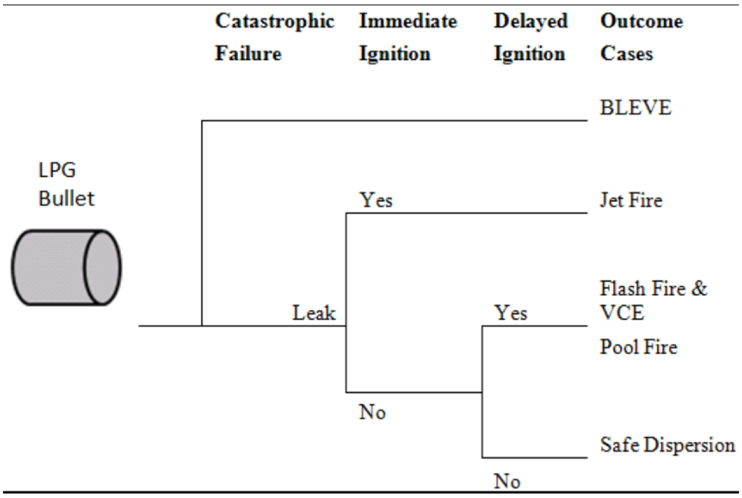

Figure 4. Event- tree LPG tank fault [24]

A scenario with a LPG failure mode could lead to different consequences due to failure of any component in the system. A catastrophic rupture of vessel or pipe causing a totally failure produces a massive release of LPG into atmosphere which results in explosion such as BLEVE if it is immediately ignited. If the scenario results in a leak with an immediate ignition, a jet fire scenario would take place. If the ignition of this leak is delayed, it will result in a pool fire (if the LPG is stored at ambient temperature and at a pressure higher than the atmospheric pressure), flash fire (it finds an ignition point the whole mass between the flammability limits will be ignited) or a confined vapor cloud explosion (the burning vapor causes a degree of "self confinement" allowing the combustion process to proceed at a speed that produces explosive overpressures) because this allows the formation of a cloud [19]. When the leak is not ignited, then a safe dispersion is produced and no unsafe event will happen [24]. All these scenarios must be considered on a LPG catastrophic rupture analysis.

3.2.1 Boiling liquid expanding vapor explosion (BLEVE)

The definition of BLEVE proposed by CCPS was defined as a sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, resulting in rapidly expanding vapor and flashing liquid. A BLEVE refers also a failure of a major container into two or more pieces as a mechanical explosion [19].

The physics of BLEVE in a LPG tank is as following: the impacting heat flux leads to an increase of wall temperatures and therefore material weakening. Heat is also transferred to the liquid phase, which increases the liquid temperature and the vapor pressure. This internal pressure increase leads to creep and thinning in the hot wall area and this may eventually lead to formation of a tear or fissure in the tank wall. If the tear propagates the entire length of the tank, then a BLEVE takes place. If the fissure stops short, then a transient jet release takes place [19].

Determining whether a heated LPG tank will entail a BLEVE is a complex task. The maximum wall temperature occurs when the liquid level is low in the tank, on portions of the vessel that are not internally wetted by the liquid content. The internal pressure results from LPG boiling, fluid temperature increase and stratification. Rupture occurs when internal pressure exceeds heated steel resistance.

LPG containers are equipped with pressure relief devices set to maintain sufficient pressure to keep the LPG liquid but to relieve any pressure greater than the container is designed to carry. At 36 °C, a pressure of about 1380 kPa is needed to liquefy propane. Butane will exert a pressure of about 415 kPa on the container at 38 °C. The pressure necessary to keep the gas a liquid is, therefore, a function of the gas and the temperature of the gas.

At normal temperatures, a container shell will easily handle the pressure in the container. If, however, the steel is heated above about 200°C, it begins to lose its strength and at 425 to 540 °C will fail even though the pressure in the container is at or below the setting of the relief device. A container holding LPG has portions of the container which are in contact with the liquid (wetted surface) and other portions which are above the liquid level and therefore not in contact with the liquid (unwetted surface). Under fire exposure, the temperature of the wetted portion will remain essentially the same as the liquid due to heat transfer to the liquid. The unwetted surface on the other hand will rise rather quickly to steel failure temperature. The rupture and resultant explosion is this special form of a BLEVE. When the pressurized, liquefied gas is suddenly released into the atmosphere, about one-third of the gas (in the case of propane) will immediately vaporize. Another portion of the liquid will be expelled as droplets or mist. Due to the violence of the rupture, the gas and droplets will mix quickly with air and a large fireball will result. The size of the fireball is a function of the size of the container, the fullness of the container, the composition of the gas, and the temperature and pressure of the gas in the container. Because a sizable portion of the liquid is not vaporized and burned in the initial fireball, an intense fire will burn for a number of minutes in the immediate vicinity of the point where the tank ruptured resulting in severe exposure to adjacent tanks. In addition to damage from the fireball, pieces of the ruptured container can travel up to 2500 m doing extensive damage to surrounding property. The effects to people and property from BLEVEs have been modeled by various organizations [26].

Several notable disasters have occurred involving BLEVEs at large LPG storage facilities. These are the incidents at Port Newark, New Jersey in 1S51, Feyzin, France in 1966, Texas City, Texas in 1978 and San Juan Ixhuatepec, Mexico City. Numerous BLEVEs of rail and truck tank vehicles have occurred.

3.2.2 Vapor cloud explosion (VCE)

3.2.2.1 Unconfined explosion

At times, when large quantities of flammable vapors are released and ignited, a phenomenon known as an Unconfined Vapor Cloud Explosion (UVCE) may occur. These have occurred in varying degrees of severity over the years. The effects have ranged from minor damage to structures to major damage to entire chemical plants and refineries. The exact mechanism by which the UVCE occurs is still being debated. It is believed that turbulence created by the burning vapor causes a degree of "self confinement" allowing the combustion process to proceed at a speed that produces damaging, explosive overpressures. In many cases, a degree of "partial confinement" was offered by building walls, chemical plant process equipment or vegetation [25], [26].

Certainly, the most notable industrial incident prior to the Bhopal toxic gas release was the unconfined vapor cloud explosion in Flixborough, England in 1974. Because of the severity of the Flixborough disaster, the incident was thoroughly investigated and was the basis of much study of the UVCE phenomenon. Models of unconfined vapor cloud dispersion and explosions have been developed and are in use by various organizations throughout the world [26].

3.2.2.2 Confined explosions

The largest losses caused by LPG, both from a loss of life and property damage standpoints, have involved BLEVEs and UVCEs. Confined explosions have been the cause of numerous smaller incidents, however. Typical of these is the explosion at Indianapolis, Indiana in 1963 [26].

3.2.3 Fires

Because of the volatility of LPG, most notable incidents involving this material are explosions. In the hydrocarbon processing industry, leaks of LPG from process piping flanges, pump seals, valve packing's and relief valves which ignite do so soon after the start of the leak resulting in a severe localized fire [28].

3.2.3.1 Flash fire

This type of fire may occur if the ignition does not take place immediately after the leak. This allows the formation of a cloud, which evolves so that if it finds an ignition point the whole mass between the flammability limits will be ignited.

In contrast, in the case of container collapse or significant rupture, flash evaporation of propane will occur, resulting in an instantaneous emission of the material into the atmosphere.

In the event that the leak is produced by the lower part, it is considered that the entire product contained in the tank is emitted. The liquid propane inside the tank is usually considered to follow an adiabatic evolution, so that the product cools because of evaporation, thus reducing the vapor pressure and, therefore also reducing the leakage rate [25], [26].

3.2.3.2 Pool fire

If the liquefied gas is stored at ambient temperature and at a pressure higher than the atmospheric pressure, when the leakage occurs the liquefied gas will escape to the outside, producing a flash evaporation that will lead to a biphasic leakage. Some amount of liquid in the form of drops will be drawn by the outflow. Some of these drops could fall to the ground, forming a puddle due to cooling and condensation. This fuel, if it encounters an ignition point or is struck by a flare, will result in a fire [25], [26].

3.2.4 Jet fire

Jet fires are associated to very high heat fluxes and if they impinge on equipment, they can originate a catastrophic failure in a very short time.

An example of such a situation is the accident that occurred in San Juan Ixhuatepec, Mexico, in 1984: an initial vapor cloud explosion (due to a release of flammable gas during maintenance work) originated diverse LPG jet fires and, after only 69 seconds, the first boiling liquid expanding vapor explosion occurred and a very short exposure time was enough to cause the failure of a pressurized vessel [26]. This caused 500 people killed and about 7000 people severely injured.

While in this accident the jet fires followed a previous explosion, in other cases the gas release has been due to much less significant events. Once the jet of a flammable material (usually a pressurized gas or a two-phase mixture) is released, two sequences are possible: or the jet is quickly ignited by an electrostatic spark or another ignition source, or a vapor cloud is formed which is a little bit later ignited, the fire flashes back to the leak source and a jet fire is finally originated. Other cases could be mentioned in the field of the transport of flammable materials, when, following a road accident originating a further explosion/fireball event. In these cases, jet fires can result eventually in important major accidents [27].

3.3 Effects on an LPG tank of a fire burning in its vicinity

When a tank is heated by fire, it is important to quantify how quickly the vapor space wall will heat up and how quickly the tank internal pressure will rise. These depend on many factors including:

a. Fire size, surface emissive power, and geometry
b. Tank geometry, orientation and distance relative to the fire
c. Initial temperature
d. Liquid fill level
e. PRV set pressure and flow capacity
f. Local winds, wind velocity

The impact of a heat flux on a LPG tank leads to an increase of wall temperatures and therefore material weakening. Heat is also transferred to the liquid phase, which increases the liquid temperature and the vapor pressure. This internal pressure increasing leads to impact in the hot wall area and this could eventually lead to the formation of a tear or fissure in the tank wall. If the tear propagates the entire length of the tank, then a BLEVE can take place and the effects could be serious, as it can be shown in *Table 5*. If the fissure stops short, then a jet release takes place.

Table 5. Impact of thermal radiation: effects [16]

Thermal Radiation (kW/m^2)	Effects
4.7	Causes burns after 30 s
7.0	Maximum tolerable value for firefighters completely covered by special clothes
10.0	Certain polymers can ignite
11.7	Thin Steel can lose mechanical integrity
12.6	Wood can ignite after a long exposure
37.5	Collapse of mechanical structures

Modelling the thermo-hydraulic behavior of a LPG tank requires a comprehensive study of the heat and mass transfer processes involved within the tank. Time rupture can be modelled but a safety margin has to be considered since LPG tanks can be old and can present weaknesses.

To assess the risk of these scenarios (as for example the effects caused by a specific thermal radiation as *Table 5*), vulnerability models are often used to establish a relationship between the magnitude of the impact and the damage caused. For this, the most used model is the Probit function.

In this case, the response information versus the delivered dose is correlated so that the probability is taken into account. To do this, in case of quantifying, for example, damages caused by the radiation emitted by a fire, the exposure time as well as the radiation provided in each case will be taken into account and these values will be adjusted to a Probit equation that predicts the probability to certain consequences.

Some institutions as The American Petroleum Institute recommended critical values for safety studies. The critical value for a LPG tank equipped with a pressure relief valve is 7000 British thermal units per hour per square foot (22 kW/m^2). A vessel shell surface receiving more than this value will require cooling to prevent overheating and loss of strength. This is a very strict safety limit that should prevent BLEVE for long time of fire (more than 30 min) [16].

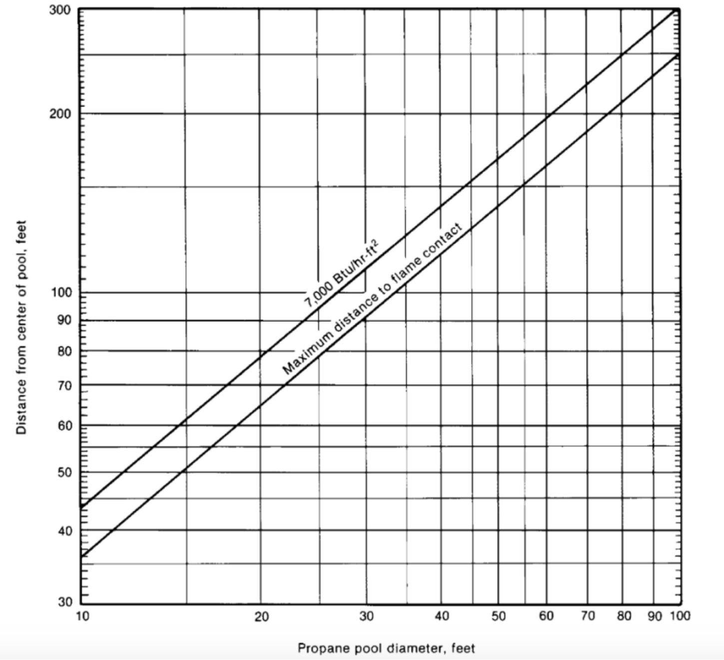

Figure 5. Heat Flux limit recommendations [3]

However, in case of wildfire it is very unlikely to have such long exposure times: exposure time of a target submitted to a wildfire is much more less, so the criteria applied for the API could not be very approached for a short and intense fire scenario. In the scope of this project, the presence of radiative heat flux emitted by vegetation during a short period of time will be the point on the quantification of risk for applying a risk assessment.

3.4 Historical accidents involving LPG facilities

In Port Newark (New Jersey, July 7, 1951) facility had one hundred 115 m^3 horizontal tanks for receiving propane from ships and distributing by tank truck or tank rail car. A leak of unknown origin occurred in piping near one group of tanks. Ignition was immediate and about three minutes later operators were able to actuate an emergency shut-down station which operated shut-off valves on all tanks. In spite of this action, shortly thereafter, the first of the tanks ruptured. Over the next hours, all 70 tanks in a group ruptured with varying degrees of violence. Some tank pieces were thrown up to 800 m doing damage and puncturing tanks in neighboring plants. None of the tanks in another group, located 107 m away, ruptured. Firefighters were able to control a number of flange leaks that did occur at those tanks. The loss was $1,050,000 in 1952 dollars. A number of full propane tank cars located on a rail siding adjacent to and seriously exposed by the fire did not rupture because of the insulating effect of cork insulation material installed on the tank cars [26].

In Texas (May 30, 1978), a tank farm used to store propane, propylene, butane, and butylene in conjunction with a refinery alkylation unit was located directly adjacent to the alkylation unit and other production units. The tank farm contained three 800 m^3 (210,000 gal) spheres, five 160 m^3 horizontal "bullets" and four 160 m^3 vertical "bullets." A sphere was being filled from a pipeline delivery. Due to instrument failure and a faulty relief valve, one of the spheres was overfilled and overpressured to the point of rupture. The huge fireball and ensuing fire caused the subsequent rupture, over the next 20 minutes, of all of the remaining tanks and spheres in the tank farm. Sphere and tank fragments went in all directions causing severe damage to other operating units, tankage and fire protection facilities. One major portion of a sphere traveled 230 m. One of the vertical "bullets" traveled 150 m. A domed end of a horizontal "bullet" traveled 60 m and went completely through an empty atmospheric oil storage tank. The loss was in excess of $100 million [26].

In San Juan Ixhuatepect (Mexico City, November 19, 1984), there was a facility for storing propane and butane received by pipelines consisted of four 1600 m^3 and two spheres and an additional 48 horizontal "bullet" storage tanks of varying size. The total storage capacity of the terminal was 16,000 m^3. The terminal was originally constructed in 1962 in open country well remote from high population areas. Since that time, however, nearly 4,000 people had moved into the immediate area. The built-up area began just 130 m from the LPG storage area.

A leak occurred at the site while tanks were being filled from a pipeline. The leak may have been caused by overfilling and over-pressure of one or more tanks. A vapor cloud was ignited at a neighboring plant and about one minute later, one or possibly two spheres ruptured. Burning and unburned gases entered houses setting fire to everything. Over the next hour and twenty minutes nine major and numerous smaller explosions occurred from vessel BLEVEs. Approximately 500 people were killed and about 7000 people were severely injured by the fire. The majority of the dead were found within a distance of 300 m of the center of the storage area [26], [27].

4. LPG facilities in wildland-urban interfaces

4.1 Introduction

The wildland-urban interface (WUI) refers to the zone of transition between unoccupied land and human development. These areas adjacent to and surrounded by wildlands are at risk of wildfires. Traditionally it was defined as that interface as the occurrence of fire spreading from wildland fuel (in this case vegetation) to urban fuel (homes that form the neighborhood), in terms of the wildland fire becoming close enough for its flames and its firebrands (lofted burning embers) to contact flammable parts of a home or the home's immediate surroundings. The main question is related with the estimation of distances between fire and houses to cause any dangerous situation. The threat to homes and their destruction during wildland fires, with associated risks for life safety, are significant problems for emergency managers and land managers because of the difficulties to manage these situations under unknown scenarios. In the past, wildfires resulting in residential destruction occurred for example in Australia, Canada, several Mediterranean countries and the United States [16].

The increase of the occurrence of wildfires combined with the growing of the population leads to an increasing impact of wildfires on infrastructures. Inhabitants can also be exposed to the high heat fluxes from the fire front. The growth of the WUI implies that firefighters have to protect more and more property and remain at a close distance from the fire front. Habitants can face the same problem if they stay to protect their homes or if they cannot be evacuated. In several countries, the law obliges homeowners to clear the undergrowth within a distance from their house in order to stop the fire and prevent it from burning the house. The main problem is the difference between normative and legislations on countries because they are not the same requirements for countries as Spain, France, Portugal, Italy or EE.UU. The problem of ornamental vegetation near a LPG tank is not always collected in the legislation. The danger of presence of vegetation near a tank in a WUI is real and it was demonstrated with numerous cases of incidents happened on the past (Valencia and Madeira fires in 2016 as European examples and Calabasas Hill fire, also in 2016, as American examples, *Figure 6 and 7*) [16], [17]. For this reason, it is very important to investigate and quantify the vulnerability of these type of WUI scenarios and the possible damage caused by a WUI-LPG related fires with certain characteristics in terms of weather and wind conditions, ornamental vegetation around and tank features.

Figure 6. Calabasas Hill fire. (Photo: KABC-TV via AP) This still image from video provided by KABC-TV shows where a wildfire has come close to a preschool complex, burning outbuildings and igniting a propane storage tank, as a fast-moving brush fire swept through hills in Calabasas, California, northwest of downtown Los Angeles Saturday, June 4, 2016. The main structure was saved.

Figure 7. LPG damaged tank in Benitatxell fire (Valencia, 2016). Foto: David Caballero

It is known that Liquefied Petroleum Gas (LPG) is a common fuel used for home heating, hot water production or cooking. This fuel is usually stored out of the house in pressurized cylindrical tanks of medium capacity (1 to 3 m^3) [18]. These tanks are not protected by a passive protection layer against fire but are prevented from excessive pressure by a relief valve and other control devices. However, when such a tank is exposed to external fire, there is a chance that the tank will fail despite the action of the pressure relief valve. If the failure mode is catastrophic then this could lead to a boiling liquid expanding vapor explosion (BLEVE) followed by a fire ball. In turn, with non-catastrophic failure a jet fire lasting during several time (minutes to hours) can also occur. These hazards may hurt or kill population and firemen fighting against wildfire in a residential area.

4.2 State of the art on analysis of wildfires interaction with LPG tanks

Referring the LPG and wildfire investigation, this topic has not been developed in a very extensive way despite the importance of the problem. Current research has focused on general issues such as the characterization of the impact of wildfire fronts on LPG tanks, the effect of a remote wall fire in a low filled level tank and the study of the safety of LPG tanks located in a WUI related to the existence of vegetation near these facilities.

4.2.1 Impact of wildfires on a LPG tank [20]

Modelling the radiative heat flux from a wildland fire to a target requires to know the emitted radiative power of the fire and to calculate the transmission of the radiative energy to the target by view factor considerations. The emitted power depends on many variables such as flame combustion kinetics and temperatures, flame thickness, emissivity of gases and soot.

Here, an approach for the estimation of the radiation flux from wildland fires is the use of the solid flame model (SFM). In this model, the visible flame is idealized as a solid body with a simple geometrical shape and with thermal radiation emitted from its surface. The contribution of non-visible zones of the fire plume to the radiant heat flux is usually not taken into account. The SFM model gives results with experimental data and it was used to calculate safety distances preventing from BLEVE. The radiant heat flux per unit area reaching a remote target is given by *Eq. 1*:

$$q = \tau F E \qquad \text{Eq. 1}$$

Where F is the view factor, E the surface emissive power (SEP) of the visible flame, and τ the transmittivity of the air (of gas) layer between the flame and the target. The atmospheric transmittivity corresponds to the fraction of the thermal radiation that is transmitted from the fire to the target and is function of the atmospheric humidity, the concentration of carbon dioxide and the distance, and can be calculated using semi-empirical equations. The surface emissive power of the flame may be calculated as:

$$\mathrm{E} = \varepsilon\,\sigma\,\mathrm{T}^4 \qquad \text{Eq. 2}$$

Where ε is the effective emissivity of the flame, T is the flame temperature and σ is the Stefan-Boltzmann constant. The amount of time during which an LPG tank will be affected by the radiative heat flux emitted from a wildfire depends on many considerations such as wind velocity, spreading rate, geometric considerations and humidity. The view factor F is defined as the fraction of the radiation leaving a surface A that is intercepted by a surface B.

The view factor F is defined as the fraction of the radiation leaving a surface A that is intercepted by a surface B. Oriented elemental areas dA and dB are connected by a line of length R, which forms the polar angles θ_A and θ_B, respectively, with the surface normal vectors n_A and n_A. The values of R, θ_A and θ_B vary with the position of the elemental areas on A and B. Assuming that both surfaces emits and reflects diffusely, and that the radiation heat is uniform, the view factor can be defined as:

$$F = \frac{1}{A}\int_A \int_B \frac{\cos\theta_A \cos\theta_B}{\pi R^2} dAdB \qquad \text{Eq.3}$$

The solving of the previous equation is achieved by meshing the A surface into i cells (dA_i) and the B surface into j cells (dB_j). The equation can be written as:

$$F = \frac{1}{A}\sum_i \sum_j \frac{\cos\theta_{Ai} \cos\theta_{Bi}}{\pi R^{2i}} dAidBi \qquad \text{Eq.4}$$

In this study, the first aim was to check the validity of F modeling through the investigation of height and length of the firewall as well as the distance between the fire and the tank, obtaining good results [20], [22]. Then, all values were compared in order to extract the highest value of temperature impacting the tank and this value was always located in the upper part of the tank.

According the criteria fixed by API standard with a value of 22 kW/m^2 fixed for being in a safety zone, the height of the fire was calculated in order to apply these criteria and obtain a safety distance correlation according each scenario (showed by *Figure 8*).

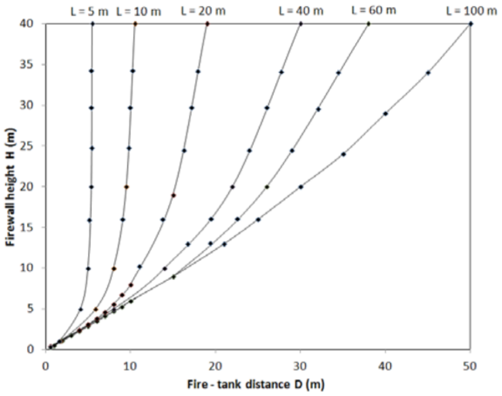

Figure 8. Safety distance f (firewall height and length) [20]

In order to verify the safety distances required by law in different countries, some values were checked, resulting that the FE model studied on this investigation confirm that a safety distance of 50 m prevents from BLEVE, even with large crown fires (height 40 m, length 100 m).

Results showed that a mandatory safety distance of 50 m is enough to prevent from BLEVE in any case of wildfire fronts, taking the criteria of a 22 kW/m^2 heat flux fire giving by the API. Safety distances of 30 and 25 m should prevent from BLEVE in most cases of wildfire.

4.2.2 Study made for the impact of a distant wildfire on a LPG tank [18]

In this case, authors were focused on the description of the behavior of a cylindrical tank filled with LPG under the effect of an experimental radiative heat flux.

Here, the maximum wall temperature reached in the tank and the change in internal pressure are the key factors. These depends on the radiative heat flux impacting it, the internal and external convection with fluids in contact with the wall, the radiative heat flux emitted by the steel and the conductive heat transfer in it. The hottest point of steel is always located on unwetted steel. In this case, the maximum radiative heat flux on the tank and the total heat flux impacting the tank were considered.

A medium scale fire set-up was designed to simulate a crown fire. The firewall was achieved by a burning wall of natural gas burners. Therefore, the experimental fire height could not exceed 4m, because of practical considerations. The size of the firewall, and the distance between the fire and the tank required rigorous analysis of the scaling effects.

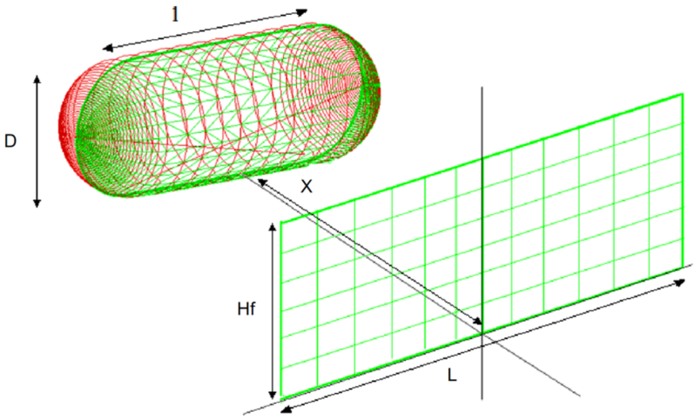

Figure 9. Configuration of the thermal system [18]

The configuration analyzed is drawn in *Figure 9*: the wildland fire is assumed to be represented by a rectangular solid firewall (black body) and faces a horizontal 2m^3 LPG tank where the firewall and LPG tank were parallel to each other. The average SEP (Surface Emissive Power) is assumed to be 90 kW/m^2 and it is used to calculate the maximum heat flux (MHF) and total heat flux (THF) that would impact a 2m^3 LPG tank if exposed to a large crown fire. The maximum size of fire would be a total flame height of 40 m and a length of 100 m. The distance between the fire and the tank wall was defined as 50 m.

During the experiments, a 2m^3 tank was filled at 15% with commercial LPG. The gas burner system was designed with horizontal tubes pierced with two rows of holes.

Before putting the tanks in front of the fire for the real test, several experiments with radiative heat flux meters were performed to check the best distance (3.8 m). The tank was also equipped with external wall thermocouples and 8 of them were arranged on a vertical pole to measure fluid temperatures and 3 convective heat flux sensor were glued on the wall covered with a thin nickel polished surface. Then, the internal pressure was measured with a pressure gauge, and convective heat flux transferred was measured by the sensors. The test was performed during 20 minutes. The results obtained were the following:

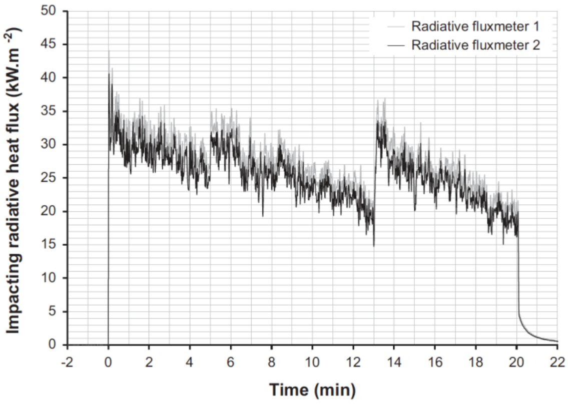

Figure 10. Radiative heat flux on the LPG tank [18]

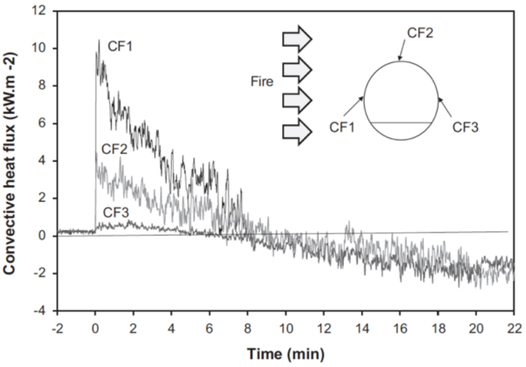

Figure 11. Convective heat flux on the LPG tank [18]

Both curves (*Figure 10* and *11*) show that the fire was symmetrical. The heat flux was not very constant because of the fluctuation of NG pressure and the maximum heat flux was recorded at the beginning of the trial. The average value of the heat flux was calculated to be 26 kW/m^2 during the experiment. Referring *Figure 11*, the convective heat flux is at its maximum at the beginning, when the tank wall is cold and the hot gases of the flames transfer heat to the wall. A maximum value of 10 kW/m^2 was recorded.

For the authors, the experiment confirms that an LPG tank will not BLEVE if it is impacted by a 24 kW/m^2 radiant heat flux, and confirms the criteria of the American Petroleum Institute, which state that if a tank with a pressure relief valve is impacted by a heat flux below 22 kW/m^2, it should remain safe. The scenario reported is very dangerous and the safety distance for an LPG is obtained from the parametric study developed in *Figure 12* with a safety value for MHP of 24 kW/m^2:

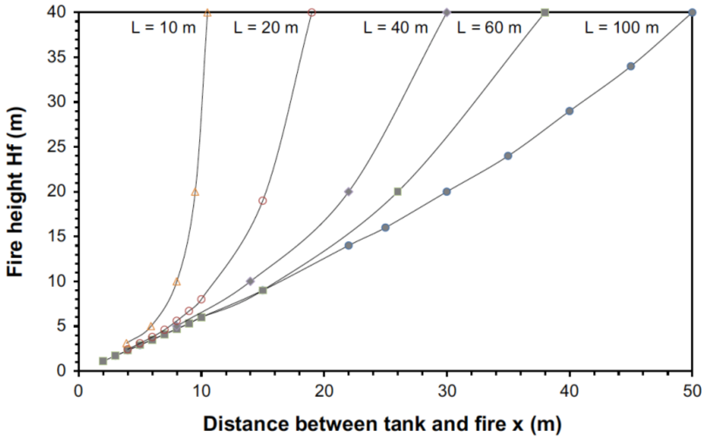

Figure 12. Parametric study for LPG safety distance [18]

Definitely, it is important to notify that for close fires the height of the fire does not play a strong role in the MHF. A fire located very high on a burning tree does not radiate strongly on a tank located at the base of the fire. However, at such a short distance, heat transfer by convection has to be taken into account and it can add a significant amount of heat to the tank.

4.2.3 Effect of a distant fire in a LPG tank with a low percentage of liquid [17]

This investigation consists on the description of an experimental study with a pressure vessel of 2300 L exposed to remote fire heating by a natural gas fuelled wall fire simulator. In this case, the tank is filled to 15% capacity with commercial liquid propane and the flame intensity and the distance are varied to study the effect of different heating levels on the tank and its lading.

The fire simulator is first characterized using fire thermocouples, radiative flux meters and thermal imaging. Then, three tests are conducted with the tank positioned at three different distances resulting in a measured average heat flux at the tank surfaces ranging between 24 and 43 kW/m^2.

The fire heat transfer to the tank was modified by varying the distance between the fire and the tank. The tank was equipped with 23 thermocouples and configured as in other studies. The fire was designed as a rectangular radiating wall and a thermal imaging system was used to view the fire at a distance of 25 m. In *Figure 13*, the main zone (zone 1) corresponds to the area where the metal panels between the pipes increase and homogenize the emitted heat flux. A second zone corresponds to the free flames area without panels; the emitted heat flux remains high but significantly lower than in zone 1. The zone 3 corresponds to hot gases with a lower temperature and low emissivity (<350 °C).

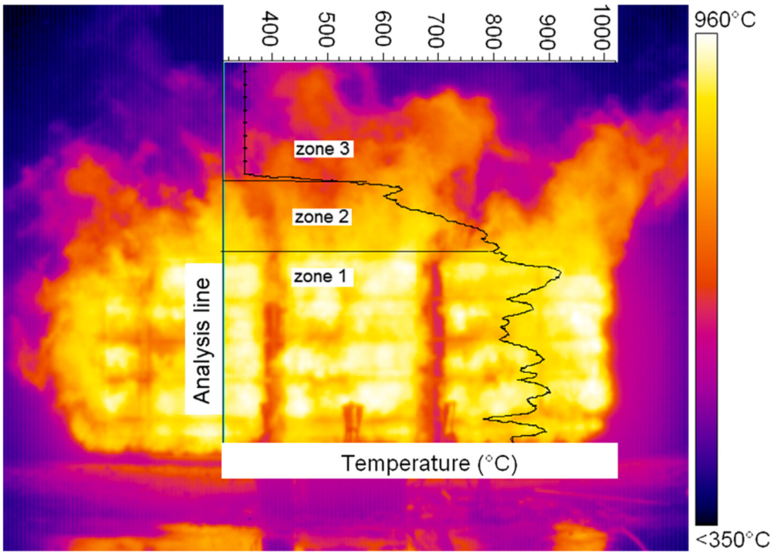

Figure 13. Thermal image of fire in test [17]

In the tests, the fire thickness could vary depending on the wind and natural gas pressure variations so it would affect the fire emissive power. Another effect of fire thickness variation is that the separation distance between tank and fire could have been different and this of course would affect the view factor between the tank and fire.

The different experiments developed shows that the fire exposure itself was probably not sufficient to cause a thermal rupture of the tank. However, the heating was sufficient to cause the release of propane because the failure of the fittings on the vessel.

The following figure (*Figure 14*) shows the measured tank wall temperatures from a test. As can be seen from the figure, the main fire was extinguished at 11 min. However, leaking propane continued to burn as a jet impinging the top of the tank resulting in very high wall temperatures. At 20 min, the highest wall temperature measurement changed dramatically suggesting the thermocouples detached from the tank.

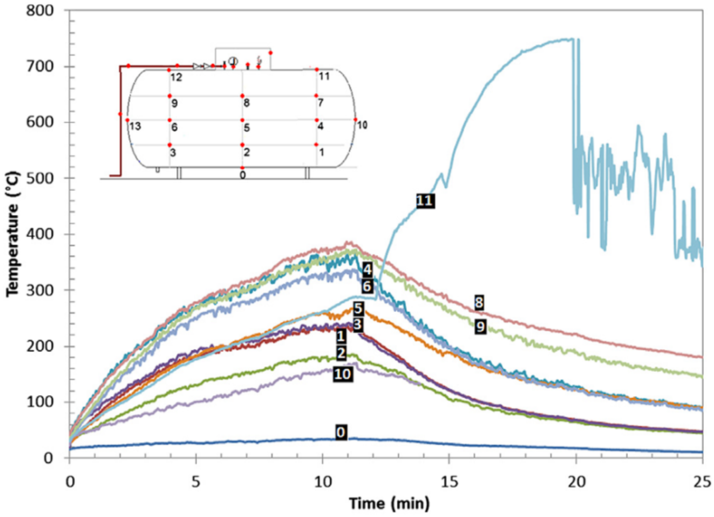

Figure 14. Measured wall temperatures in test [17]

To sum up, this work has shown that incident radiative heat flux from a remote fire depends on the size of the fire and distance to the target. The intensity of incident flux is usually lower than in scenarios as jetting fire or pool fire, but may remain high enough to cause serious damage to the target. Very significant rises in wall temperature and tank pressure can be expected and can lead to the activation of pressure relief devices. Fire heating that may not be sufficient to cause rupture of the tank may be sufficient to cause the failure of certain fittings and this could lead to a leak of propane that could be ignited.

4.2.4 Study about LPG tank response under a WUI fire with a specific impacting heat flux [16]

As in previous investigations, the modelling approach considered the fire as a solid flame. In this case, the target is cylindrical and cannot be represented by a flat rectangle. A finite elements modeling was therefore developed in order to compute the impacting heat fluxes on the tank. Here, it will be considered long fire scenarios and selected a medium value of 90 kW/m² to be realistic.

Radiant heat impacting the tank was calculated in different scenarios giving a map of heat fluxes on the tank, depending on the position relative to the direction of the fire. The maximum heat flux is observed in areas were the surface faces the fire. Modelling accurately the behavior of a LPG tank requires many parameters, such as thermodynamic properties, convection coefficients, surface radiative properties, temperature stratification, etc. To avoid uncertainties about modelling, it was preferred to perform real size experiments to study the response of a LPG tank when submitted to high radiative fluxes.

The experiments were performed with 2 m^3 tanks filled at 15% with commercial LPG and the LPG tank was equipped with standard equipment maintained the same set up as in other experiments. Then, the modelling was compared with a case test from literature, to validate the finite elements modelling and it was used to calculate heat fluxes impacting a LPG tank by considering fire scenarios from literature.

Modelling results revealed that in severe cases the LPG tank exposed to a wildfire can be impacted with high exceeding the safety criteria of API. Three experiments were therefore performed to investigate the behavior of the tank in a scenario that exceeds that safety value. The worst experimental scenario performed in this work impacted the tank with an average peak heat flux of 43 kW/m^2 and it has to be noted that the fire was not constant due to gas supply pressure variations. The other tests were less severe with an average peak heat flux of 26 and 24 kW/m^2.

A BLEVE or a loss of containment were not observed during the tests and until 10 minutes and the pressure relief valve remained closed. The next figure *(Figure 15*) shows the peak wall temperature for all three tests and to evaluate them, the American Petroleum Institute considers that the wall remains safe if its temperature remains below 427°C.

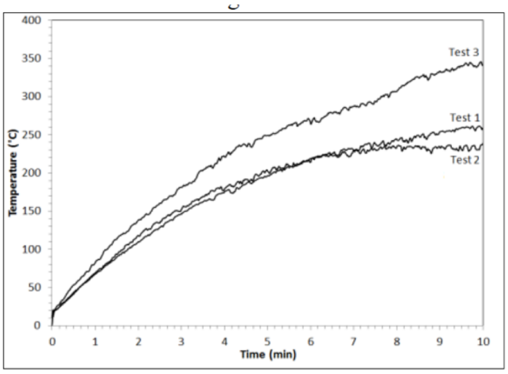

Figure 15. Experimental results [16]

These results indicate that a tank should remain safe for short exposure duration such as ten minutes. However, all tests were continued after ten minutes and the pressure relief valve opened several times two minutes later. This point is dangerous for a tank and could entail a domino effect.

5. Legislation and regulations

5.1 Background

In this section, a comparative review of the regulations, codes and standards relevant to the safety of Liquefied Petroleum Gas (LPG) facilities is done with an emphasis on substance volumes between 1 to 5 m^3 storage tanks which are the most common in wildland-urban interfaces.

The analysis of legislation and regulations stablishes a comparison country-by-country of the overall system of control of LPG facilities related with design, construction and operation of LPG facilities. Countries as Spain, Portugal, Italy and France are going to be analyzed in order to stand the problems and solutions purposed by their administrations to face the problem existing in WUI with not controlled fires which put in contact with vegetation near tanks.

5.2 Spain

5.2.1 Introduction

UNE 60250:2008 has the objective to establish the criteria for the design, construction, mounting and exploitation of LPG installations by fixed deposits with a geometry capacity equal or less than 2000 m^3. The scope of this regulation goes since the installation and the equipment between charging port and end valves (including these ones).

The whole of the installation and equipment comprises the charging port, tank and its accessories, piping between the charging port and the outlet valves, transfer equipment, vaporization, regulation and control devices.

In this regulation the pressure is related to atmosphere pressure (gauge pressure). The installations used for the bulk distributions of LPG are excluded of this regulation.

5.2.2 Terms and definitions

An **LPG installation** is a surface projected in a limited plant for the security distances reflected on the *Table 6*:

Table 6. Safety distances [7]

Aerial tanks (A) (m)			Buried tanks (E) (m)	
	D_0[1]	D_p[2]		D_0
A-1	1.5	1.0	E-1	0.75
A-5	3.0	2.0	E-5	1.5
A-13	5.0	3.0	E-13	3.0
A-35	7.5	5.0	E-60	4.0
A-60	8.5	6.5	E-120	5.0
A-120	10.0	7.5	E-500	10.0
A-500	15.0	10.0	D_0 = distance to orifice	
A-2000	30.0	20.0	D_p = distance to walls	

The maximum level of liquid is considered to be the indicated by the tank's manufacturer in the design conditions or, in their absence, the 85% of the geometric capacity of the tank at

20°C. The maximum work pressure will be the declared by the equipment's manufacturer according their characteristics.

5.2.3 Classification

The storage of LPG in fixed deposits could be only done in aerial or mounded tanks. The storage tanks are considered aerial when the surface is in contact with air and its lower part is higher than surrounding floor.

The LPG storage tanks could be classified as it is shown:

a. Aerial storage tanks
    1. A-1: Volume $\leq 1m^3$
    2. A-5: $1\ m^3 <$ Volume $\leq 5\ m^3$
    3. A-13: $5\ m^3 <$ Volume $\leq 13\ m^3$
    4. A-35: $13\ m^3 <$ Volume $\leq 35\ m^3$
    5. A-60: $35\ m^3 <$ Volume $\leq 60\ m^3$
    6. A-120: $60\ m^3 <$ Volume $\leq 120\ m^3$
    7. A-500: $120\ m^3 <$ Volume $\leq 500\ m^3$
    8. A-2000: $500\ m^3 <$ Volume $\leq 2000m^3$

b. Buried storage tanks
    1. E-1: Volume $\leq 1m^3$
    2. E-5: $1\ m^3 <$ Volume $\leq 5\ m^3$
    3. E-13: $5\ m^3 <$ Volume $\leq 13\ m^3$
    4. E-60: $35\ m^3 <$ Volume $\leq 60\ m^3$
    5. E-120: $60\ m^3 <$ Volume $\leq 120\ m^3$
    6. E-500: $120\ m^3 <$ Volume $\leq 500\ m^3$

The interest in this work will be focus on A-1 and A-5 storage tanks.

5.2.4 Implementation of LPG installation

The distances are measured to the orifices or walls as it is indicated in the following *Figure 16*:

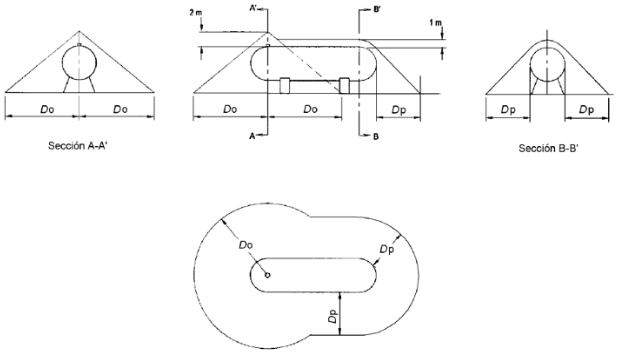

Figure 16. Distances between walls and orifices [7]

A hole or orifice is any opening that is not closed by means of threaded plugs, flanges or cut-off keys that ensure leak tightness, such as the loading port or safety valves. The discharge of the safety valve may be conducted within the LPG station, the free end of the conduit being the orifice D_0 for distances.

For reference 4 (*Table 7*), the following method is applied (see *Figure 17*): from the projection of the holes (safety valve or loading mouth), the distances D_0 are taken in orthogonal projections on the ground the distance chart and, by joining the perimeter of the circle formed with a point 2 m above the hole in question, a volume V is obtained. Then, from the projections of the walls, also in orthogonal projection onto the ground, the figure formed by taking distances D_p indicated in the distance chart and joining its perimeter with a hypothetical envelope located 1 m from the walls, obtaining another volume (V_1).

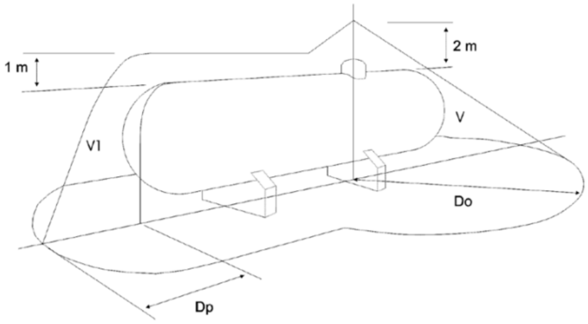

Figure 17. Distances LPG tanks [7]

Table 7. Safety distances LPG tanks [7]

	Aerial Tanks			
	A-1 (Volume ≤ $1m^3$)		A-5 ($1\ m^3$ < Volume ≤ $5\ m^3$)	
	D_0	D_p	D_0	D_p
Reference 1		0.3		0.6
Reference 2		0.65		1.25
Reference 3		0.3		0.6
Reference 4	1.5	1	3	2
Reference 6	3			

Where:

- Reference 1: Free space around the projection on the ground of the walls
- Reference 2: Distance to the enclosure
- Reference 3: Distance to walls or blind walls (RF-120)
- Reference 4: Distances to property limits, property openings, fixed ignition pockets, fixed explosion engines, public roads, railways or rivers, projection of overhead lines, basements, sewers or drains
- Reference 6: Distances from the loading port to the transfer tank

The use of walls, blind walls or screens can reduce the distances corresponding to reference 4 (except distances to projection of high voltage overhead lines in surface tanks) up to 50% according to the following criteria: the wall, the blind walls or screens must be straight, without any opening and be constructed in such a way that the fire resistance is at least RF-120.

- The use of more than one wall, blind wall or screen per point to protect, or more than two walls per installation is not allowed.

- The use of a wall, blind wall or screen should in no case imply the reduction of distances in the rest of the references in the table of distances in the annex. (For example in the case of distance to fencing, see *Figure 18)*
- The minimum height of the wall, blind wall or screen is determined by the hypotenuse of the right triangle formed by joining points A, B and C. (With a minimum of 1.5 m)
- The length of the wall (*Figure 19*), blind wall or screen must be such that the horizontal path of a possible gas leak is not shorter than the distance indicated in the distance table ($d_1 + d_2 + d_3 \geq D_o$).

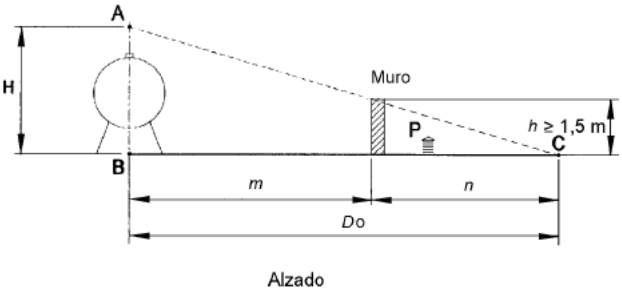

Figure 18. Height determination [7]

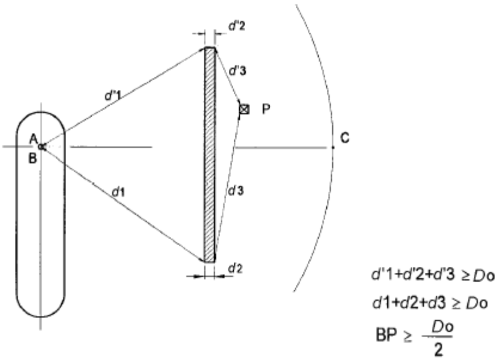

Figure 19. Wall's longitude determination [7]

For installations with a geometric capacity of less than or equal to 1 m^3, the distances of category A-5 in the previous *Table 7* may be reduced to 50%.

The installation of LPG cannot be located inside or under the buildings, nor in the patios that do not fulfill the conditions that are indicated now. Only LPG supply facilities may be located in yards where they have a direct access for maintenance personnel and meet at least one of the following two sets of conditions:

- Be fully open to permanently ventilated streets or outdoor areas and to a level of floor at least one-sixth of the perimeter of the yard, ideally considered closed by the lines connecting the inside corners of the open parts.
- The average height of the buildings, obtained by weighting the height of each building with its facade length to the yard, cannot exceed: $H < 7 + 0.7 \times V$ for aerial deposits; And $H < 8 + 0.3 \times V$ for buried deposits where H is the height of the building, in meters (m); V is the volume of the supply facility, in cubic meters (m^3).

And free surface of the yard cannot be less than:

$S \geq 96 + 50 \times V$ for aerial tanks;

where S is the free surface of the yard, in square meters (m^2); V is the volume of the supply facility, in cubic meters (m^3). The use of walls, blind walls or screens is not allowed to reduce the distances indicated in the distance chart. The LPG station must, in any case, be discovered and cannot have a total geometric capacity greater than 20 m^3.

5.2.5 Equipment characteristics

Storage tanks and their accessories for the storage of LPG must be designed in accordance with current legislation. They must be provided for at least a double-closing filling device, an indicator of continuous measurement level, an indicator of maximum level of filling, pressure gauge, over pressure safety valve connected to the gas phase of the deposit, two devices destined to the output of LPG and an earth terminal.

Changes have been made in the devices that carry the reservoirs themselves, being able to put a blind plug in the lower drainage hole, and using another drainage device through a diver tube on the top. Said change will allow the non-mandatory to maintain the distance of less than 50 cm or 80 cm depending on the case, if a blind plug is provided in the lower purge, so it would not be necessary to provide benches for the location of the tank. The design pressure of the reservoir is but for tanks less than 7 m^3, 20 bar is enough.

5.2.6 Construction and mounting

Vessels must be installed horizontally or vertically according to their design. At the location of the tanks and equipment, there must be a minimum 2 m high enclosure that can be of metallic mesh or any other similar system of class M1, which allows good ventilation and prevents the access of people outside the building. If this enclosure is fitted with a base, its height should not exceed 30 cm. The doors of the enclosures must open to the outside, they must also be of class M1, and the fastenings must be of quick drive from the interior without needing to use keys. The use of walls, blind walls or screens regulated in previous section can be considered as enclosure, supplemented, if necessary, with wire mesh or similar system to reach the height of 2 m. These enclosures must be placed at the distances of the tanks marked in the distance chart, reference 2. When there are transfer, vaporization, regulation or measurement equipment in an installation, they must be inside the enclosure.

The enclosure can be dispensed with when the LPG installation is located inside industrial plants that already have a closed and controlled enclosure. Installations A-5 can dispense with the enclosure if the cargo ports, keys, regulating equipment and tank accessories are enclosed in a casing or canopy of materials M1 according to The Norm UNE 23727, provided with a lock or padlock, and in addition one of the following conditions is fulfilled:

- The LPG station is located on a single-family dwelling with enclosure.
- The LPG station is located in a public building (hotels, restaurants, barracks, etc.) and in an area of restricted access only to its own personnel, and access to the general public is not allowed.

On the case of aerial tanks, they must be installed so that their longitudinal axis does not interfere with any other LPG tank. In tanks that have drainage in the generatrix or bottom wall of the same, the placement on the supports must be made in such a way that the hole in the tank for the drainage is placed at a minimum distance of 50 cm to the ground in the tanks of up to 20 m^3 and of 80 in the majors. This point will allow us to place the reservoirs without maintaining this lower distance, if we provide the reservoirs with a blind stopper in its purge hole. As a substitute of supports, a rubber base will be placed on the supports. The distance between tanks should never be less than the half-height of their radii and at least 1 m. They must be grounded with a resistance less than 80 ohms.

The valves of the tank and accessories must be protected by a casing with a registration cover and when vehicles can move on it, it must be protected with the necessary means to avoid it. The valves should be perfectly accessible from the outside, and control accessories easily readable.

5.2.7 Security against fire

Fire protection facilities must comply with current legislation (The current legislation at the time of this standard is Royal Decree 1942/1993 of 5 November).

Table 8. Extinguish method according deposit [7]

Volume (m^3)	V≤1	1<V≤5
Aerial	Not necessary	Extinguish material or water at a distances less than 15 m

Fire extinguishers (*Table 8*) used must be dry chemical dust, portable or on wheels. The quantities of fire extinguishing material must be at least as follows: LPG installations classified A-5 must have at least two fire extinguishers with a minimum unit efficiency of 21A-113B-C.

In addition, the area of pumps and compressors of LPG must be equipped with 2.5 kg of powder dry chemical per cubic meter per hour of transfer capacity, with a minimum of 50 kg distributed in at least two extinguishers. If the transfer equipment is located in a shed, these extinguishers must be placed on the outside of the same. The vaporizer booths, if any, must have at least one minimum efficiency 34A-183B-C, as supplementary to the established previously.

Installations that do not have an external water supply must be provided with storage tanks and pumping means that allow the mains operation for 1 h 30 min at the set pressure and flow rates. The water hoses and their coupling fittings must be adjusted to UNE Standards 23091 and UNE 23400, respectively.

5.3 Italy

5.3.1 Introduction

The ''Approvazione della regola tecnica di prevenzione incendi per l'installazione e l'esercizio dei depositi di gas di petrolio liquefatto con capacità complessiva non superiore a 13 m^3 (2014)'' decree is stipulated to order the subject of fire prevention for the installation and operation of LPG deposits in fixed tanks with a total geometric capacity not exceeding 13 m^3, intended for fuel distribution systems for civil, industrial, artisanal and agricultural use.

The provisions of this decree apply to the installation of new reservoirs. The same applies to deposits existing at the date of entry into force of this measure in case of substantial changes or extensions. The deposits in possession of a provisional permit, of the Law December 7, 1984, n. 818 (Official Gazette No. 338 of 10 December 1984) are adapted to the provisions contained in the Technical Annex no later than three years from the date of entry into force of this decree.

5.3.2 Objective

This decree is established for the purposes of fire prevention and safety for the protection of people and the protection of property against fire risks, the LPG deposits with total capacity up to 13 m^3 are installed and managed in order to ensure the achievement of the following objectives:

a. minimize the causes of LPG accidental release, fire and explosion
b. limit, in case of accidental event, injury to persons
c. limit, in case of accidental event, damage to buildings and/or adjacent spaces to the system
d. to enable rescuers to operate in safe conditions

According to the law, a fixed tank is a pressure vessel intended to contain liquefied petroleum gas, stably installed in the ground and stably connected to the distribution system. A tank for underground use (or underground tank): fixed tank intended specifically for underground installation. It is completely placed below the surface of the floor.

The pressure equipment and/or the constituent sets the deposit are specifically constructed and prepared for the intended installation, above or below ground, in accordance with the applicable European and national regulations.

5.3.3 Related normative

For the purposes of this technical rule shows an indicative and not exhaustive enumeration, technical standards pertaining to the sector of fixed LPG tanks with capacity of up to 13 m^3.

- UNI EN 12542- equipment and accessories for LPG - Cylindrical stationary tanks of welded steel, for liquefied petroleum gas (LPG), produced in series, geometric capacity of up to 13 m^3 - Design and manufacture.
- UNI EN-14570 LPG equipment and accessories - Equipment for LPG tanks, above ground and underground.
- UNI EN 12817-equipment and accessories for LPG - Inspection and requalification of tanks for liquefied petroleum gas (LPG) of smaller geometric capacity than or equal to 13 m^3.

5.3.4 Installation

The maximum total capacity of the tank is fixed in 13 m^3 and can be obtained with one or more tanks of any capacity. For the purposes of determining the overall capacity of the deposit referred to previously, two or more tanks, at the same catchment service, are considered distinct deposits when both of the following conditions are verified:

a. The distance between the perimeter of the nearest tanks of individual deposits is not less than 15 m, can be reduced to half by burial of tanks or interposition of the wall.
b. The deposit does not have in common with other deposits the filling point and vaporizers and first-stage pressure reducer.

1. The containers shall only be installed in areas with clear sky. It is forbidden to install on terraces and in any case the overlying areas of enclosed spaces.

2. Installation in backyards may be allowed provided that:
    a) the tanks are of a buried type
    b) has the courtyard area not less than 1,000 m^2 and has at least a quarter of the free perimeter of the buildings; for the remaining three quarters of said perimeter they are not allowed buildings intended to crowding of people or to civil room against fire with height greater than 12 m
    c) the access has a width and a height not less than 4 m

3. The installation of tanks on sloping ground is permitted. In this case the safety distances must be measured in horizontal projection. When the slope of the land is greater than 5%, do not apply the reductions of safety distances provided to the next step. The pitches of installation of the tanks must be flat and adequate surface to allow the outer edge of the same DISTI not less than 1 m 0.60 m from the perimeter of the tanks.
4. The installation of tanks ramps is not allowed.

When the tanks are installed in less than 3 m from trafficable areas by vehicles, it must be realized a suitable defense fixing adapted to prevent accidental impact against above ground tanks, or transit of vehicles on the area of underground tanks. This protection must be placed at a distance of at least 1 m from the perimeter in plan view of the tank. In the case the defense is simply constituted by a curb, even discontinuous, this must have a minimum height of 0.2 m and minimum distance from the reservoir not less than 1.5 m.

5.3.5 Dangerous elements and safety distances

They are considered dangerous elements of the deposit, for the purposes of determination of safety distances, the tank, the filling point, the multivalve group and all the shut-off and control bodies, with a working pressure exceeding 1.5 bar. Compared to the dangerous elements of the deposit, the safety distances must be observed indicated in next point and the protective distances indicated also.

- Compared to the dangerous elements of the deposit referred to, the following minimum safety distances must be observed:

    a) manufactured, sewer openings, closed tunnels, any sources of ignition, openings to the laying surface of the tanks and communicating with premises located below ground level, deposits of combustible materials or flammable not included among the assets subject to the fire prevention inspections in Annex I to Presidential Decree August 1, 2011, no. 151:
        - 2.5 m, capacity for deposits up to 0.3 m^3
        - 5 m, for deposits of greater capacity of 0.3 m^3 and up to 3 m^3

  - 7.5 m, capacity for deposits over 3 m^3 to 5 m^3
  - 15 m, for deposits over 5 m^3 to 13 m^3

b) buildings or premises also in part to public exercises, in communities, in gathering places of detention or public spectacle, deposits of combustible materials or flammable element activities subject to fire prevention inspections in Annex I to the DPR August 1, 2011, no. 151:
  - 5 m, capacity for deposits up to 0.3 m^3
  - 10 m, for deposits of greater capacity of 0.3 m^3 and up to 3 m^3
  - 15 m, capacity for deposits over 3 m^3 to 5 m^3
  - 22 m, for deposits over 5 m^3 to 13 m^3

c) railway and tram lines:
  - 15 m, subject in each case the application of specific provisions issued in this

d) vertical projection of high voltage power lines:
  - 15 m

e) fixed tanks G.P.L. to benefit other properties:

1) at least 6 m reciprocal, if within 15 m measured from the perimeter of the tanks that are to be installed, there are deposits whose total capacity, added to that of the deposit that is to be installed, is shown as greater than 5 m^3.
2) at least 15 m if the aggregate capacity of all existing deposits and install, obtained with the verifications referred to is greater than 5 m^3.

- The safety distances referred to in the previous paragraph 1, letters a), b), c), d) and e), can be reduced until the second half as indicated below:

- distances referred to in points a), c) and e), by burial of tanks or, alternatively, the interposition of the walls between the dangerous elements of the deposit and the elements to be protected so that the horizontal path of a possible release of gas, have a development not less than the safety distance. The walls must rise by at least 0.5 m above the highest dangerous element to be shielded.

- distances referred to in point b), limited to buildings and / or premises served by the filing, also intended in part to public exercises, in communities, in places of assembly, detention or public entertainment, for capacity stores up to 5 m^3, exclusively by burial of tanks.

- distances referred to in point d), exclusively by burial of tanks.

- The horizontal distance between two of the same storage tanks, both above ground which underground, must be at least equal to the diameter of the largest of tanks, with a minimum of 0.8 m.

- Among the perimeter of the tanker and the perimeter of the tank or tanks must be kept at a minimum distance of 3 m.

- Between the perimeter of the tanker and the perimeter of manufactured must be kept at a minimum distance of 5 m.

5.3.6 Protection distances

Compared to the dangerous elements of the deposit referred to in point 5.3.5, the following minimum safety distances must be observed:

- capacity for deposits up to 0.3 m^3: 1.5 m
- for deposits of greater capacity of 0.3 m^3 and up to 5 m^3: 3 m
- Capacitance deposits over 5 m^3 to 13 m3: 6 m

The above-mentioned distances can be reduced by up to half in accordance with the previous point. In case of interposition of the wall, the latter may coincide with the wall of the property boundary.

5.3.7 Fence

The dangerous elements of the deposit must be placed in a special area bounded by wire mesh fence at least 1.8 m high and provided with an openable door to the outside, lockable with a lock or padlock; part of the fence may coincide with the fence of the ground where the activity takes place served by the LPG tank although in masonry, provided that the installation area of the deposit itself proves well ventilated and the distances are respected referred to in point 5, 6 and 8. Among the dangerous elements of the deposit and the fence must be observed a minimum distance of 1 m.

The protection shall be deemed equivalent if it consists of a structure that meets the following requirements: is non-combustible, encloses the cockpit with all dangerous elements of the deposit and both ventilated and lockable with padlock.

For deposits of residential complexes service, at most four families, the fence is not necessary provided that the tanks are installed on private property, not accessible to strangers and equipped with its own fence. In this case the dimensions of underground tanks must be reported by means of special stakes while the above-ground tanks must be equipped with lid, fitted with a lock or padlock, enclosing the multivalve group, the filling connection, the pressure gauge and the device for control the maximum liquid level.

In cases where it is not possible to install on the tanks of the filling point, this can be located in another position, devoid of fence, in accordance with the distances referred previously. The reservoir coated can be protected, as an alternative to the fence, using a special structure in concrete, even prefabricated, whose attractive superior walls of at least 0.5 m from the tank walls.

5.3.8 Fire extinguisher systems

Referred to fire extinguisher:

a. At least two portable fire extinguishers shall be kept in the vicinity of the tank outside the enclosure adjacent to the manufactured buildings, which must have at least two portable fire extinguishers with a minimum charge of 4 kg and capacity up to 5 m^3 extinguishing agent not less than 13A 89B-C, while for deposits above 5 m^3 must have a minimum charge of 6 kg and extinguishing capacity of not less than 21A 113B-C. For deposits up to 0.3 m^3, only one fire extinguisher with a minimum charge of 4 kg and an extinguishing capacity of not less than 13 ° 89B-C shall be kept.

b. Aerial tanks with a capacity of more than 5 m^3 shall be protected with at least one DN 25 horn, made in accordance with the UNI regulations in force and powered by aqueducts or by a suitable water reserve, capable of ensuring the following hydraulic performance: Less than 60 l / min; Residual pressure at least 2 bar; Autonomy at least 30 minutes early.

5.4 France

5.4.1 Introduction

In France, the main law is the Decree of 30 July 1979 on the technical and safety standards applicable to the storage of fixed liquefied hydrocarbons not subject to legislation on classified installations or publicly-owned buildings.

Without prejudice to the application of other regulations, in particular the special provisions by the Decree of 18 January 1943, as amended, regulating gas pressure appliances, the fixed rules for hydrocarbons shall be subject to the provisions of the rules annexed to this Decree Liquefied compounds consisting of tanks or containers. Distributors for the purposes of this Order shall be regarded as distributors of commercial butane, commercial propane or special fuel mixture.

These rules shall apply to storages of liquefied hydrocarbons consisting of one or more fixed tanks or containers connected to a use facility, the nominal storage capacity of which is less than or equal to the classification threshold for installations classified for protection of the environment and that are located outside the right of way of the buildings receiving the public.

The storage of liquefied hydrocarbons in fixed tanks can be aerial or buried. It is said to be aerial when the tank is placed in open air, under a shelter or in an open space. It is said to be buried when the tank is placed below the surrounding soil wholly or partly (semi-buried tank) under the conditions laid down in Article 3 of these rules.

5.4.2 Storage implementation

Aerial storage must be placed in the open air or under a simple shelter (awning or awning) or, if necessary, in an open space with a light and ventilated roof (the solid parts of the walls must not exceed 75 per cent of the total lateral surface area).

If the storage is on sloping ground, it must not be embedded in the surrounding soil on more than 75% of its perimeter. If the storage is located on a deck, it must be watertight and fire-rated degree two hours.

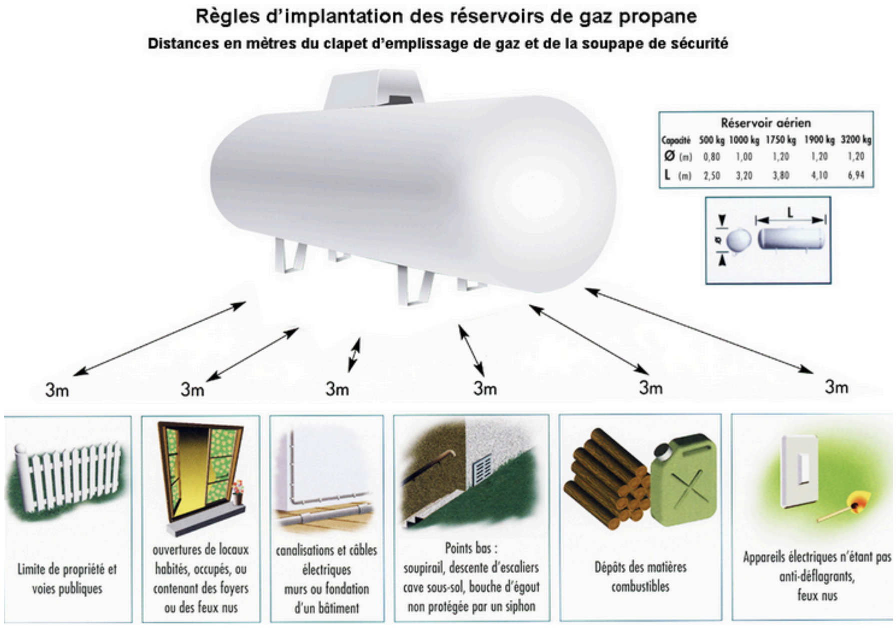

Figure 20. Security distances in aerial tanks [13]

Arrangements shall be made to ensure that the supply vehicle cannot approach within 3 meters (As it can be seen in *Figure 20*) of the shells of the tanks and may interfere with the access and clearance of collective buildings. Except in the case of public roads, the floor of the parking area of the refueling vehicle shall be made incombustible. The tanks shall rest stably by means of cradles, legs or supports constructed of non-combustible materials. The foundations, if necessary, are calculated to support the weight of the tank supposed to be filled with water.

A clearance of at least 0.60 meters must be reserved around the overhead tanks and at least 0.10 meters below. Two air tanks must be at least 0.20 meters apart. Air tanks must be moored if they are in a floodable location. Underground tanks must always be moored. Tanks containing liquefied hydrocarbons shall be subject to the regulation of pressure vessels.

5.4.3 Distances

Related to air tanks:

- The filler and the open vent of the tank safety valve must be positioned with respect to:
    - Any bay in an inhabited or occupied space
    - Any opening of rooms containing fireplaces or other bare fires
    - Any opening of premises below
    - Any sewer outlet not protected by a siphon
    - Any deposition of combustible materials

- The ownership limit and the public road, at a distance "d" which varies according to the quantities stored. When the stored quantity is at most 3500 kg, the distance d must be at least 3 meters. When this quantity is greater than 3500 kg and not more than 3500 kg, the distance d is increased to 5 meters.

- With respect to the walls of liquid or liquefied hydrocarbon distribution apparatus, this distance is increased by 1 meter.

Particular dispositions:

- Distance d may be reduced to 1.50 meters provided that the open vent of the valve and that of the filler are isolated from the above locations by a solid wall constructed Fire-resistant material of two-hour degree, the height of which exceeds that of the filling mouth and the orifice of the valve by 0.50 meters, and the length of which is such that the horizontal projection of the actual path of the vapors Between the aforementioned orifices and the above-mentioned locations (except distribution points), i.e. at least 3 meters, if the stored quantity is at most 3500 kg and 4 meters if it is greater.

These lengths are increased by 1 meter respectively for liquid or liquefied hydrocarbon distributors. In all cases, a clearance of at least 0.60 meters must be left laterally around the tank.

- When the filling mouth is offset more than four meters from the wall of the tank, it may be 2 meters from the locations listed. It may, however, be installed on the side of the public thoroughfare if it is enclosed in an incombustible and locked box.

Tanks must be effectively protected from external corrosion and paint, if outdoor propane tanks, must have low absorbency. Faucets and fittings must be protected by a ventilated grill or cover and locked if the tank is accessible to the public.

5.4.4 Equipment

The tanks shall comprise: a double filling valve (or any other device offering equivalent safety), a continuous level gauge and a device for checking the maximum level of filling, the value of which is determined by the distributing company (possibly a purge device, which must be offset for underground tanks or with a dip tube).

The exhaust ports of the valves of the tanks shall be equipped with an ejectable cap (or equivalent device), the exhaust line of the valves shall be carried out from the bottom upwards, without encountering any obstacle, and in particular of roof protrusion.

The outlet ports for use in liquid and gaseous phases must be equipped with an automatic safety device, for example a flow restrictor, placed either inside the tank or downstream and as close as possible to the shut-off valve; The latter having to be itself located in the immediate vicinity of the reservoir. If a remote filling terminal is used, it shall have at its inlet a double flap or other device offering equivalent safety.

The constituent materials of the storage-dependent pipes, their dimensions and their method of assembly must be chosen so as to ensure, with a sufficient safety factor, resistance to the mechanical, physical and chemical actions due to the products conveyed. The mechanical resistance and the tightness of all the piping systems must be tested, after assembly, under pressure.

5.4.5 Fight against fire

The following means of control must be provided:

- A portable fire extinguisher approved N. F. MIH 55 B minimum 4 kg if the stored quantity is not more than 3500 kg
- Two fire extinguishers of the same type if the stored quantity is greater than 3500 kg

In the case of overhead storage, fire extinguishers can be replaced by a water station (with hose and lance) with an easy access control valve. These provisions do not apply to depots serving residential premises or their dependencies which are located in urbanized areas equipped with a public fire system.

5.5 Portugal

5.5.1 Related Normative and Legislation

Licensing of tanks is required if the capacity exceeds 1,200 liters for aerial tanks and 3,000 liters for buried tanks. If the installation capacity is less than 5,000 liters, it does not require licensing, but it must always comply with the safety standards - Class B1. The safety regulations are as follows:

1. Decree No. 36 270, of May 9, 1947 [30]
2. Ordinance nº 131/2002, of February 9 [31].

In order to obtain a license, the following is required: project elaboration, project approval, installation surveys and issuance of the license by the DGE / City Hall.

5.5.2 Product classification

The Decree No 36 270 exposes that regulated products can be classified according to the safety point of view of the respective installations in the following categories:

- 1st category. Products whose gases or vapors form with air at ordinary temperature explosive mixtures: All petroleum products and the like having a flash point below 25 °C; Such as: crude oils, gases, gas, gasoline certain components of fuel mixtures when they have a flash point below 25 °C.
- 2nd category. Flammable products: All petroleum derivatives and the like having a flash point between 25 °C and 65 °C.
- 3rd category. Combustible products: All petroleum products and the like having a flash point above 65 °C.

According to their visibility (and consequently the greater their vulnerability) they will be classified in:

1. Superficial: when they are located sore the surface of the ground and therefore can only become invisible by artifice of dissimulation.
2. Underground: when placed in natural or artificial cavities and hidden by their situation to aerial observation.

For the purpose of applying this regulation, the calculation of the total capacity of installations containing products of more than one category shall be carried out taking into account the following values for storage tanks:

1. Products of 1st category: 100% of its useful capacity.
2. Products of 2nd category: 50% of its useful capacity.
3. Products of 3rd category: 25% of its useful capacity.

The capacity of a tank is defined as the actual capacity of the tank reduced by 2%. The capacity of the liquefied petroleum gas reservoirs and warehouses is calculated by arbitrating 200% of their useful and maximum capacity, respectively.

5.5.3 General conditions for safety

The construction and operation of oil storage and handling facilities and their derivatives is not permitted when the following locations occur: warehouse or inconvenient dependencies in relation to habitable houses, public buildings, etc; in areas of tourism or scientific, historical or military interest; in bridges normally flooded in times of rain or winter or where the wastewater can come into contact with sea water, rivers, sources, etc; and on geological faults.

Storage or handling facilities must be located within private enclosures with a separation of at least 2.50 m minimum height, counted from the level of the exterior terrain. This separation shall be constructed of non-combustible material and with a structure that ensures sufficient protection against the entry of foreign persons into the service of the installation.

When there are parts of separation that are in direct contact with public or communication ways, open sea or waterways and canals, military installations, etc. This wall must be constructed in such a way as to prevent any eventual discharge into the exterior of the liquids existing in the installation and in case of explosion, fire or breakage, the number of doors in that installation will be absolutely essential.

The installations whose total capacity of the deposits, referring to products of 1st category, is superior to $1.5m^3$ must have in all its periphery an access way and that allows its immediate defense and vigilance in case of accident. For the purposes of classification of precautions in regard to the risk of fire or explosion in facilities, the following areas of interest are distinguished:

1. Areas of immediate explosion or fire hazard: storage rooms or handling of category 1 and 2. The immediate vicinity of the deposits up to a distance of 10 m from its periphery for products of 1st category. All the space around the exit holes of the gases or vapors of the products of 1st category up to a distance of 10 m.
2. Non-hazardous areas.
3. Protection zones.

5.5.4 Safety distances

Safety distances are the minimum distances at which the various parts of hazardous areas of the installations must be between them. This will take into account the constructions, the walls of limitation, ways of communication, etc.

The protection distances to be taken into account are as follows:

- The distance between two tanks contained within the same installation shall be equal to or greater than the following values: for products of 1st category, half of the largest of the diameters of the tanks considered contiguous in the installation. The minimum distance in any case will be 4 m.

- The minimum distance between an installation and various constructions within the limits of the installation shall be 20 m for products of the first category. When the installation has a capacity of less than 200 m^3, these distances need not be maintained, and it is very necessary that the buildings are located outside the very dangerous areas.
- The minimum distance between buildings intended for operations other than the installation must be at least 8 m for products of the first category.
- The sources of ignition shall be at least 25 meters from the surface tanks and from all inlets or outlets of the 1st category products, this being a measured distance on the line defining the shortest path. When the installation has a capacity of less than 25 m^3, these distances need not be maintained, and it is very necessary that the buildings are located outside the very dangerous areas.

Garages are considered to be local where fires can be produced, and may be installed next to storage tanks when they have a capacity of less than 25m^3, provided all appropriate safety measures are taken.

5.5.5 Construction and mounting for aerial tanks

For an aerial tank, the characteristics (schematized in *Figure 21*) it has to have are:

- The plates used in the construction of the tanks must be of the appropriate quality.
- The maximum stress in these plates will be calculated assuming that the tank is full of water and should not exceed one-third of the metal breaking limit used.
- The design shall take into account an overload of at least 50 kg per m^2, according to the pressure or depression to which they are subjected in their operating mode.
- The roofs of the tanks shall be constructed less resistant than the other parts in order to be the first to give in case of explosion.
- All entrance doors and holes in the tanks shall be closed by safety devices with a perfect seal, constructed of steel or bronze.
- All holes in tanks shall be protected by appropriate devices preventing flame propagation.
- All tanks of products of 1st category must be provided by the accessories required for their safety conditions and must work under pressure, with the exception of those with a capacity of less than 25m^3.

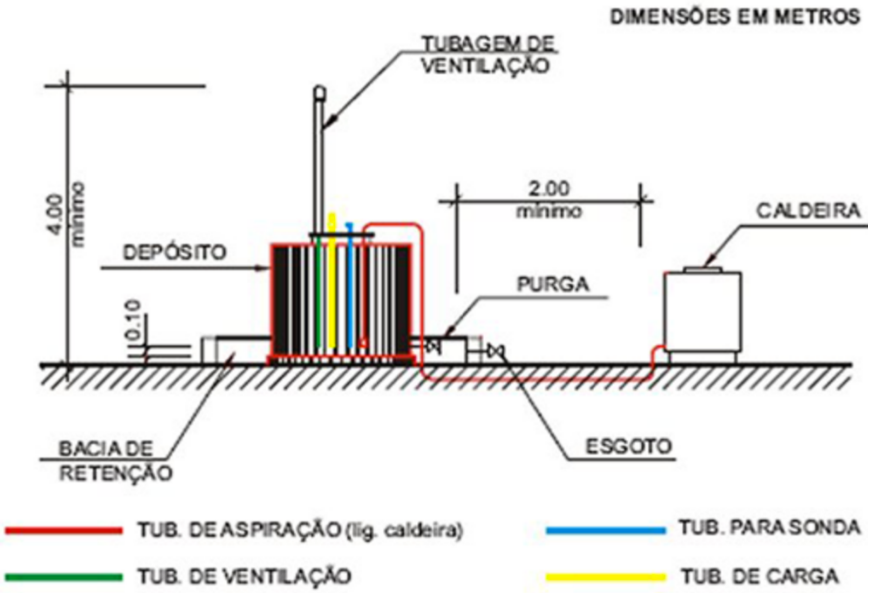

Figure 21. Aerial tanks distances [15]

The main recommendations collected by the regulation related to aerial tanks are:

- The reservoir, if constructed of plastic material, should not be under direct light or near heat sources.
- The tank must be earthed.
- Preferably, there must be a ground terminal where the tank car can be switched on during the filling operation.
- The reservoir must have a ventilation line (vent), which must have a minimum height of 4m, counted from the ground level, and must terminate in a free and unimpeded zone.
- Where necessary, there may be a remote supply, so that the tank can be supplied to the tank without having to move to the tank.
- At the location of the tank, the boiler and the ventilation piping, there must be: a dry chemical powder extinguisher of 6 kg for fire type ABC and a bucket with dry sand.

5.5.6 LPG tank installations

This particular chapter applies to all storage and handling facilities for petroleum, by-products and related waste having a vapor pressure of more than 1.5 kg /cm^2 at 25 °C.

The minimum distance between two LPG tanks will be of 4m for installations of less than 100 m^3 of capacity. On the case of tanks with different volume, the distances comprised will be for the highest volume tank. Valve bodies shall be made of steel or brass and the joints shall be of stainless steel or brass.

For products whose boiling points are above 10 °C, they shall have a containment wall of 40 cm maximum, forming a safety raft which may contain 25% of their capacity. The tanks must be positioned in such a way as to ensure thermal expansion. These shall be constructed of non-combustible materials and shall be fully protected at 10 and 17 hours of summer.

The storage conditions shall always be estimated for a pressure never lower than the pressure of the vapors of the products contained at the following temperatures:

- Surface, heat-insulated or sheltered: 45 °C

- Supercritical, non-heat-emitting: 60 °C
- Painted aluminum or white: 50 °C

For any of the calculations the pressure cannot be less than 7kg/cm^2 for the aerial tanks.

5.5.7 Fight against fire

In the extinction of fires in facilities for storage or manipulation of petroleum products will be considered mandatory:

1. **Water.** The water distribution network used will be independent of the utility water distribution network. The numbers of valves and fire hydrants considered suitable for the protection of the installation and adjacent buildings will be introduced.
2. **Foam**. They will be fixed or mobile, using an emulsifier that acts with water, releasing anhydrous carbonic or other non-combustible product. In fixed installations it will be better to use a chemical foam extinguishing system, reserving those that require water as a portable measure. The capacity to generate a foam should be such as to cover the surface of the largest diameter reservoir exist with a foam height of 0.40 m with a response time of 10 minutes.
3. **Fire extinguishers.** There must be for every 100m^2 of surface a portable fire extinguisher with a capacity of at least 9 liters (extinguisher that works with inert gas). In non-hazardous areas of the installation the number of extinguishers may be reduced by half. Where there are electronic devices, there must be at least two non-conducting fluid extinguishers.
4. **Sand.** There must be sand sites at a rate of 1 m^3 of sand per 2500m^2 of uncovered surface, and there must be enough sand buckets inside the buildings where flammable or combustible products are stored.

5.6 Comparative Table

Table 9. Comparative legislation table I [2], [3], [7], [12], [14], [28], [29]

	Spain	Portugal	France	Italy
Normative &Regulations	• Real Decree 919/2006, of 28 July • IT-ICG 03 • AENOR 60250:2008	• Decree No. 36 270, of May 9, 1947 • Ordinance nº 131/2002, of February 9	• Decree of 30 July 1979 • Decree of 18 January 1943	• Approval of the technical regulation of fire prevention for the installation and operation of liquefied petroleum gas deposits with a total capacity not exceeding 13 m^3 (2014)
Purpose	''Establish the criteria for the design, construction, mounting and exploitation of LPG installations by fixed deposits with a geometry capacity equal or less than 2000 m^3.''	''Establish the safety conditions to be met by the construction and operation of filling stations for gasoline, diesel and LPG for the supply of road vehicles, vessels or aircraft and supply stations for own, public and cooperative consumption.''	''These rules shall apply to storages of liquefied hydrocarbons consisting of one or more fixed tanks or containers connected to a use facility, the nominal storage capacity of which is less than or equal to the classification threshold for installations classified for protection of the environment and that are located outside the right of way of the buildings receiving the public.''	''Establish the purposes of fire prevention and safety for the protection of people and the protection of property against fire risks, the G.P.L. deposits with total capacity up to 13 m^3 are installed and managed in order to ensure the achievement of objectives.''
Definition of aerial tank	''Tank where the surface is in contact with air and its lower part is higher than surrounding floor.''	''A tank located sore the surface of the ground and therefore can only become invisible by artifice of dissimulation.''	''It is said to be aerial when the tank is placed in open air, under a shelter or in an open space''.	Not included specifically (considered opposite definition of a buried tank): ''A Fixed tank is a pressure vessel intended to contain liquefied petroleum gas, stably installed in the ground and stably connected to the distribution system''.
Main parts of the installation	• Charging port • Tank and its accessories • Piping between the charging port and the outlet valves • Transfer equipment, vaporization, regulation and control devices	Same as Spain	• A double filling valve • A continuous level gauge • A device for checking the maximum level of filling	Same as Spain and Portugal

Table 10. Comparative legislation table II [2], [3], [7], [12], [14], [28], [29]

	Spain	Portugal	France	Italy
Safety distances	A-1: 1,5m (D_0), 1,0m (D_p) A-5: 3,0m (D_0), 2,0m (D_p) + TABLE 8	The minimum distances between the LPG supply unit and any buildings, reservoirs, equipment and the limit of the property on which the filling station is situated shall be equal to or greater than the following: A. An integrated building: 5 m. B. At the property limit: 7 m. C. To a building occupied or inhabited: 10 m. D. To a building that receives public: 17 m. E. To sensitive areas: 40 m. F. To the wall of a surface oil tank: 4 m; G. To the wall of a buried tank of gasoline or diesel fuel: 3 m. H. To the filling nozzle of surface oil reservoir: 5 m. I. To the filling nozzle for gasoline or diesel oil: 4 m. +5.5.4 + Figure 17	The ownership limit and the public road, at a distance which varies according to the quantities stored: • Stored quantity is at most 3500 kg, the distance d must be at least 3m. • When this quantity is greater than 3500 kg the distance is increased to 5m. With respect to the walls of liquid or liquefied hydrocarbon distribution apparatus, this distance is increased by 1 meter. • Distance d may be reduced to 1.50 meters provided that the open vent of the valve and that of the filler are isolated from the above locations by a fire resistant wall. These lengths are increased by 1 meter respectively for liquid or liquefied hydrocarbon distributors. In all cases, a clearance of at least 0.60 meters must be left laterally around the tank. • When the filling mouth is offset more than four meters from the wall of the tank, it may be 2 meters from the locations listed. It may, however, be installed on the side of the public thoroughfare if it is enclosed in an incombustible and locked box. Figure 24	For more specified values, 4.3.5: 1) Capacity for deposits up to 0.3 m^3: 1.5 m. 2) For deposits of greater capacity of 0.3 m^3 and up to 5 m^3: 3 m. 3) Capacitance deposits over 5 m^3 to 13 m^3: 6 m. The distances can be reduced by up to half in accordance with the previous point. In case of interposition of the wall, the latter may coincide with the wall of the property boundary. 5.3.5 + 5.3.6

Table 11. Comparative table legislation III [2], [3], [7], [12], [14], [28], [29]

	Spain	**Portugal**	**France**	**Italy**
Operation conditions	Maximum level of liquid is: 85% of the geometric capacity of the tank at 20°C. Volume less than 7m^3: 20 bar pressure design.	The storage conditions shall always be estimated for a pressure never lower than the pressure of the vapors of the products contained: • Surface, heat-insulated or sheltered: 45°C • Supercritical, non-heat-emitting: 60°C • Painted aluminum or white: 50°C The pressure cannot be less than 7kg/cm^2 for the aerial tanks.	Maximum level of liquid is 85% of the geometric capacity of the tank at 20°C	Maximum level of liquid is 85% of the geometric capacity of the tank at 20°C
Key points related with vegetation	No reference to any vegetables or plants and trees around the LPG installation.	Specific reference to vegetable and combustible substances. No combustible materials could be inside the limits of the installation	Specific reference to vegetable and combustible substances. A distance of 3 m above the tank must be applied in order to achieve the Normative requirements.	Specific reference the vegetable walls: the protection shall be deemed equivalent if it consists of a structure that **is a non-combustible enclose.** The aerial tanks must be surrounded by an area, having amplitude not less than 5m, completely clear and devoid of vegetation. If this distance cannot be met, the base of the wire mesh, it will be constituted by a high wall at least 0.5 m. For the underground tanks is prohibited the presence of tall trees for a radius of 5 m from the boundary of the reservoir.

Table 12. Comparative legislation IV [2], [3], [7], [12], [14], [28], [29]

	Spain	Portugal	France	Italy
Safety against fire	V≤ 1 m^3: not necessary 1<V≤ 5 m^3: Extinguish material or water at a distances less than 15 m **Fire extinguishers** must be dry chemical dust, portable or on wheels. A-5 must have at least two fire extinguishers and 2.5 kg of powder dry chemical per cubic meter per hour of transfer capacity. Installations that do not have an external water supply must be provided with **storage tanks and pumping** means that allow the mains operation for 1 h 30 min at the set pressure and flow rates.	• **Water.** • **Foam**. The capacity to generate a foam should be such as to cover the surface of the largest diameter reservoir exist with a foam height of 0.40 m with a response time of 10 minutes. • **Fire extinguishers:** for every $100m^2$ of surface a portable extinguisher with a capacity of at least 9 liters. In non-hazardous areas may be reduced by half. Where there are electronic devices, there must be at least two non-conducting fluid extinguishers. • **Sand.** There must be sand sites at a rate of 1 m^3 of sand per $2500m^2$ of uncovered surface.	The following means of control must be provided: • **A portable fire extinguisher** minimum 4 kg if the stored quantity is not more than 3500 kg • **Two fire extinguishers** of the same type if the stored quantity is greater than 3500 kg In the case of overhead storage, fire extinguishers can be replaced by a water station (with hose and lance) with an easy access control valve.	At least **two portable fire extinguishers** shall be kept in the vicinity of the tank with a minimum charge of 4 kg and capacity up to 5 m^3. Deposits above 5 m^3 must have a minimum charge of 6 kg and extinguishing capacity of not less than 21A 113B-C. For deposits up to 0.3 m^3, only one fire extinguisher with a minimum charge of 4 kg and an extinguishing capacity of not less than 13 ° 89B-C shall be kept. Aerial tanks with a capacity of more than 5 m^3 shall be protected with at least one DN 25 horn and powered by aqueducts or by a suitable water reserve, capable of ensuring the following hydraulic performance: Less than 60 l / min; Residual pressure at least 2 bar; Autonomy at least 30 minutes early.

Wall specifications	At the location of the tanks and equipment there must be a minimum 2 m high enclosure that can be of metallic mesh or any other similar system of class M1, which allows good ventilation and prevents the access of people outside the building. If this enclosure is fitted with a base, its height should not exceed 30 cm. The doors of the enclosures must open to the outside, they must also be of class M1, and the fastenings must be of quick drive from the interior without needing to use keys. The use of walls, blind walls or screens regulated can be considered as enclosure, supplemented with wire mesh or similar system to reach the height of 2 m.	Storage or handling facilities must be located within private enclosures with a separation of at least 2.50 m minimum height, counted from the level of the exterior terrain. This separation shall be **constructed of non-combustible material**. • This wall must be constructed in such a way as to prevent any eventual discharge into the exterior of the liquids existing in the installation and in case of explosion, fire or breakage, the number of doors in that installation will be absolutely essential	It must be a solid wall **constructed with a fire-resistant material of two-hour degree**. The height of which exceeds that of the filling mouth and the orifice of the valve by 0.50 meters, and the length of which is such that the horizontal projection of the actual path of the vapors between the aforementioned orifices.	**Specific paragraph for fences.** Between the dangerous elements of the deposit and the fence must be observed a minimum distance of 1 m. For deposits of residential complexes service, at most four families, the fence is not necessary provided that the tanks are installed on private property. In cases where it is not possible to install on the tanks of the filling point, this can be located in another position, devoid of fence, in accordance with the distances referred previously. The reservoir coated can be protected, as an alternative to the fence, using a special structure in concrete, even prefabricated, whose attractive superior walls of at least 0.5 m from the tank walls.

6. Study case

6.1 Introduction

Once the situation relative to the existing problem with WUI fire in contact with LPG facilities is exposed, different scenarios will be generated according to several variables. To do this, it is going to be studied the influence of variables such as the direction of the wind and the distance of this vegetation to the tank itself.

For the development of the simulation scenarios, the vegetation mass, as an existing problem for safety in LPG facilities, will be the generator of the fire and it will be represented by finite and solid elements with a fixed fire curve. The main objective of this study is, with a fixed tank of designed dimension, relate the influence in its performance with the variables of study (wind velocity and separation between the shrubs as a flammable element to the tank). Parameters as the radiative heat flux emitted by the fire, the temperature in the surface, the temperature inside the wall and the temperature inside the tank will be exposed in order to characterize the scenarios.

Using FDS (Fire Dynamics Simulator) CFD simulation tool, temperature and radiation heat emitted by the fire on the surface of the tank will be investigated during a 40 seconds fire (residence time of typical ornamental vegetation).

Taking into account the scenarios set-up and the results obtained, safety criteria and dangerousness of these situations will be discussed.

6.2 Fire Dynamic Simulator (FDS)

6.2.1 Introduction

Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) simulation of fire-driven fluid flow developed by NIST (National Institute of Standards and Technology) [33]. CFD typically divides the space of interest into a large number of discreet 3D control volumes for which the fundamental equations governing the conservation of mass, species, temperature, velocity and density are solved. The FDS model numerically solves a form of the Navies-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. the default computational mode uses the Smagorinsky form of Large-Eddy Simulation (LES) technique to solve large scale hydrodynamic turbulence, a condition that typically occurs in fires. The current version of FDS is 6.5.3 released on 2017.

FDS requires an input file for each fire scenario in a simple text format to represent the building geometry, materials specification, computational scope, grid resolution, boundary conditions, design fire and energy source parameters, and specifications of fire safety and mechanical systems, as well as the simulation output types [30].

The FDS computational domain is user defined and usually represents the overall physical bounding box enclosing a building or zone of interest. The computational domain is made up of one or more rectangular meshes, each with its own 3D rectilinear grid system. The resolution of the grid is also user specified in the input file, but the grid dimensions must meet the criteria for the Poisson solver. All solid obstructions and voids are forced to conform to the numerical grids [30].

As it was mentioned, creating the input geometry for FDS simulations is a complicated, laborious and time-consuming process especially for complex models with several complicated components. Nowadays, several advanced graphical user interfaces (GUI) are available.

On this case, PyroSim is a GUI developed by Thunderhead Engineering Consultants, Inc., USA in order to facilitate preparation of inputs for FDS simulations. The main functions of PyroSim cover an interactive creation of complex models (the use of ground plans, creation of multiple repetitious objects, curved walls, etc.), import of existing input FDS files, PyroSim files and CAD files. PyroSim enables importing a ground plan, saving it as a background image and displaying it in its 2D or 3D view modes. The background image scale can be modified to correspond to the computational mesh chosen for intended FDS simulation. This feature greatly facilitates the creation of geometry of complicated models. In the 2D view mode, there are several useful tools for creating the basic elements and their combinations, which represent the input FDS geometry of objects appearing in buildings [31]. The current PyroSim version includes FDS and allows to run FDS simulations.

6.2.2 FDS inputs

The creation of the FDS input file is a part of the fire modelling process and requires varying degrees of manual input and editing particularly when considering multiple fire scenarios. Generally, the most time consuming part of the input data creation is the transfer of SOLID geometry information from paper or CAD drawings to the format required by FDS. However, these tools require the reconstruction of the building in one form or another, using information derived from printed plans or CAD files.

It can also incorporate a set of pre-defined FDS input parameters such as the computational domain and grid sizes, selected surface materials, prescribed fire source, etc. To assist with the construction of the 3D building model similar to the obstruction blocks in FDS, a 2D image of the building plan can be overlaid on the graphics editor screen to allow three-dimensional wall elements to be manually positioned by tracing over the lines [30].

6.2.3 FDS outputs

The simulation outputs from FDS can be visualized graphically in an interactive 3D environment using an application called SmokeView. FDS can produce graphical output files containing the 3D model geometry, animated quantities per unit time, as well as static pictures of the flow field in Plot3D format which can be accessed and visualized using SmokeView. The type of output quantities includes also space and boundary conditions such as the temperature profile, heat flux and mass flow rate, the history of heat release rates, the levels of oxygen, carbon dioxide and carbon monoxide, and other combustion products as variables to be studied, including its variation during the scenario resolution (Excel output files).

6.3 Design of experiments

An LPG storage tank impacted by flames from ornamental vegetation will be studied in different conditions, according to differences in wind and separation distances. The variables under study will be the temperatures reached by the system and heat flow on the surface of the tank.

To do so, using a series of assumptions, a base and simplified scenario will be simulated in which a LPG tank filled to 30% (simplified and simulated as a solid block part of the tank) of its capacity will be subjected to thermal radiation coming from a front of burning shrubs located in its vicinity. The dimensions of the tank are 1.0 m diameter x 1.9 m long, with a total volume of 1.50 m^3. (*Figure 22*) Concerning the components of the system, the steel, which it can support strong efforts, is the main component of the tank and the one considered in the design.

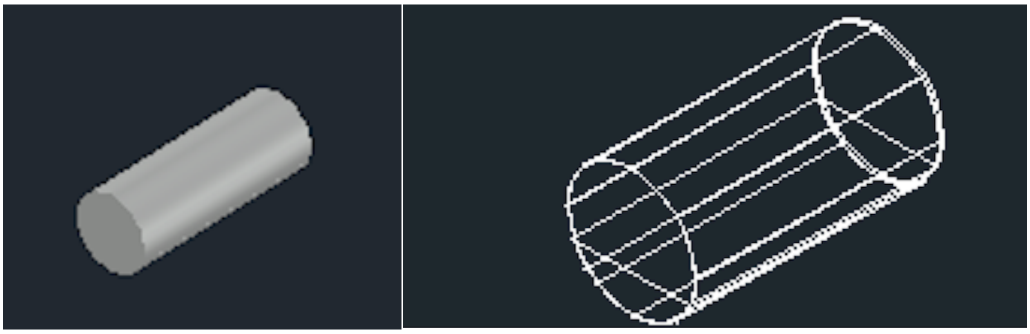

Figure 22. Tank modelling

For the generation of the different scenarios, a specific fire curve has been introduced. For the measurement of the various heat flows and temperatures, several meters have been installed in the tank at 3 different heights and at different thicknesses of the tank: one on the outside, another in the middle of the tank wall, and another one on the inner wall. The main variables to analyze in all cases will be the temperatures and the heat flux in the LPG tank.

For the simulation of the burning vegetation, 22 rectangular elements with fixed dimensions will be used at a distance of 0.8 m (*Figure 23*).

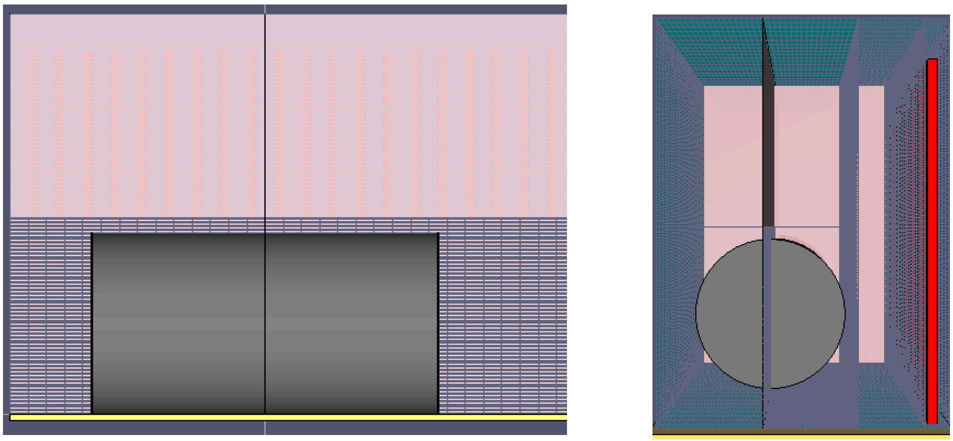

Figure 23. Scenario Construction

For this, and taking into account the enormous variability of conditions that could be assumed, tank dimensions and height of shrubs will be fixed, so that the different scenarios are comparable to each other. One of the main variables to be set will be the wind profile. The three main scenarios will be presented taking into account the considerations indicated previously and attending to the computational speed of the simulator, generating three different responses according the wind velocities:

- Scenario 1 (FS1): 0 m/s wind

- Scenario 2 (FS2): 1 m/s wind
- Scenario 3 (FS3): 3 m/s wind

Once the profiles and data obtained from these three scenarios are analyzed, the worst scenario will be selected according to the temperatures and two new scenarios will be simulated considering two different distances between the shrub and the LPG tank. These distances will be those proposed by the legislation for those mentioned countries that contemplate the permissibility of a shrub or vegetal mass next to a LPG tank:

- Scenario 4 (FS4): 0.75 m shrub from LPG tank
- Scenario 5 (FS5): 1.5 m shrub from LPG tank

In this way, it will be possible to compare the effects that the fire can cause and try to conclude whether these distances are adequate or if other considerations should be taken into account in a wildland-urban interfaces fire.

FDS codes for each of the scenarios can be consulted in the Annex.

6.4 FDS settings

The volume modelled was divided in five different meshes (according next *Figure 24*) with different cell sizes according to FDS specifications.

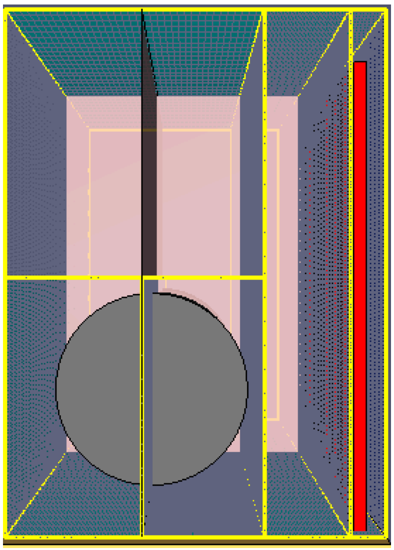

Figure 24. Mesh scenario

- Mesh 1

Table 13. Mesh 1 definition

Mesh Boundary:	Min X: 0.87 m	Min Y: -2.0 m	Min Z: 0.0 m	
	Max X: 1.02 m	Max Y: 1.4 m	Max Z: 2.2 m	
X Cells: 15	**Cell Size ratio: 1**			
Y Cells: 68	**Cell Size ratio: 5**	**Cell size (m):**	0.01x 0.05x 0.01	
Z Cells: 220	**Cell Size ratio: 1**	**Number of cells for mesh:**		224,400

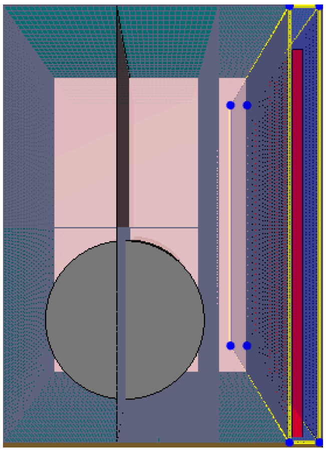

Figure 25. Mesh 1

- Mesh 2:

Table 14. Mesh 2 definition

Mesh Boundary:	Min X: 0.00 m	Min Y: -2.0 m	Min Z: 0.0 m	
	Max X: 0.51 m	Max Y: 1.4 m	Max Z: 1.08 m	
X Cells: 85	**Cell Size ratio: 1**			
Y Cells: 34	**Cell Size ratio: 16.67**	**Cell size (m):**	0.006x 0.1x 0.010	
Z Cells: 108	**Cell Size ratio: 1.67**	**Number of cells for mesh:**		312,120

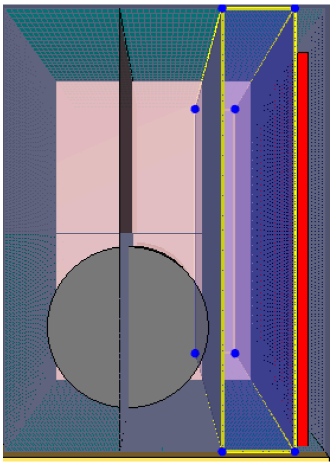

Figure 26. Mesh 2

- Mesh 3:

Table 15. Mesh 3 definition

Mesh Boundary:	Min X: -0.57 m	Min Y: -2.0 m	Min Z: 0.0 m	
	Max X: 0.00 m	Max Y: 1.4 m	Max Z: 1.08 m	
X Cells: 57	**Cell Size ratio: 1.0**			
Y Cells: 34	**Cell Size ratio: 10.0**	**Cell size (m):**	0.01x 0.1x 0.01	
Z Cells: 108	**Cell Size ratio: 1.0**	**Number of cells for mesh:**		209,304

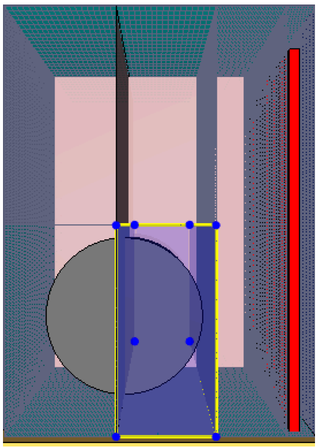

Figure 27. Mesh 3

- Mesh 4:

Table 16. Mesh 4 definition

Mesh Boundary:	Min X: -0.57 m	Min Y: -2.0 m	Min Z: 0.0 m	
	Max X: 0.00 m	Max Y: 1.4 m	Max Z: 1.08 m	
X Cells: 57	**Cell Size ratio: 1.0**			
Y Cells: 34	**Cell Size ratio: 10.0**	**Cell size (m):**	0.01x 0.1x 0.01	
Z Cells: 108	**Cell Size ratio: 1.0**	**Number of cells for mesh:**		209,304

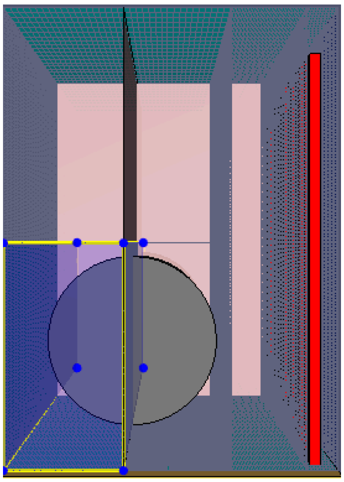

Figure 28. Mesh 4

- Mesh 5:

Table 17. Mesh 5 definition

Mesh Boundary:	Min X: -0.57 m	Min Y: -2.0 m	Min Z: 1.08 m	
	Max X: 0.51 m	Max Y: 1.4 m	Max Z: 2.2 m	
X Cells: 36	**Cell Size ratio: 3.0**			
Y Cells: 34	**Cell Size ratio: 10.0**	**Cell size (m):**	0.03x 0.1x 0.01	
Z Cells: 112	**Cell Size ratio: 1.0**	**Number of cells for mesh:**		137,088

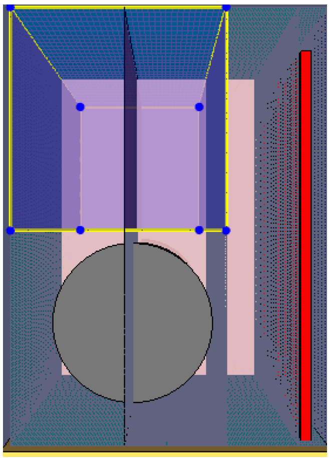

Figure 29. Mesh 5

The solid phase was modelled by using the simple pyrolysis model while the gas phase combustion was described by employing the single chemistry mixing-controlled approach. This combustion method assumes an infinitely fast reaction of fuel and oxygen and only allows one single gaseous fuel resulting from the combustion process. For simplification, polyethylene (PE) was selected as the main fuel of the reaction of combustion (*Table 18*).

Table 18. Reaction characteristics [36]

Parameter	Polyethylene
Formula	C_2H_4
CO yield (kg/kg)	0.042
Soot yield (kg/kg)	0.198
Heat of combustion (kJ/kg)	38,400
Critical Flame Temperature (°C)	1327,0

First of all, various measurement points, by which we obtained the punctual time evolution of the three selected variables, were located at different heights over the stepped surface (as it can be seen on the *Figure 30* and *Table 19*). Finally, the temperatures (wall temperature tanks surface, wall temperature inside tanks surface and temperature inside the tank), the thermal flux at the tank surface were quantified. Then, diverse slice files, which are able to graphically represent the time evolution of the variables of interest in a particular plane, were horizontally located at the heights stated before.

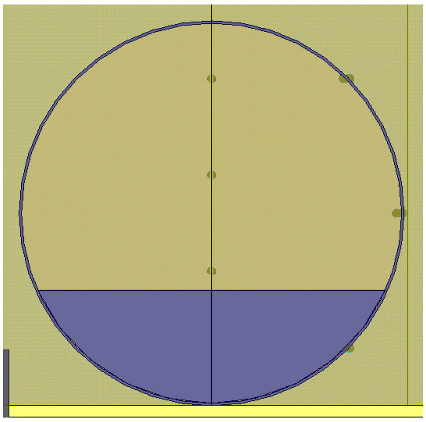

Figure 30. Measurement device

Table 19. Measurement Devices List

Measurement Device name	Height (m) Y Plane	Out/ Middle/ In
WT_360_Up	0.85	Out
WT_354cm_Up	0.85	Middle
T_342cm_Up	0.85	In
Qnet_360cm_Up	0.85	Out
Qnet_354cm_Up	0.85	Middle
Qrad_360cm_Up	0.85	Out
Qrad_354cm_Up	0.85	Middle
WT_498cm_Middle	0.50	Out
WT_492cm_Middle	0.50	Middle
T_480cm_ Middle	0.50	In
Qnet_498cm_ Middle	0.50	Out
Qnet_492cm_ Middle	0.50	Middle
Qrad_498cm_ Middle	0.50	Out
Qnet_492cm_ Middle	0.50	Middle
WT_360cm_Down	0.15	Out
WT_354cm_ Down	0.15	Middle
T_342cm_ Down	0.15	In
Qnet_360cm_ Down	0.15	Out
Qnet_354cm_ Down	0.15	Middle
Qrad_360cm_ Down	0.15	Out
Qnet_354cm_ Down	0.15	Middle
P_Up	0.85	In
P_Middle	0.6	In
P_Down	0.35	In

The fire origin, which was located on the shrubs represented by the rectangular forms as it could be observed in *Figure 31*, was simulated by using the simple pyrolysis model which requires the HRR. To take into account the heat losses and its influence on fire behavior, the tank material’s thermal properties were defined according to data given by FDS:

Table 20. Steel properties FDS simulator

Parameter	Steel
Specific heat (kJ/kg·K)	0.46
Conductivity (W/m·K)	45.8
Density (kg/m^3)	7,850
Emissivity	0.95
Heat Release Rate per Area (HRRPUA) (kW/m^2)	1000,0
Wall thickness (m)	0.062

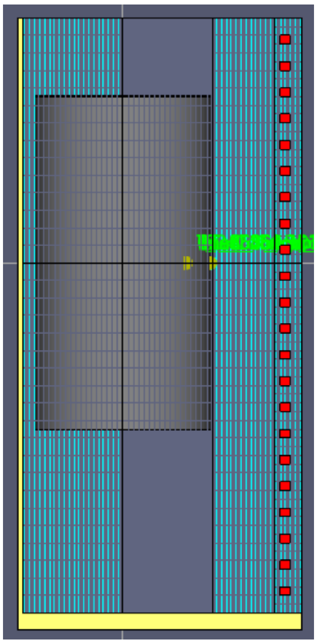

Figure 31. Fire vegetable front, represented by finite elements in red

The definition of the shrubs represented as 22 polygons was made as follows:

Table 21. Vegetable mass dimensions

Bounding Box		
Min X: 0,9 m	Min Y: -1.9 m	Min Z: 0.0 m
Max X: 0,954 m	Max Y: 1.3 m	Max Z: 2.0 m
Volume: 0,05m x 0,05mx 2m	Separation between them:	0.10m

For the generation of fire scenarios, the fire profile ramp was defined as an input following the next parameters included on *Table 22* and *Figure 32*.

Table 22. Fire profile input

t_1: 0 seconds	F (fire efficiency): 0	
t_2: 10 seconds	F (fire efficiency): 1	**MLRPUA: 0,1633**
t_3: 15 seconds	F (fire efficiency): 0,5	
t_4: 20 seconds	F (fire efficiency): 0,12	
t_5: 40 seconds	F (fire efficiency): 0	

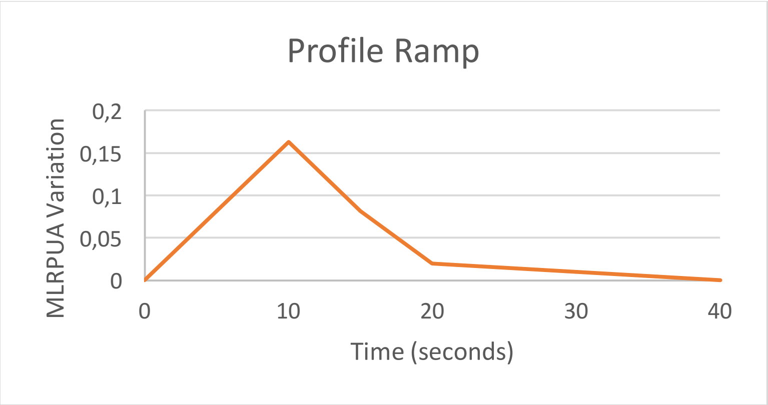

Figure 32. MLRPUA Variation

Where, MLRPUA (Mass Loss Rate Per Unit Area) is:

$$MLRPUA = \frac{Volumetric\ flow\ rate * Density}{Burner\ area} \qquad \text{Eq. 5}$$

At the time of analyzing the scenarios, these were run during different times due to the high computational load:

- Scenario 1: 31.44 seconds
- Scenario 2: 30.60 seconds
- Scenario 3: 17.96 seconds
- Scenario 4: 40.00 seconds
- Scenario 5: 40.00 seconds

6.5 Results

6.5.1 Scenario 1

Supposing a 0 m/s wind situation, the different profiles of temperature are obtained. Firstly, it is going to be shown the different temperatures outside the wall surface for the different measurement devices height (0.15 m, 0.5 m and 0.85 m in Y plane) which name corresponds to its position in X plane:

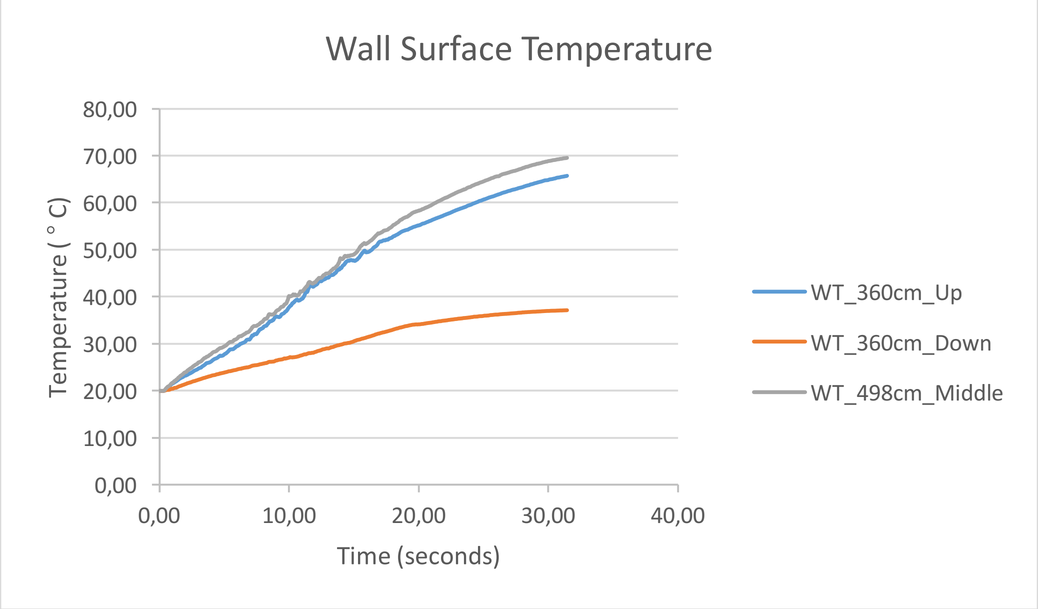

Figure 33. Wall surface temperature profile 3 different heights 0 m/s wind

As can be seen in *Figure 33*, the maximum profile temperature is reached on the middle part of the tank (0.5 m), followed by the upper part, achieving a temperature near 70 °C in 30 seconds. The temperature at the lowest part of the tank could be considered constant at 20 seconds after ignition with a final wall temperature of 37 °C.

Then, the same is done for the wall temperature interface (the space in the middle of the wall, between the outside and the inside of the tank):

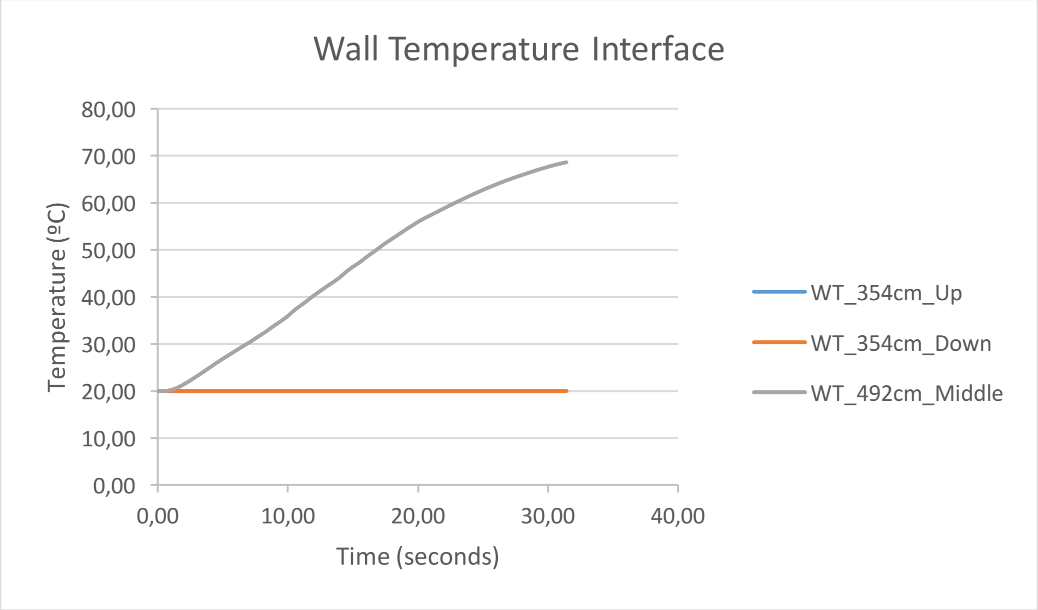

Figure 34. Wall temperature interface profile 3 different heights 0 m/s wind

As we can see in *Figure 34*, the maximum profile temperature is reached on the middle part of the tank, achieving a temperature near 70 °C in 30 seconds, as it happens on the outside wall temperature. The temperature on the lowest and highest part of the tank is the same and it could be considered constant at 20 seconds until the end in an outside wall temperature of 20 °C (both curves are superposed). As it can be shown in the *Figure 34*, when we are nearer to inside tank, the temperatures are increasing continuously on it and the medium height is the most affected part and.

Finally, in order to characterize the system and compare with the literature values, the curve of thermal flux heat transfer to the wall outside is also obtained (0.15 m, 0.5 m and 0.85 m in Y plane):

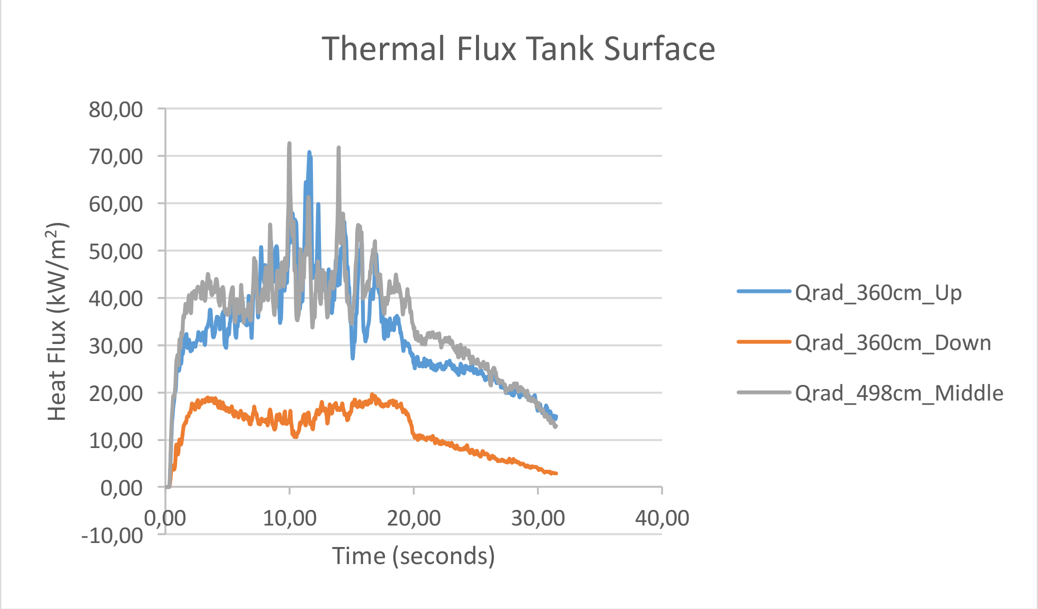

Figure 35. Thermal Flux on the Tank Surface 0 m/s wind

As it happens with temperature, the thermal heat flux (*Figure 35*) reaches its maximum value on the middle and up part, giving a value near 72 kW/m^2, so far from the giving value of 22 kW/m^2 mentioned on literature.

In addition, the Smoke View Simulator gives a visualization of the simulation in a plan view, giving the image at the highest peak of thermal flux (10 seconds to 20 seconds) with temperature values between 20 ° C (blue profile) and 980 °C (red profile):

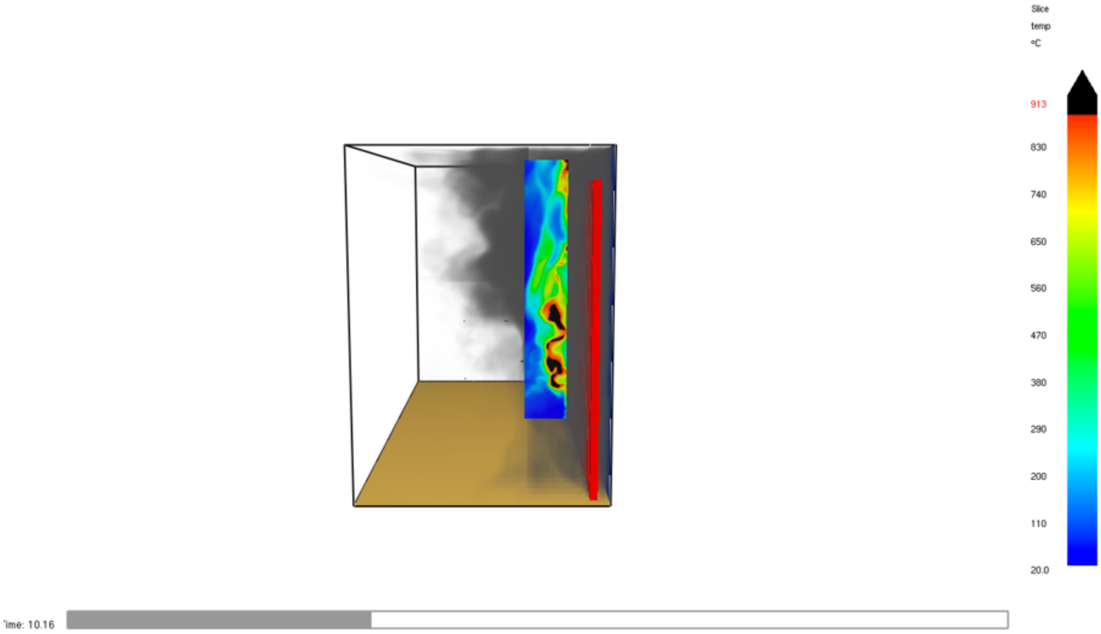

Figure 36. 10 seconds simulation results 0 m/s wind

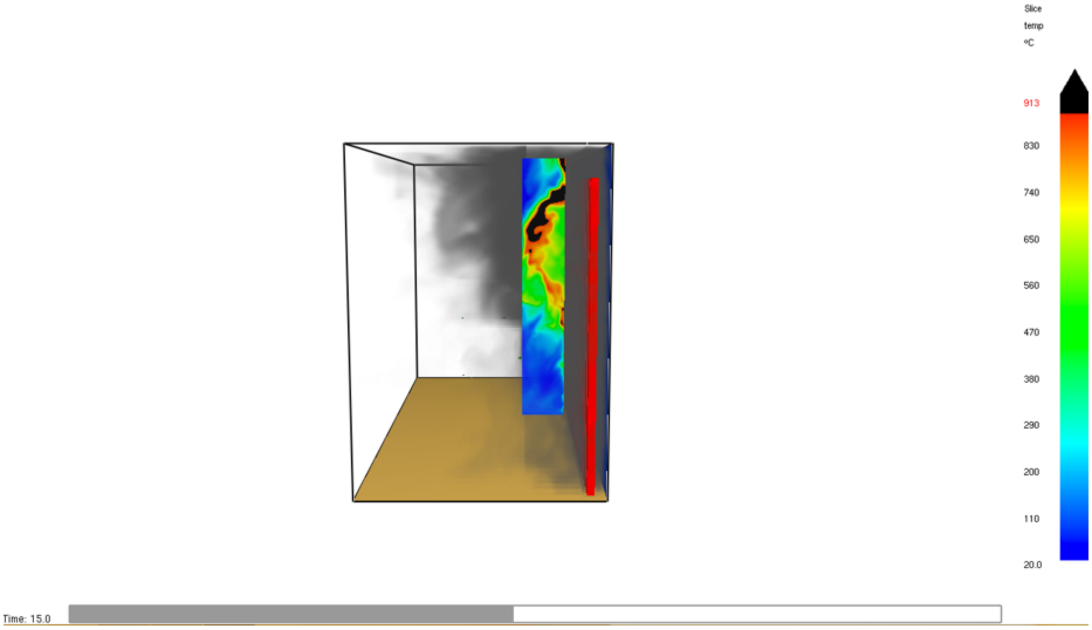

Figure 37. 15 seconds fire simulation 0 m/s wind

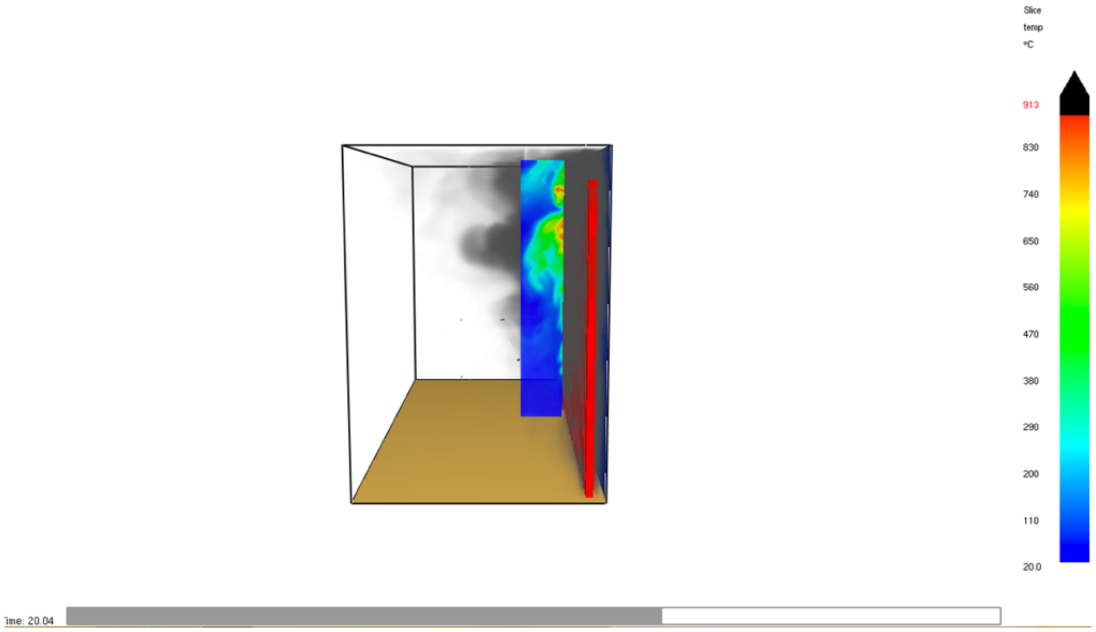

Figure 38. 20 seconds fire simulation 0 m/s wind

6.5.2 Scenario 2

As in Scenario 1, supposing a 1 m/s wind situation, the different profiles of temperature are obtained. Firstly, it is going to be shown the different temperatures outside the wall surface for the different measurement devices height (0.15 m, 0.5 m and 0.85 m in Y plane):

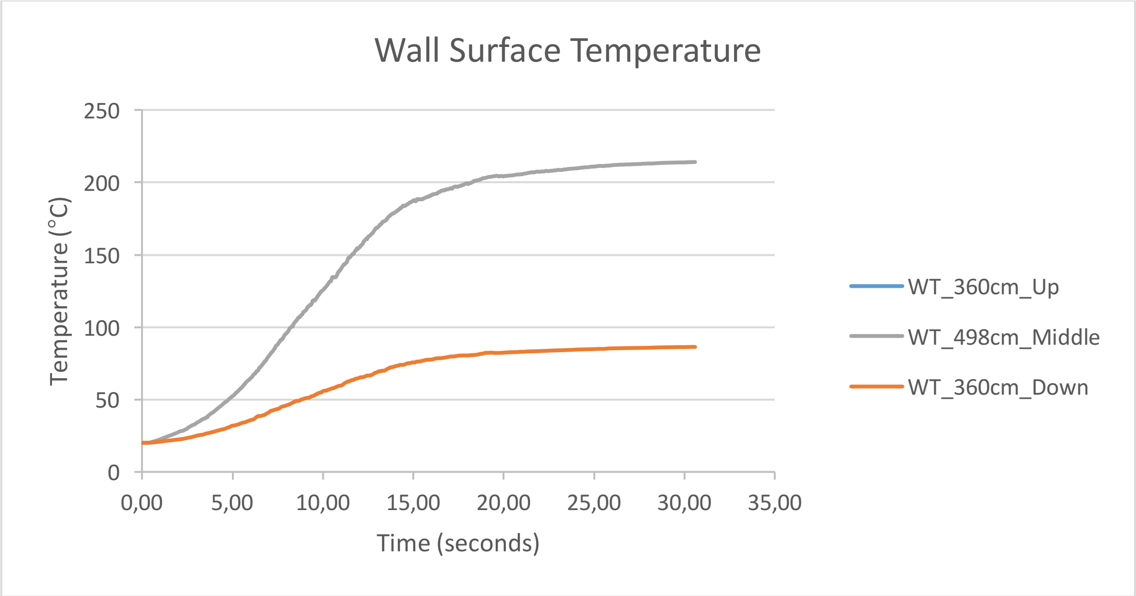

Figure 39. Wall surface temperature profile 3 different heights 1 m/s wind

As we can see (Figure 39), the maximum profile temperature is reached on the up and middle part of the tank, reaching the same values, achieving a temperature near 210 °C in 18 seconds (the curves of both parts are superposed). The temperature on the lowest part of the tank has reached a final value of 80 °C in 15 seconds.

Then, the same is done for the wall temperature interface:

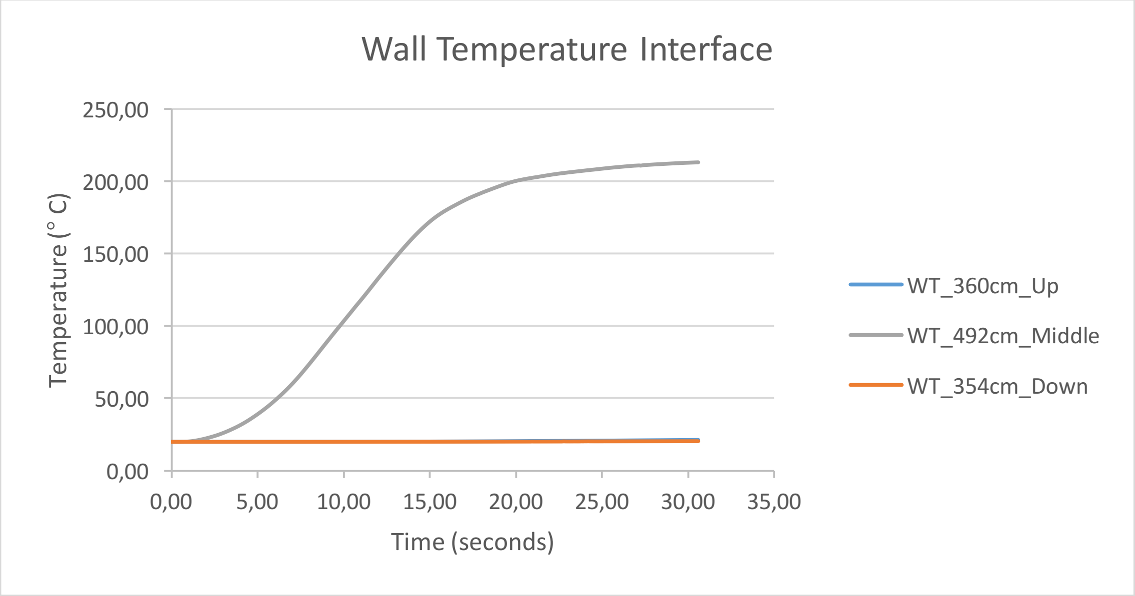

Figure 40. Wall temperature interface profile 3 different heights 1 m/s wind

As we can see, the maximum profile (*Figure 40*) temperature is reached on the middle part of the tank, achieving a temperature near 205-210 °C in 15-20 seconds, as it happens on the outside wall temperature, but reaching a final temperature lightly smaller than the external part. The temperature on the lowest and highest part of the tank could be considered constant until the end in an outside wall temperature of 20 °C and these values are superposed.

Finally, in order to characterize the system and compare with the literature values, the curve of thermal flux heat transfer to the wall outside is also obtained:

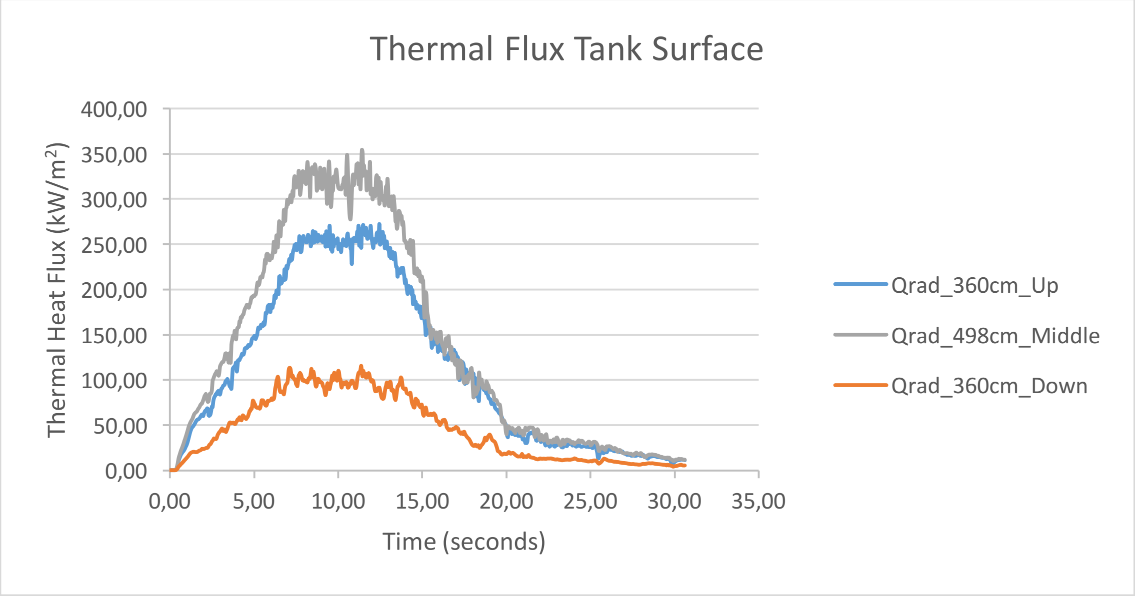

Figure 41. Thermal Flux on the Tank Surface 1 m/s wind

As it happens with temperature, the thermal heat flux reaches its maximum value on the middle part, giving a value near 350 kW/m^2, much bigger than the giving value of 22 kW/m^2 mentioned on literature.

In addition, the Smoke View Simulator gives a visualization of the evolution of temperature during the simulation in a plan view. The figures show the interval of highest temperature values with parts in blue (temperatures near 20 °C) to red (temperature near 1500 °C):

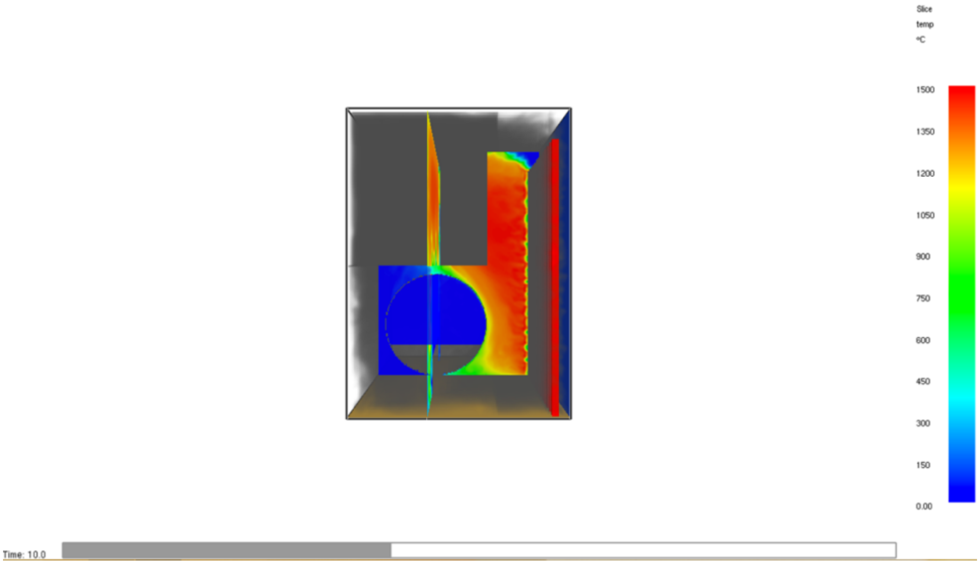

Figure 42. 10 seconds fire simulation 1 m/s wind

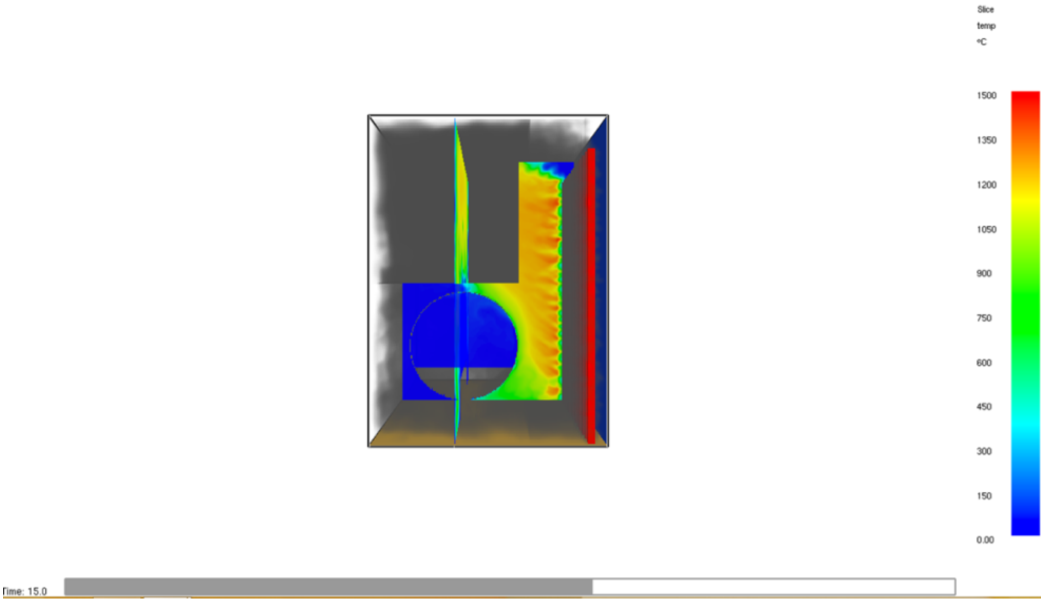

Figure 43. 15 seconds fire simulation 1 m/s wind

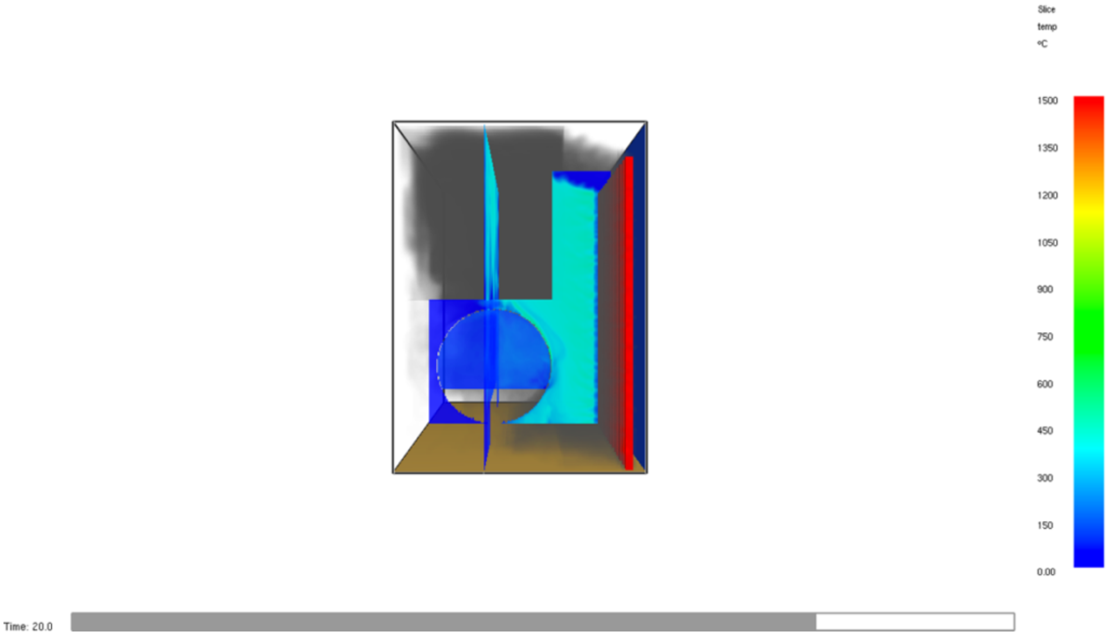

Figure 44. 20 seconds fire simulation 1 m/s wind

6.5.3 Scenario 3

Supposing a 3 m/s wind situation, the different profiles of temperature are obtained. Firstly, it is going to be shown the different temperatures outside the wall surface for the different measurement devices height (0.15 m, 0.5 m and 0.85 m on Y plane):

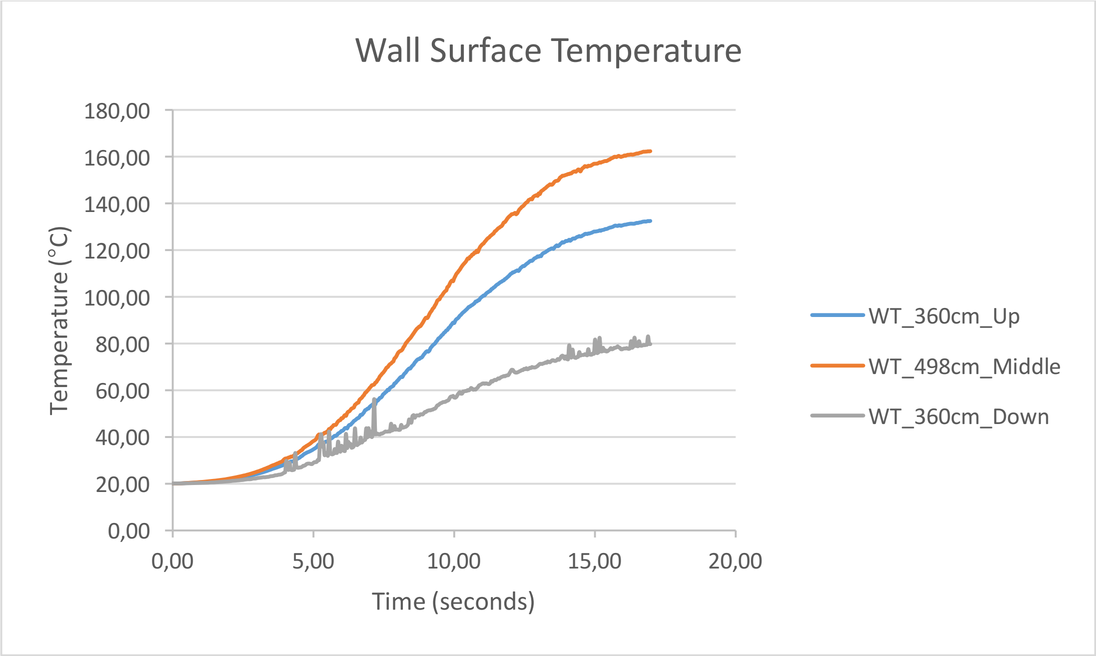

Figure 45. Wall surface temperature profile 3 different heights 3 m/s wind

As we can see in *Figure 45*, the maximum profile temperature is reached on the middle part of the tank, followed by the upper part, achieving a temperature near 165 °C in 16 seconds. The temperature on the lowest part of the tank could be considered constant at 15 seconds until the end in an outside wall temperature of 80 °C.

Then, the same is done for the wall temperature interface:

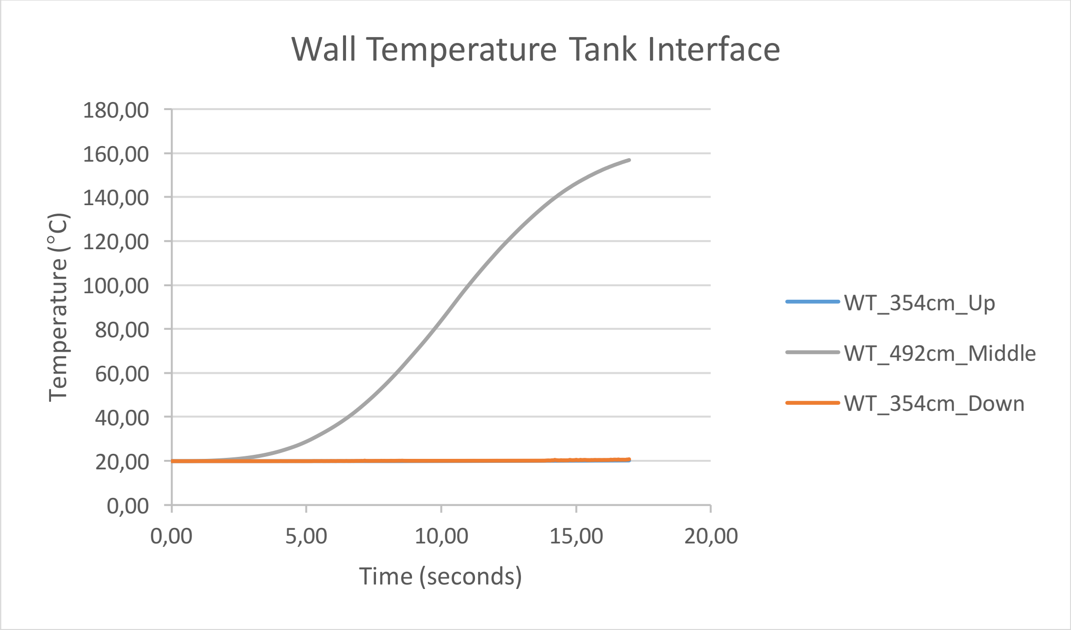

Figure 46. Wall temperature interface profile 3 different heights 3 m/s wind

As we can see in *Figure 46*, the maximum profile temperature is reached on the middle and upper part of the tank (same response), achieving a temperature near 155 °C in 16 seconds, as it happens on the outside wall temperature. The temperature on the lowest part of the tank could be considered constant until the end in an outside wall temperature of 20 °C.

Finally, in order to characterize the system and compare with the literature values, the curve of thermal flux heat transfer to the wall outside is also obtained:

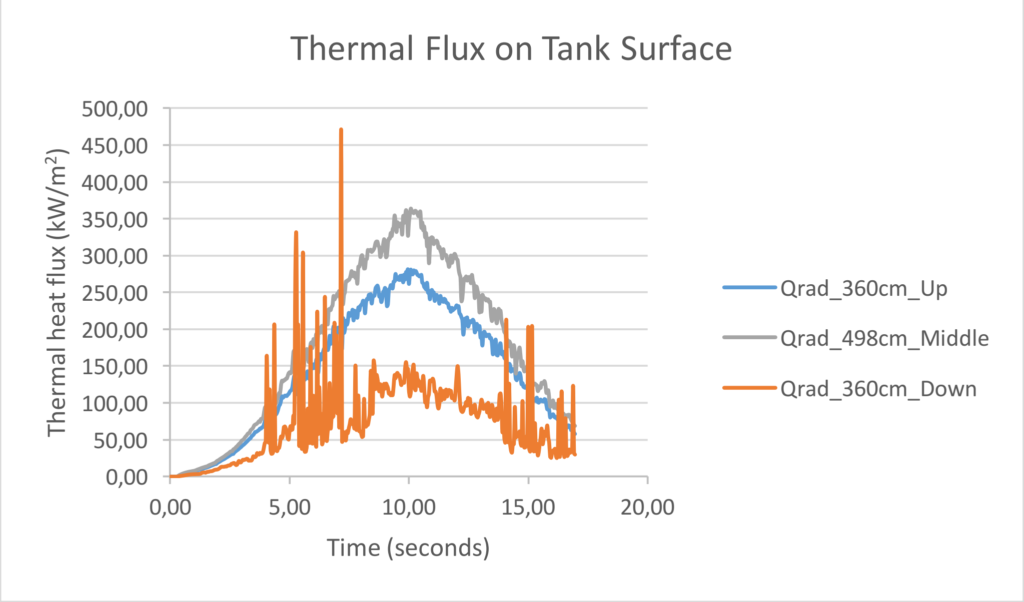

Figure 47. Thermal Flux on the Tank Surface 3 m/s wind

As it happens with temperature, the thermal heat flux (*Figure 47*) reaches its maximum value on the middle part, giving a value near 360 kW/m^2, so far from the giving value of 22 kW/m^2 mentioned on literature. There are also some peaks observed in the lowest part of the tank with values near 500 kW/m^2.

In addition, the Smoke View Simulator gives a visualization of the evolution of temperature during the simulation in a plan view. The figures show the interval of highest temperature values with parts in blue (temperatures near 20 °C) to red (temperature near 920 °C):

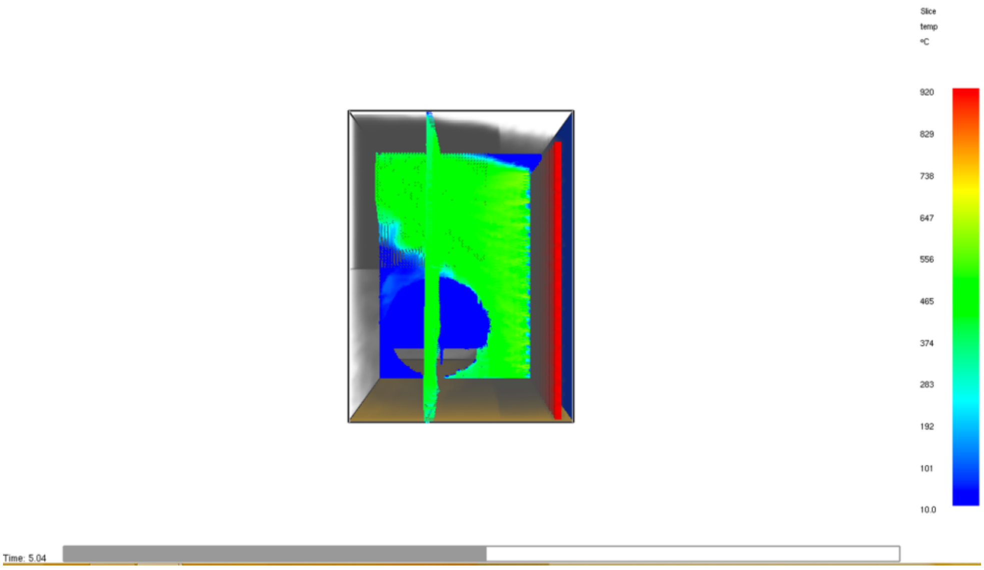

Figure 48. 5 seconds simulation results 3 m/s wind

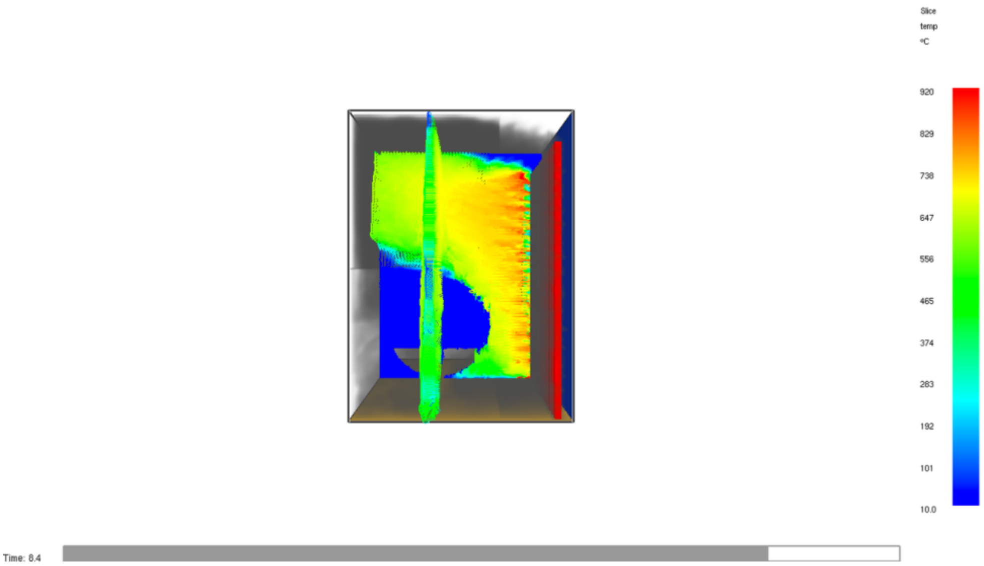

Figure 49.8,5 seconds fire simulation 3 m/s wind

6.5.4 Scenario 4

Taking into account the results analyzed in section 6.6.1, the scenario 2 will be studied as the one selected to see the affectation in the system taking into account the variable of the distance between the tank and the burning vegetation. Thus, scenario 4 will simulate a fire of ornamental vegetation with wind meteorological conditions with a velocity of 1m/s that is located 0.75 m from the LPG tank.

Firstly, it is going to be shown the different temperatures outside the wall surface for the different measurement devices height (0.15 m, 0.5 m and 0.85 m in Y plane):

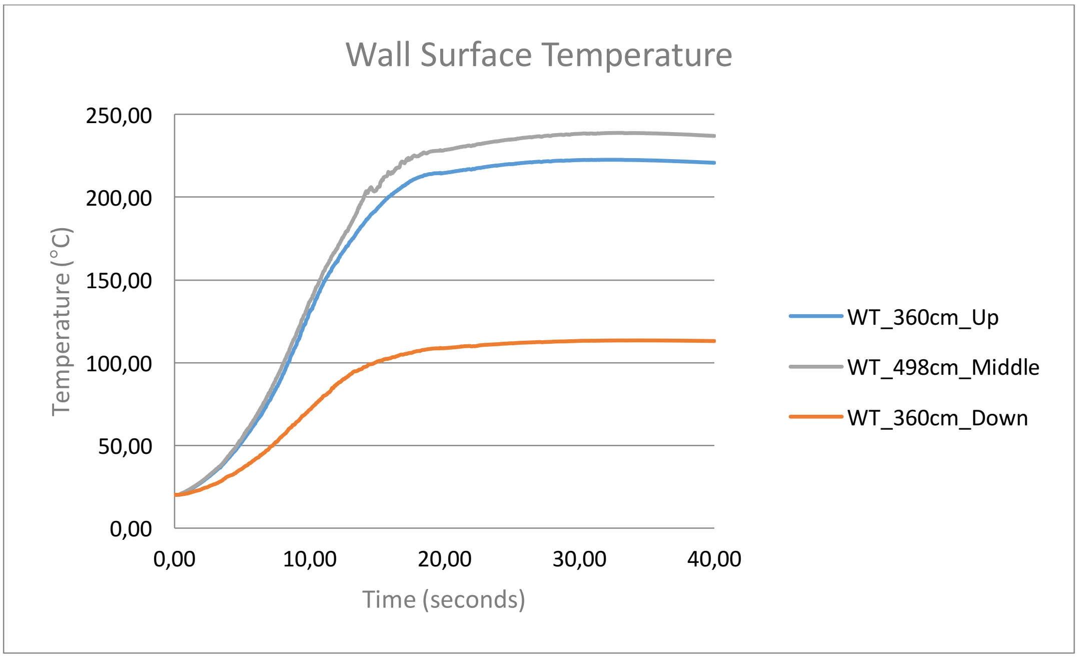

Figure 50. Wall surface temperature profile 3 different heights 1 m/s wind and 0.75 m separation

As we can see in *Figure 50*, the maximum profile temperature is reached on the middle part of the tank, followed by the upper part, achieving a temperature near 245 °C in 20 seconds. The temperature on the lowest part of the tank could be considered constant at 15 seconds until the end in an outside wall temperature of 115 °C, as it happens with up and middle temperatures.

Then, the same is done for the wall temperature interface:

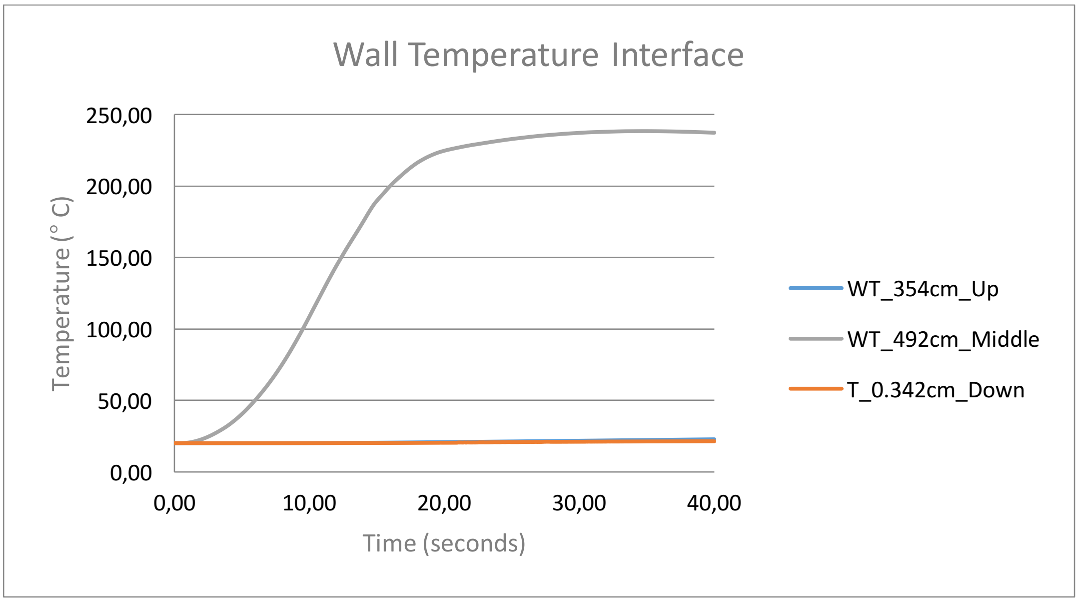

Figure 51. Wall temperature interface profile 3 different heights 1 m/s wind and 0.75 m separation

As we can see in *Figure 51*, the maximum profile temperature is reached on the middle part of the tank, achieving a temperature near 240 °C in 16 seconds, as it happens on the outside wall temperature. The temperature on the lowest and middle part (superposed) of the tank could be considered constant until the end in an outside wall temperature of 20 °C.

As it can be shown in the *Figure 52 and Figure 53*, when we are nearer to inside tank, the temperatures are increasing continuously on it.

Finally, in order to characterize the system and compare with the literature values, the curve of thermal flux heat transfer to the wall outside is also obtained:

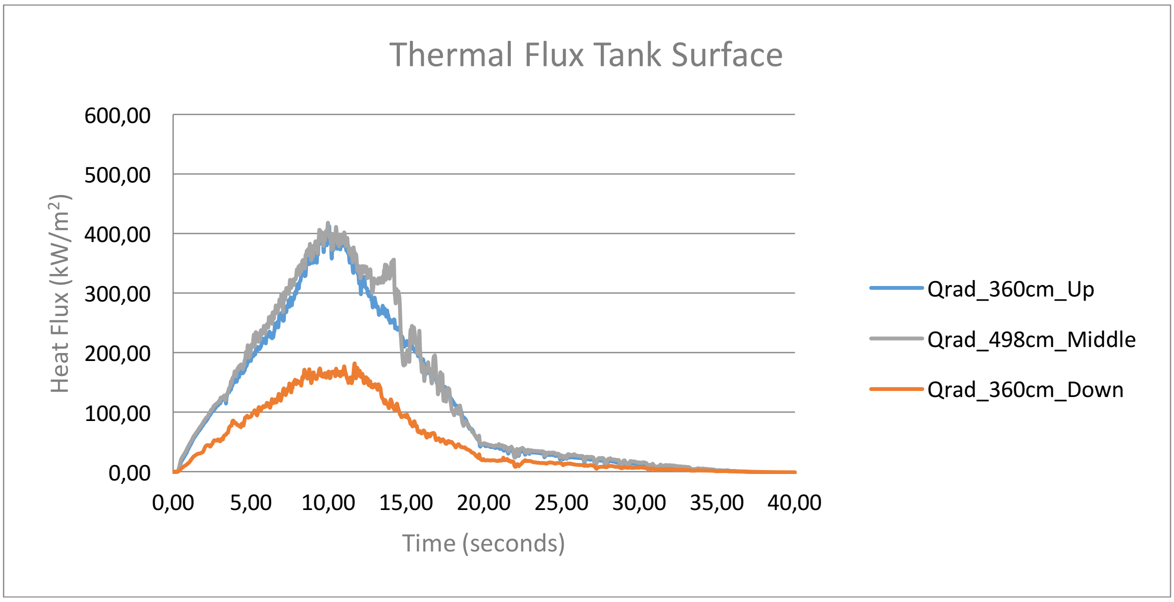

Figure 52. Thermal Flux on the Tank Surface 1 m/s wind and 0.75 m separation

The thermal heat flux (*Figure 52*) reaches its maximum value on the middle part, giving a value near 420 kW/m^2, so far from the giving value of 22 kW/m^2 mentioned on literature and followed by the upper part. At 20 seconds, it decreases considerably to values near zero.

6.5.5 Scenario 5

Taking into account the results analyzed in section 6.6.1, scenario 5 will simulate a fire of a plant mass with wind meteorological conditions with a velocity of 1m/s that is located 1.5 m from the LPG tank. Firstly, it is going to be shown the different temperatures outside the wall surface for the different measurement devices height (0.15 m, 0.5 m and 0.85 m):

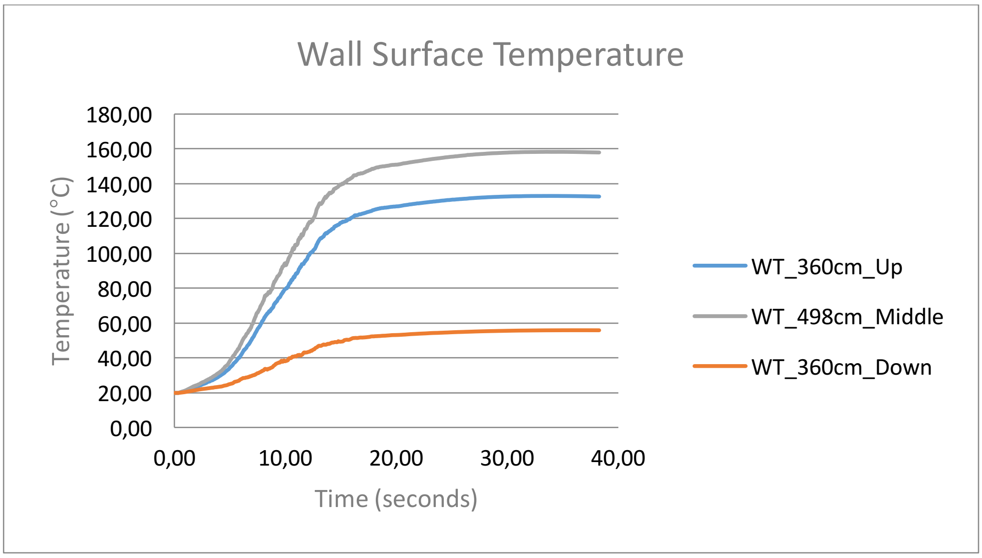

Figure 53. Wall surface temperature profile 3 different heights 1 m/s wind and 1.5 m separation

As we can see in *Figure 53*, the maximum profile temperature is reached on the middle part of the tank, followed by the upper part, achieving a temperature near 160 °C in 30 seconds. The temperature on the lowest part of the tank could be considered constant at 15 seconds until the end in an outside wall temperature of 55 °C, as it happens with up and middle temperatures.

Then, the same is done for the wall temperature interface:

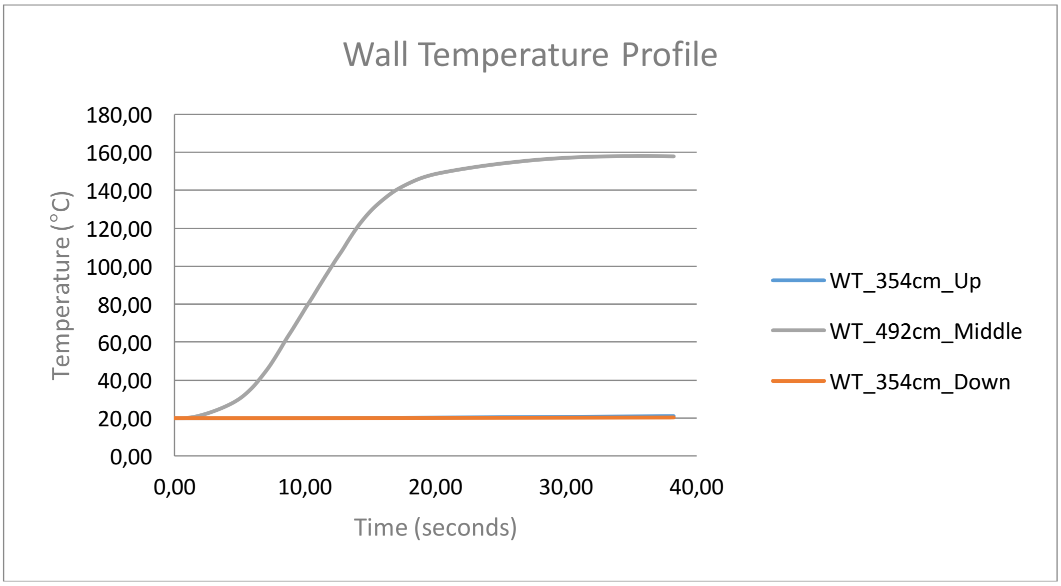

Figure 54. Wall temperature temperature profile 3 different heights 1 m/s wind and 1.5 m separation

As we can see in *Figure 54*, the maximum profile temperature is reached on the middle part of the tank, achieving a temperature near 160 °C in 25 seconds, as it happens on the outside wall temperature. The temperature on the lowest and middle part of the tank could be considered constant until the end in an outside wall temperature of 20 °C.

Finally, in order to characterize the system and compare with the literature values, the curve of thermal flux heat transfer to the wall outside is also obtained:

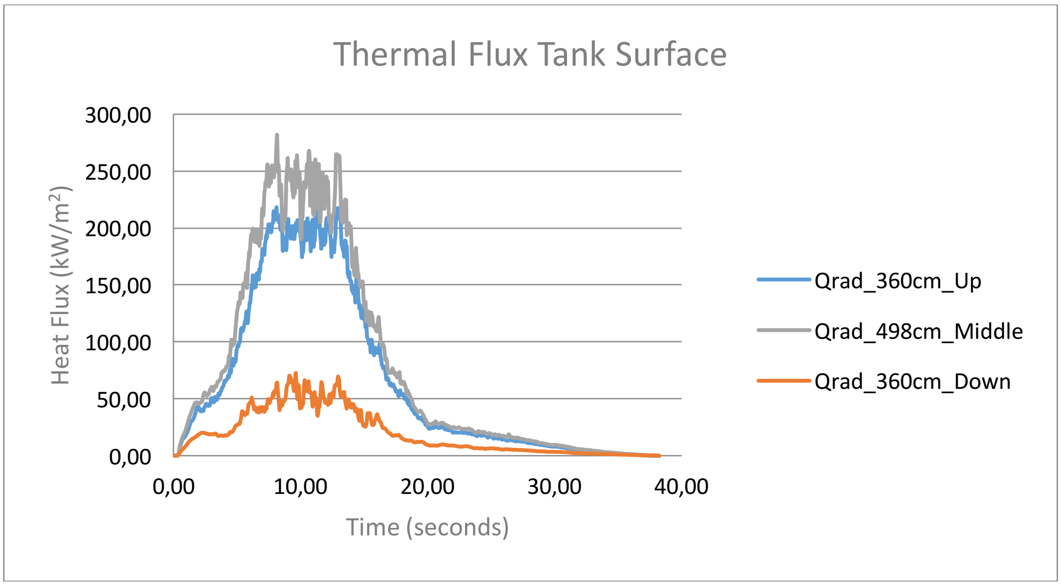

Figure 55. Thermal Flux on the Tank Surface 1 m/s wind and 1.5 m separation

The thermal heat flux reaches its maximum value on the middle part, giving a value near 270 kW/m^2, so far from the giving value of 22 kW/m^2 mentioned on literature. At 20 seconds, it decreases considerably to values near zero.

6.6 Discussion

6.6.1 Scenario 1, 2 and 3

In the case of **scenario 1**, a fire situation has been simulated in which there is no wind. In this case, the flames coming from the shrubs will not be favored in any direction, so the biggest contribution the tank will receive will be the one that is transmitted by means of convection and radiation mechanisms of the fire itself and which in turn will be determined by the distance from the bushes to the tank. Taking into account this factor and knowing that the part most exposed to this plant front will be the middle of the tank, a temperature increase will be seen in the outer zone of the wall up to a maximum value of 70 °C in the time contemplated during the simulation, which will be followed with close values by the upper part of the tank. The bottom of the tank will only reach values around 40 °C.

Due to the thickness of the wall, the temperature measured inside the wall will be very similar to that provided by the external result, with values close to 70°C, while the lower part will not see its temperature increase, remaining at a constant value of 20 °C.

If we analyze the thermal heat flux, we can observe that both the top and the middle of the exterior of the tank reach peaks of up to 72 kW/m^2, which could be considered dangerous and possibly trigger a BLEVE if it is in account the criteria defined by US law.

If we analyze **scenario 2**, the flames coming from the shrubs will be favored in the direction of the tank, so the contribution of heat to it will be greater and the view factor will favor this effect. The tank will receive heat by by convection and radiation mechanisms of the fire itself (which in turn will be determined by the distance of the shrubs to the tank, as happened in the previous scenario). Taking into account this factor and knowing that the most exposed part to this vegetal front will be the central part of the tank (the wind speed and its direction will favor the incidence in this part), a temperature increase will be seen in the outer zone of the wall up to a maximum value of 210-215 °C in the time contemplated during the simulation. The lower part of the tank will reach values close to 70-80 °C that may be potentially dangerous.

Due to the thickness of the wall, the temperature measured inside will be very similar to that provided by the external but slightly lower result, with values close to 200 °C, while the lower part will not see its temperature increased, remaining at a constant value of 20-25 °C.

In this scenario, if we analyze the thermal heat flow, we can observe that high peaks, with values of up to 350 kW/m^2 are reached in the upper, middle and lower faces of the tank exterior, which would be considered dangerous and would trigger a BLEVE if you take into account the criteria defined by US law.

If we analyze **scenario 3**, the flames from the shrubs will be favored in the direction of the tank, so the contribution of heat to it will be greater, as it happened in scenario 2. The tank will also receive heat by convection and radiation mechanisms of the fire itself (and which in turn will be determined by the distance of the shrubs to the tank, as happened in the scenarios above). Taking into account this factor and knowing that the most exposed part to this vegetation mass will be the central part of the tank a temperature increase will be seen in the outer zone of the wall up to a maximum value of 160-170 °C in the time contemplated during the simulation. The lower part of the tank will reach values close to 80 °C that may be potentially dangerous. In this case, a higher wind velocity has favored the dispersion of the heat of the flames by other parts of the tank (especially the lower one), reducing the time of contact of the flame with the own surface of the tank.

Due to the thickness of the wall, the temperature measured inside will be very similar to that provided by the external result but slightly lower, with values close to 155 °C, while the lower part will not see its temperature increased, remaining at a constant value of 20-25 °C, as in scenario 2.

In this scenario, if we analyze the thermal flow of heat, we can observe that high peaks, with values of up to 360 kW/m^2, can be observed in the upper, middle and lower faces of the exterior of the tank, which would be considered dangerous and would trigger a BLEVE if you take into account the criteria defined by US law.

At this point in the analysis, it will be necessary to compare the results obtained from the three simulations. In this case, given the results, scenario 1 (FS1) is discarded as dangerous since the increase in temperature, because the parts inside wall that are not wet remain at 70 °C and the wet parts at 20 °C. For this reason, scenarios 2 (FS2) and 3 (FS3) will be considered most virulent.

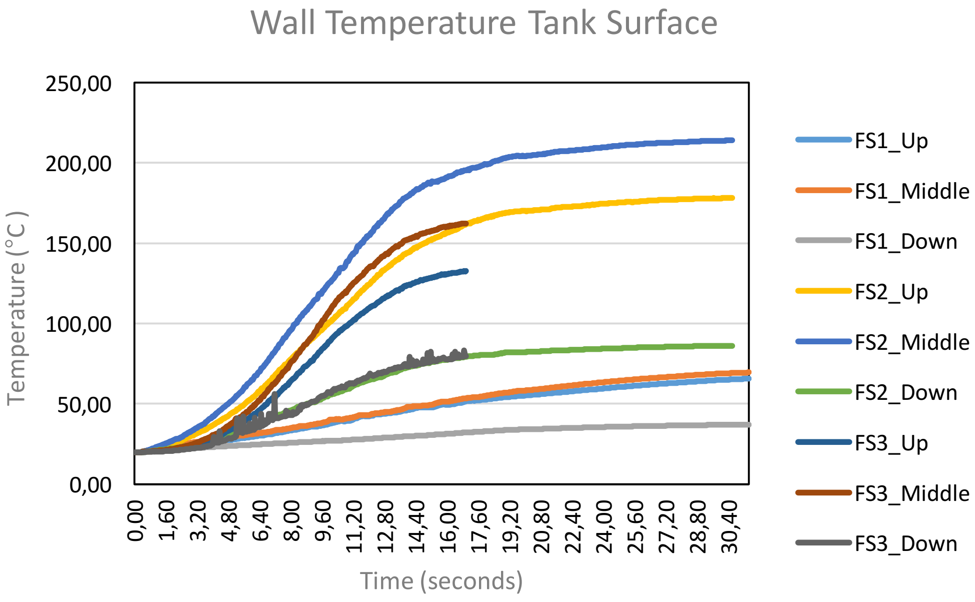

Figure 56. Outside wall temperature comparison scenarios 1, 2 and 3

If the temperatures reached by the scenarios 2 (FS2) and 3 (FS3) inside the tank wall and outside are observed, the results are more revealing in scenario 2: the temperature increases to very high values close to 220 as shown in the *Figure 56*. The values reached on the middle part of tank corresponding to most favor view factor area in FS2 are higher than FS3 in a value of almost 80 °C.

If the thermal flux variation is observed, the results will be very similar and, although a larger peak is reached in scenario 3, scenario 2 will provide a more damaging result due to reaching similar values over a greater range of weather.

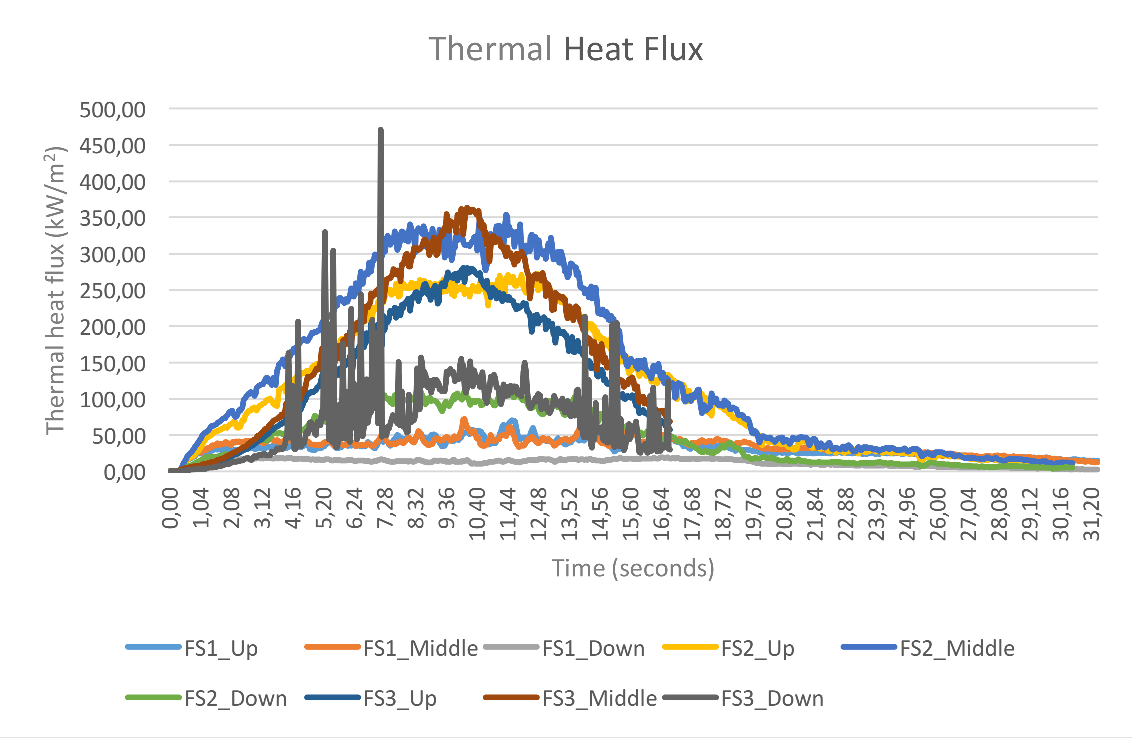

Figure 57. Thermal heat flux to tank scenarios 1, 2 and 3

On this case, both scenario 2 and 3 could lead to a possible BLEVE event according the criteria fixed by API Standard. The most favor values are also on the middle part of the tank reaching high values in a very short period of time.

6.6.2 Scenario 4 and 5

If we analyze **scenario 4**, the flames coming from the shrubs will be favored in the direction of the tank, so that the contribution of the thermal energy to it will be greater. The tank will receive heat by convection and radiation mechanisms of the fire itself (which in turn will be determined by the distance of the shrubs to the tank, in this case 0.75 m). Taking into account this factor and knowing that the most exposed part to this plant front will be the central part of the tank (the wind speed and its direction will favor the incidence in this part), a temperature increase will be observed in the outer zone of the wall up to a maximum value of 240-250 °C in the time contemplated during the simulation. The bottom of the tank will reach values close to 115-120 °C that can be potentially dangerous.

Due to the thickness of the wall, the temperature measured inside will be very similar to that provided by the external result but slightly lower, with values close to 240 °C, while the lower part will not see its temperature increased, remaining in a value constant from 20-25 °C.

In this scenario, if we analyze the thermal flow of heat, we can observe that the upper and middle faces of the exterior of the tank reach high peaks with values up to 420 kW/m^2, which would be considered dangerous and would trigger a BLEVE if take into account the criteria defined by the law of the United States

If we analyze **scenario 5**, knowing that the most exposed part to this plant front will be the central part of the tank (the wind speed and its direction will favor the incidence in this part), a temperature increase will be observed in the outer zone of the wall up to a maximum value of 160 °C in the time contemplated during the simulation. The bottom of the tank will reach values close to 55 °C that can be potentially dangerous.

Due to the thickness of the wall, the temperature measured in the interior will be very similar to that provided by the external result but slightly lower, with values close to 155 °C, whereas the lower part will not see its temperature increased, remaining in a value constant from 20-25 °C.

In this scenario, if we analyze the thermal heat flux, we can observe that the upper and middle faces of the exterior of the tank reach high peaks, with values up to 275 kW/m^2, which would be considered dangerous and would trigger a BLEVE if take into account the criteria defined by the law of the United States.

When evaluating the hazard integrated in the variable distance, we can conclude that this is a key value and the increase or decrease causes large variations in both temperature and heat contributed to the tank itself. As can be seen in *Figure 58*, the values are close to half extending a difference of 0.75 m separation.

Due to this, if the reduction factor continues to be gradual, in the legislation of many countries to maintain this type vegetation mass in a distance of 3 m, could be limiting enough to keep these risks at bay. As we can see, increasing the distance by 0.75 m, there has been a reduction of the emitted heat of approximately 37.5%, thus supporting what has been said so far.

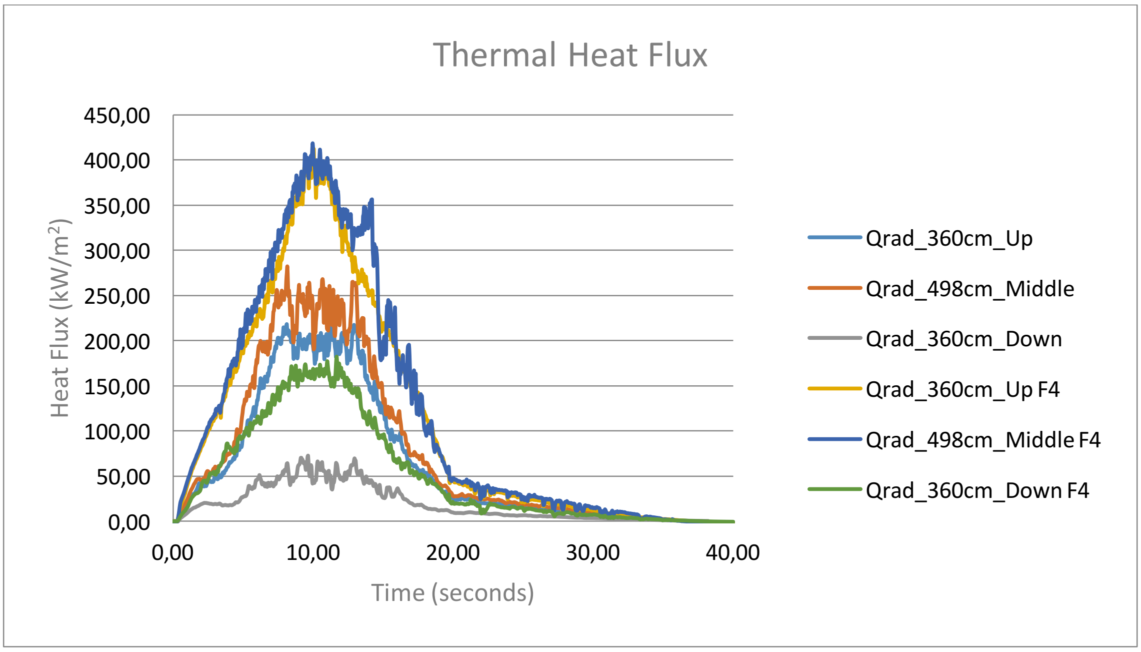

Figure 58. Heat Flux Wall Surface Scenario 4 (FS4) and 5 (FS5)

It is very important, when evaluating these scenarios, to understand the contribution of heat flow (per unit time) and the evolution of temperatures in that time interval, which will trigger or not trigger a BLEVE scenario.

7. Sustainability Study

The study of sustainability of this project is made based on the guidelines set out in the Legislative Royal Decree 1/2008 of 11 January, which presents the text of the Law on Environmental Impact Assessment Projects.

7.1 Project overview

The objective of this project is the study and analysis of the risks for LPG facilities in wildland-urban interfaces in case of fire. Therefore, the study of the sustainability of this project is subject exclusively to this task.

7.2 Alternatives Study

Being a predominantly theoretical project, it is considered that there are not alternative solutions for their realization.

7.3 Environment Description

This project was carried out in CERTEC facilities, located in the Department of Chemical Engineering EEBE during about five months. It is considered that the application did not substantially change the quality levels of the environment, including the socio-economic context.

7.4 Identification and Evaluation of Environmental Impact

This section analyzes the various potential impacts the project could have on the environment and may be due to:

- The existence of the project
- The use of natural resources
- The emission of pollutants (atmosphere, hydrosphere and lithosphere), the formation of harmful substances or waste treatment.

7.4.1 Criteria

Depending on the type of effect:

- **Positive effect:** the one which is admitted by the scientific community and the general population in the context of a comprehensive analysis of the costs and benefits of generic contingencies external of contemplated actions.
- **Negative effect:** That which results in the loss of natural value, aesthetic and cultural landscape, ecological productivity or an increase in pollution damage arising from erosion and other environmental hazards in disagreement with the eco-geographical structure, character and personality of a given location.

Depending on the impact of the effect:

- **Direct effect**: the one which has an immediate impact on some aspect of the environment.
- **Indirect or secondary effect:** the one which is an immediate impact with regard to interdependence or, in general, with respect to the relationship of environmental sector to another.

Here there are included the different definitions of the assessment of potential environmental impact referring the character of environmental compatibility:

- **Compatible EI:** one in which the recovery is immediate end of the activity and does not require protective measures.
- **Moderate EI:** That where recovery does not require intensive corrective or protective measures, but to recover the initial conditions require a certain time.
- **IA Sever:** one in which the recovery of environmental conditions requires the adequacy of corrective or protective measures, plus an extended period of time.
- **Critical EI:** those with a magnitude greater than the acceptable limit, resulting in a permanent loss of the quality of environmental conditions, without the possibility of recovery, even with the protective or corrective measures. In addition to assessing the impacts of different specific cause-effect relationships, must be evaluated regarding the overall impact of the project. The overall magnitude of the project will be positive if the overall assessment is supported, moderate or severe, while it will be negative if the overall assessment is critical.

7.4.2 Impact identification

There are some phases or major activities when the impact identification is done and they have to be considered in the construction, implementation and decommissioning activities. In this case, because it is a theoretical work, only makes sense to analyze the stage of the activity because any construction or decommissioning is done.

The resources were needed to develop this activity are electricity consumption for computers and material consumption own office consumables such as paper, printer cartridges, pens, etc.

7.4.3 Potential Environmental Impact

This section analyzes the potential impacts on the environment and society that may have caused the realization of this project as they were mentioned in 7.4.

Impact of the existence of the project

There is a positive impact for the project. The simulation validation tool could reduce the number of experiments required and, consequently, reduce the emission of pollutants resulting from combustion of real scenarios created to demonstrate the fire situations studied. Eventually, all bring a social benefit in terms of improved efficiency in firefighting since it will better understand and predict fire behavior and also it could help to improve the normative and legislation relating safety distances from LPG facilities.

Impact of resource use

There is a direct impact of resource use, primarily office supplies as a result of the use of computer equipment, refurbishment of the office, etc. Waste management is performed as set forth in *Table 23* also identifies where each waste generated according to the rules required by the Catalan Waste Agency [37].

Table 23. Residues Management [35]

CODE	GENERATED RESIDUE	PROCESS GENERATOR	MANAGEMENT
200101	Paper	Printing and noting	Blue bin for selective collection
080309	Print Ink	Document Printing	Specific recycle point
200199	Office material	Project development	No specific recycle point/bin

Impact of emissions

In order to simplify the study of the emissions impact is considered only CO_2 emissions because it is the majority contaminant.

The main consumption of resources with the consequent emission of carbon dioxide considers the existence of an indirect impact arising from the consumption of electricity resulting from the emission of combustion gases in power plants. The main contaminant is then the CO_2 responsible for the greenhouse effect. Thus, the project was developed over six months. Throughout the project has been prepared for the first three months of a computer and an average of four-six computers running the simulations in parallel during the last two months. They are on every day of the week and 24 hours per day, the average energy consumption is 7,200 hours. If it is considered that the computer requires an average power of 90 W when it is active and 5 W when is at rest; the energy consumed throughout the project (with an average of 5 computers running simulations and the other doing the document) is 207.12 kWh.

Finally, data from CO_2 emission per kWh produced published by *Red Eléctrica Española*, determines that emits 248 g CO2 / kWh produced [38]. If a character approach, considers the unit of energy produced is equivalent to the unit of energy consumed and, therefore, there is no loss in transport, the mass of CO_2 released is 51.3 kg CO_2.

7.5 Precautionary Measures

Corrective measures planned to minimize environmental impacts focus primarily on environmental management of waste (paper, printer cartridges, etc.). Also, try to minimize the consumption of sheets of paper and electronic documents not using printed paper.

8. Economical analysis

The costs associated with the project will be divided between material and human resources.

8.1 Human resources

This section analyzes costs associated with human resources, which are considered basically the hours of a person in charge of the project, as well as two others who have had participation.

It is considered a supposed cost of € 12/ hour for junior engineer who has done the project, devoting 18 hours per week for five months. The direction was given by two PhD in Industrial Engineering with a commitment of three hours per week and a fee estimated € 40 / hour respectively. In this case, a PhD student has helped also in the part of environmental simulation, with an estimated fee of € 20 / hour. *Table 24* shows the relationship of costs associated with human resources:

Table 24. Human Resources Costs

Personnel	**Cost (€/h)**	**Dedicated Hours**	**Total cost (€)**
Junior Engineer	12	378	4,356
PhD Student	20	30	600
2 PhD Industrial Engineer	40	63	5,040
TOTAL	62	504	**9,996**

8.2 Material resources

Material resources consumed during the realization of this project are related to office work: this costs arising from consumption of office supplies (electricity). Simulations activities have been developed on the CERTEC (Center for Technological Risk Studies)and, therefore, it has been used the computer equipment has this institution. Referring to this aspect, it is considered the amortization of equipment owned CERTEC. Regarding the software used, it is considered that the cost of licensing the operating system (Microsoft® Windows 7 Professional) and office suite (Microsoft® Office 2010) are included in the acquisition cost of the computer. However, regarding specific software licenses has been used (AutoCAD® and Pyrosim) the cost was zero as it has benefit from the license and the UPC CERTEC. Finally, the simulator used to carry out the project (FDS) is free software and therefore does not involve any cost of acquiring the license.

Given that the payback horizon is five years, the material resources costs are collected on the next table:

Table 25. Material Costs

COST	VALUE (€)
Office Supplies	300
Computers Payback	550
Office Supplies	70
TOTAL	**920**

8.3 Total Costs

The total costs associated to the Project are:

Table 26. Total Project Cost

COST	VALUE (€)
Human Cost	9,996
Material Cost	920
Total net cost	10,916
unexpected	15%
TOTAL COST	**12,553.4**

9. Conclusions

The work carried out here has tried to demonstrate and sketch a large amount of information about the problem of risk on LPG tanks relating fires in wildland-urban interfaces and the problem of the presence of shrubs or flammable vegetable substances near this type of installations.

In the first place, there are a large number of variables that interfere with the characterization of the analytical substance: LPG. As it is a mixture of propane and butane, with different physical and chemical properties (although similar), there is a variability in its behavior depending on the % defined in its composition, although this factor is not contemplated in this environment simulations and project. This factor would affect the response of the system in case of a fire scenario such as that contemplated here.

Historical events and accidents show that LPG is a dangerous substance involving different types of accidents (fires and explosions). Thanks to these experiences, we have learned many lessons related to the capacity and velocity of action in dangerous situations for people and the environment, as well as the intrinsic risks of the infrastructure contemplated in this work, that are present all over the world.

Although a large amount of information is currently available and regulatory agencies have a standard and legislation to protect individuals and reduce the risk of such scenarios, as we have seen, there is a great difference among countries. Spain, as an example, contemplates the possibility of having shrubs near flammable materials such as an LPG installation, while countries like Italy dedicate a specific section to talk about this problem. For this reason, I believe that it would be necessary to deal more closely with the competent bodies in order to unify the criterion within the same legal area (for example the European Union) and to apply the same criterion in this way.

Entering the field of experts and reviewing the state of the art about this problem, it is noteworthy the lack of available information or the few contributions made on the subject, but also important. There are many variables that can modify the results (wind, outdoor temperature, shrub height, distance to the tank, degree of filling of the tank, material of construction of the same, etc.) and that are very complicated to relate. In addition, no regulations, except for the US, contain a numerical limit value that can trigger an explosion scenario or BLEVE.

For this reason, tanking the contributions that have been made in the characterization of the system, the value of maximum heat flux produced by a BLEVE used as a criterion, is not 100% valid when evaluating the potential risk or danger of a scenario, since a very high thermal flux can be provided during instantaneous moments of time that do not affect practically the internal temperature of the tank. For this reason, it is interesting to study the incidence that different variables can have within a scenario.

In this case, the main variables to be studied were the wind velocity incident on a LPG tank, as well as the distance of ornamental shrubs to the tank. These two factors have been revealed crucial.

A wind of 1 m/s for the scenario that has been designed, has been shown potentially more dangerous than a greater wind, providing a better contact with the tank and therefore giving a greater amount of energy. In this case, by varying the distances of the vegetable mass and simulating the same scenario, it has been observed that the values of heat flux have been seen in the middle part of the tank with a small variation of the distances, which reveals that it is a determining factor to ensure the security in this type of environment. Furthermore, considering the temperature, this is decisive when evaluating a possible BLEVE or not, which shows that the criterion taken by the API standard is insufficient to evaluate a risk scenario and guarantee the safety of the population subject to these environments.

Finally, conclude that this work has tried to raise awareness of the lack of information on this subject that can give rise to real scenarios in day to day everyday events such as the development of a fire in the wildland-urban interface. Taking appropriate measures that are guaranteed by law, would reduce the risk inherent in this type of substances and avoid results such as those that have occurred historically and have jeopardized the lives of many people.

10. Planning

This project has been developed for approximately 5 months, which have started with a previous review and literature search. Then, I continued the following two months developing a more theoretical part in which the problem of the project is exposed and evaluated, relating LPG characterization, legislation about LPG facilities and a review of the state of the art. Next, the project is continued with the designing of the scenarios and the execution of the programs with the objective of evaluating the associated risks. Finally, the results are discussed and the conclusions drawn, followed by an environmental and cost analysis.

Table 27. Planning per week

PLANNING	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
1. Literature revision	■	■	■	■	■	■														
A. LPG characterization	■	■																		
B. Legislation	■	■	■	■	■															
C. Historical Incidents			■	■																
D. Problem characterization				■	■															
E. State of the art					■	■														
2. LPG Characterization	■	■							■									■	■	
3. Legislation	■	■	■	■	■	■	■	■	■					■	■				■	
4. Historical Incidents			■	■	■															
5. Problem Characterization	■	■	■	■	■	■											■	■	■	■
6. State of the art									■	■	■							■	■	
7. Simulation										■	■	■	■	■	■	■	■	■	■	■
A. Simulations design										■	■	■								
B. Simulations Running													■	■	■	■	■	■		
C. Results and discussion																■	■	■	■	■
8. Conclusions																		■	■	■
9. Environmental Analysis																		■	■	
10. Economical Analysis																		■	■	

11. Annex

11.1 Input File FDS

The following is the txt. used for scenario 1. For the rest, the necessary modifications will be made that will define the environment.

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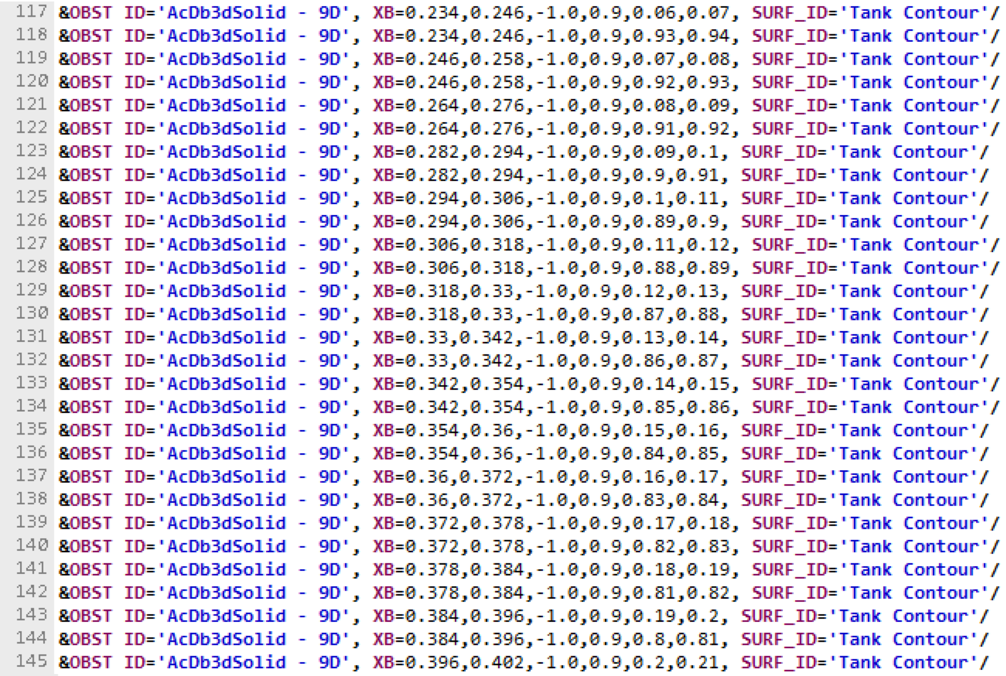

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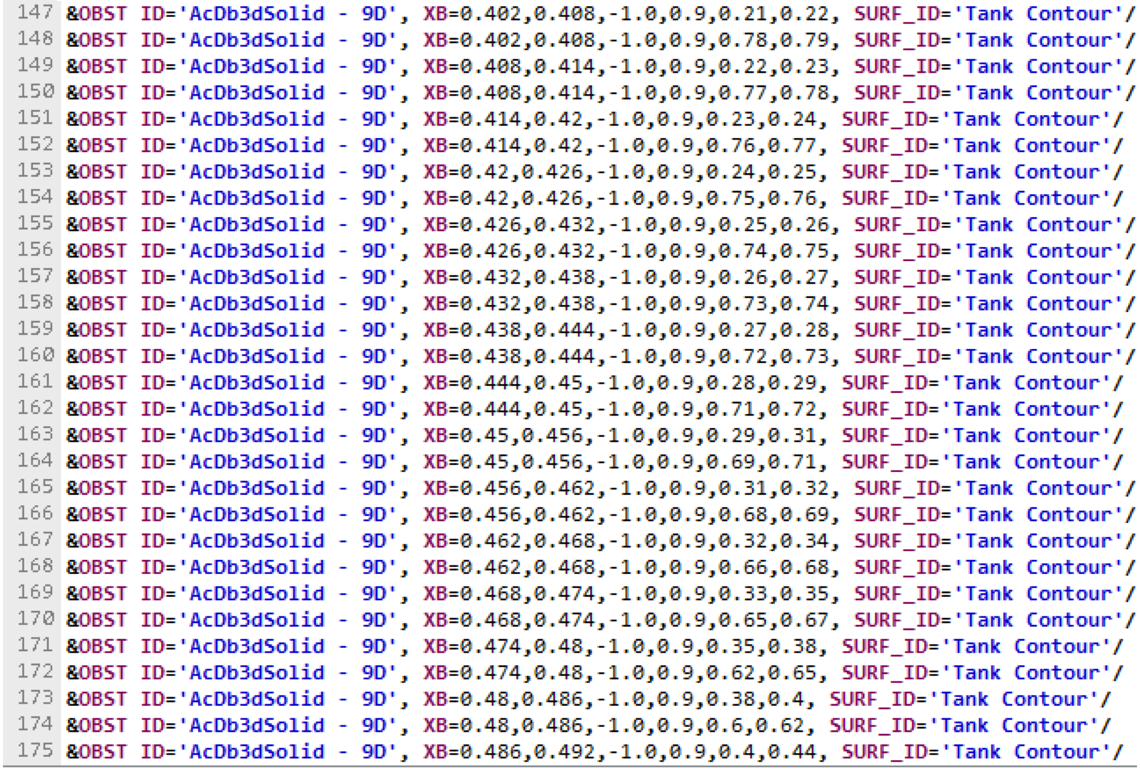

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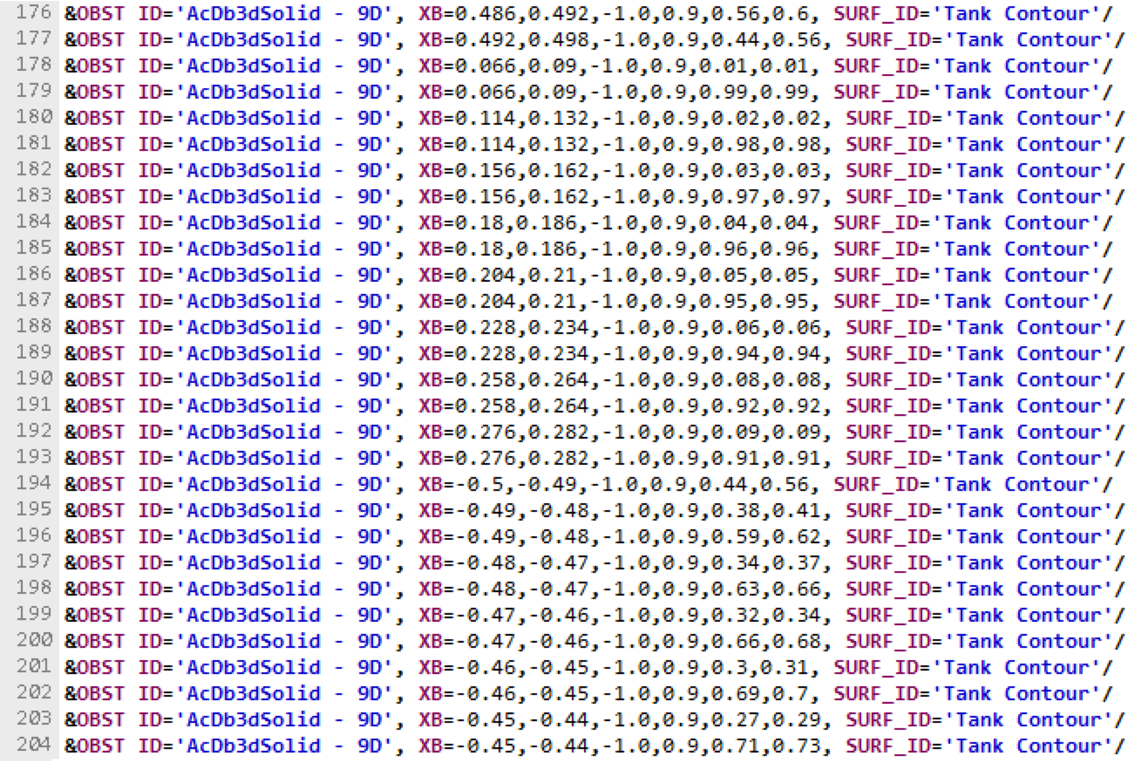

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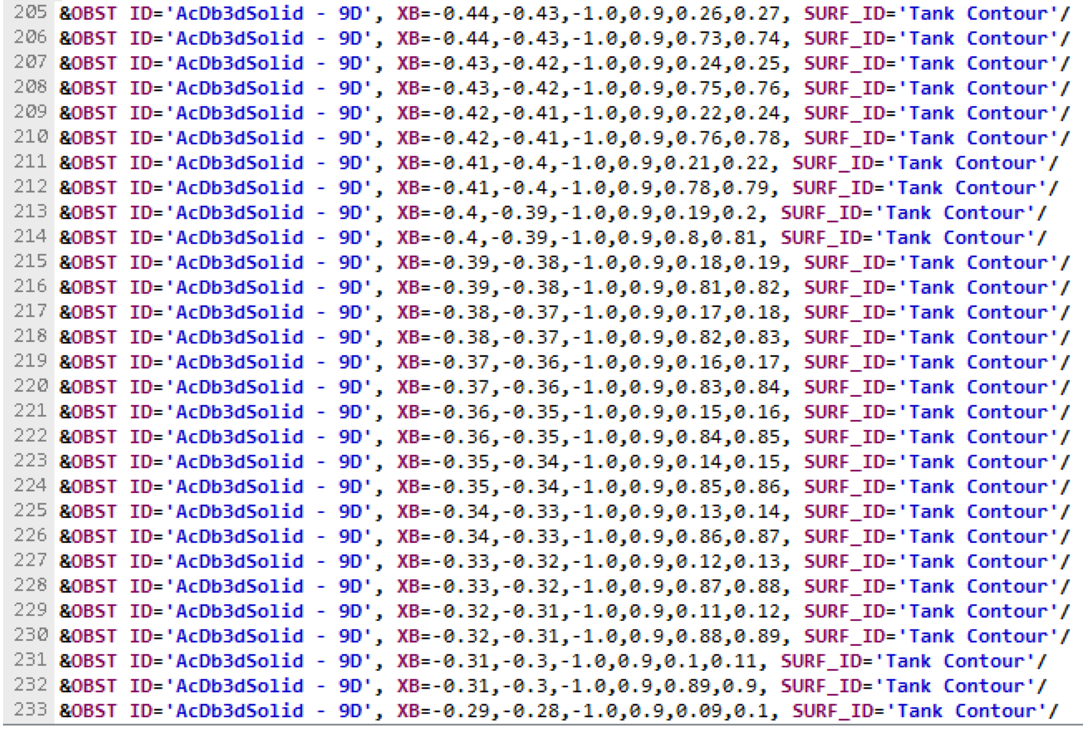

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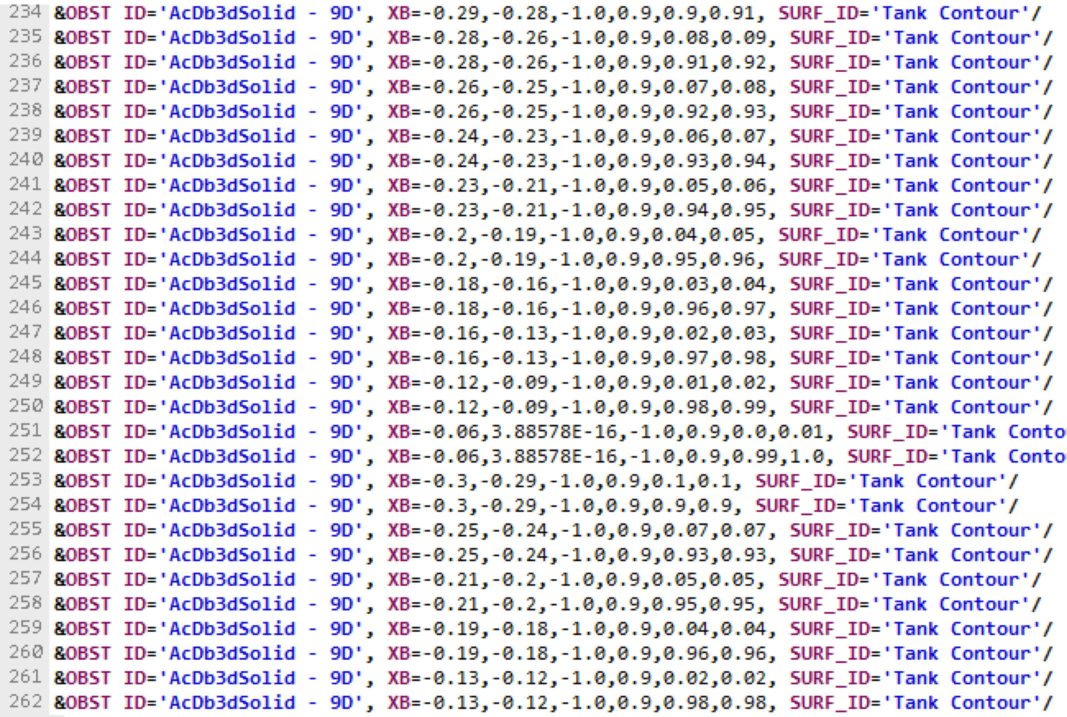

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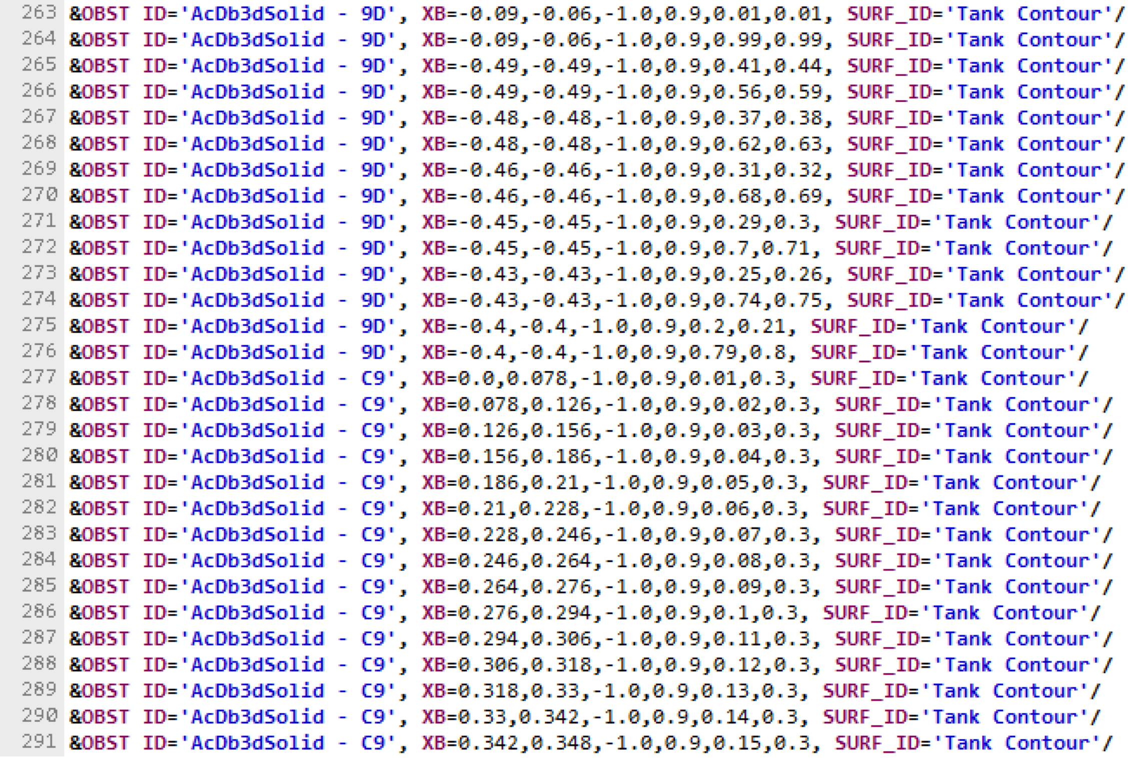

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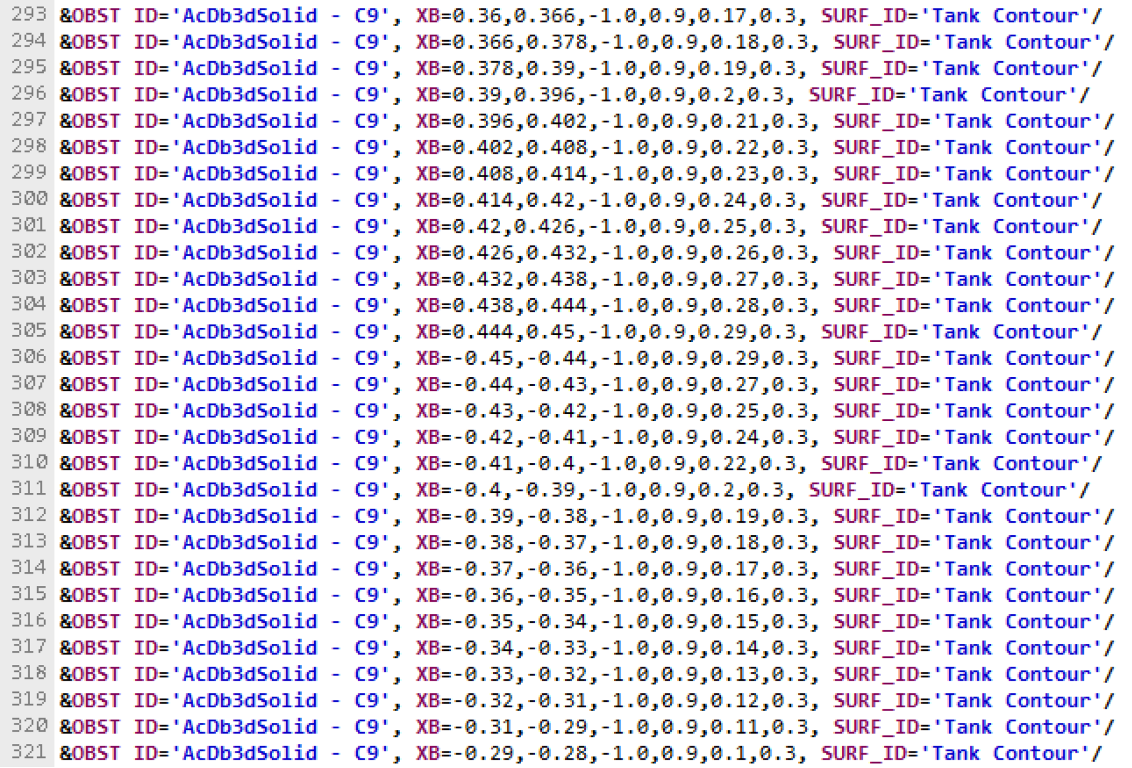

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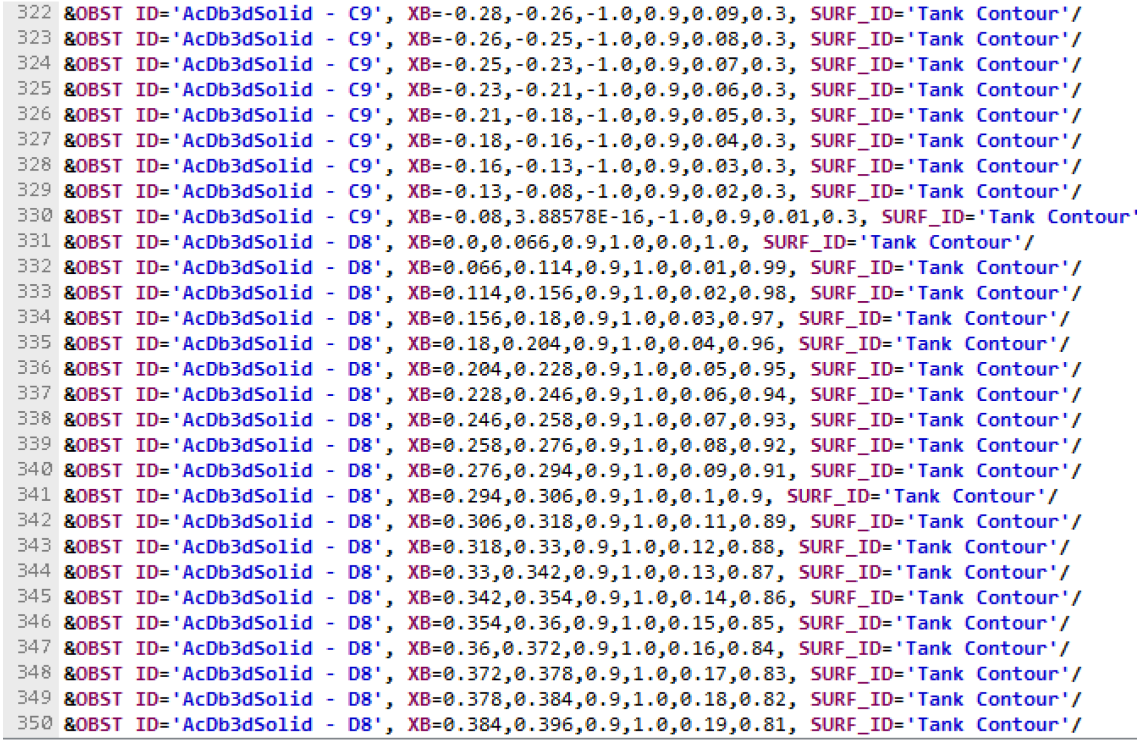

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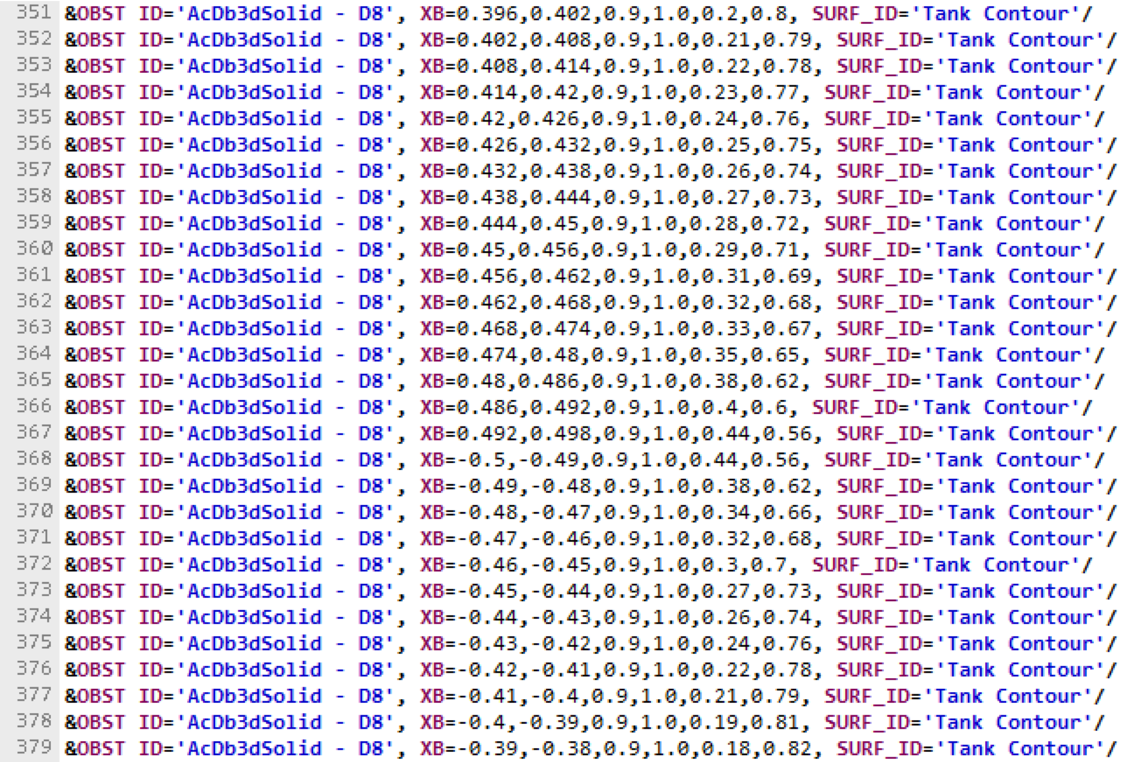

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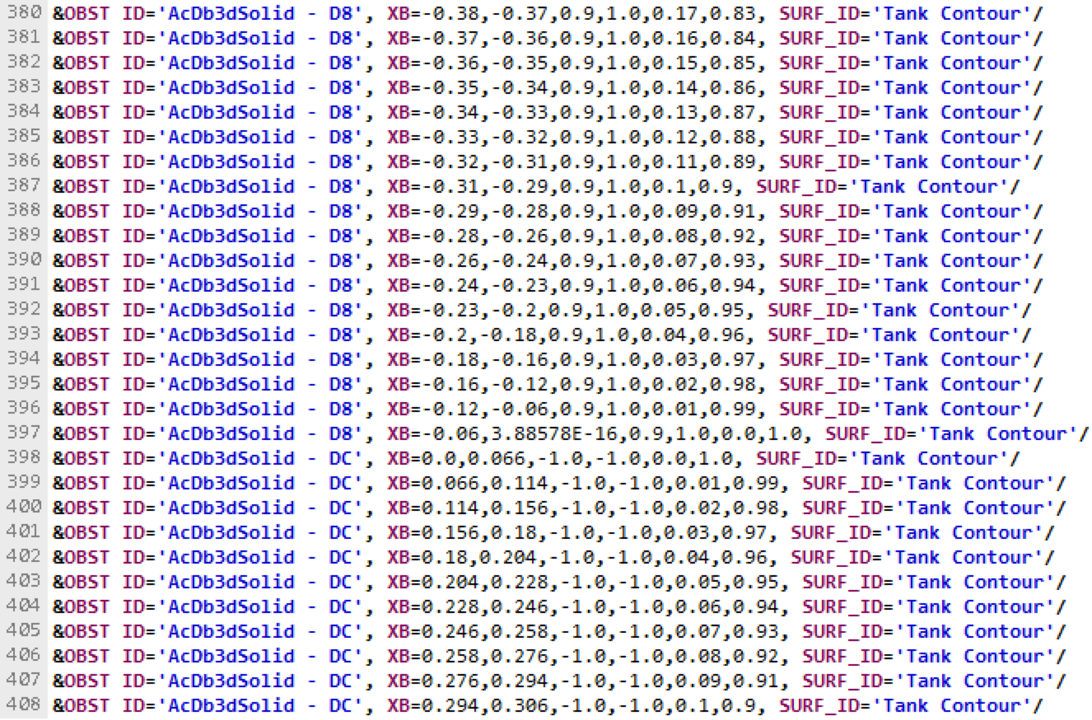

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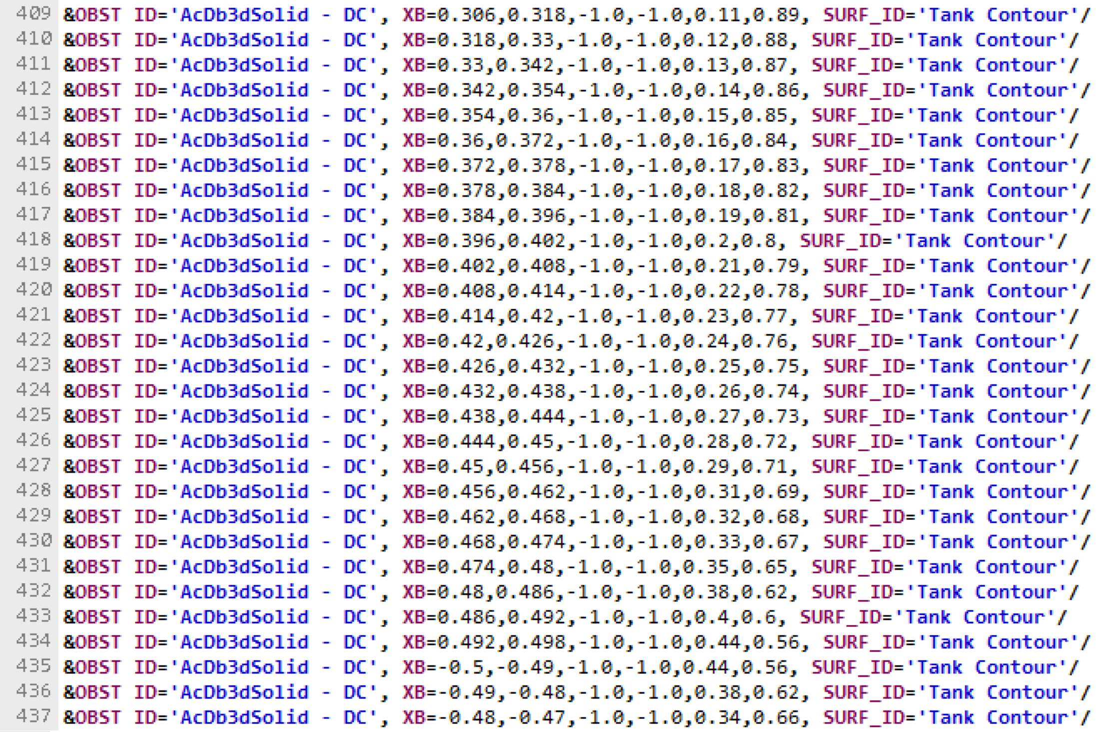

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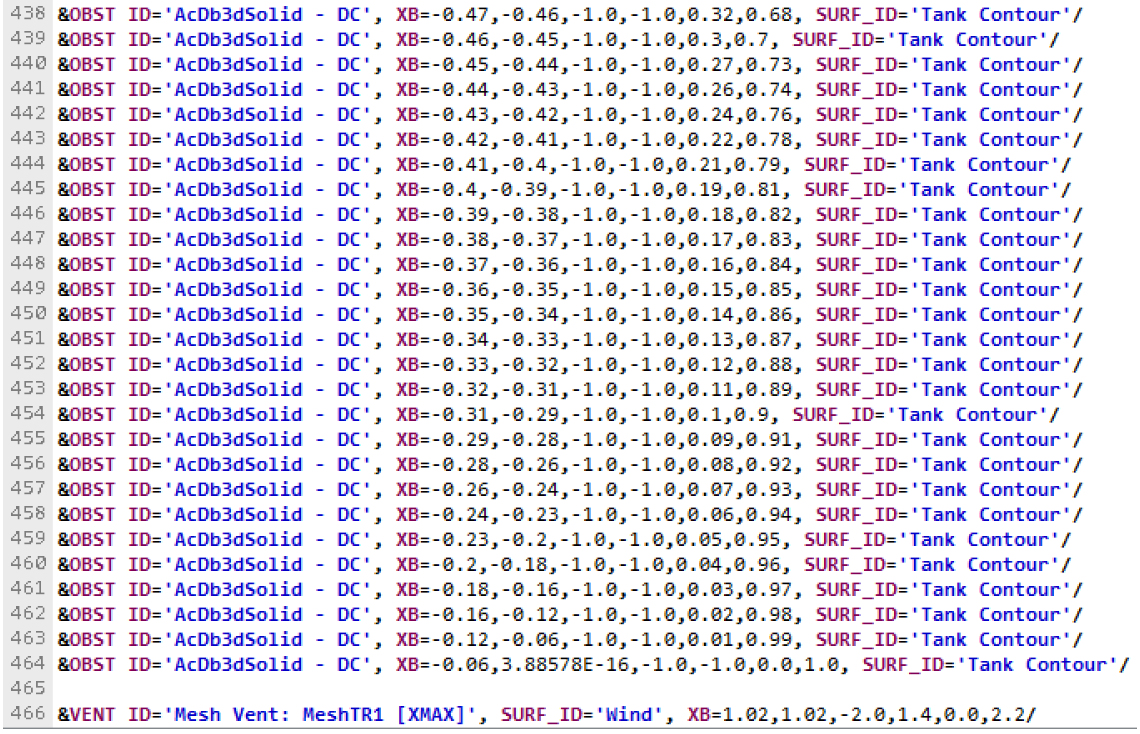

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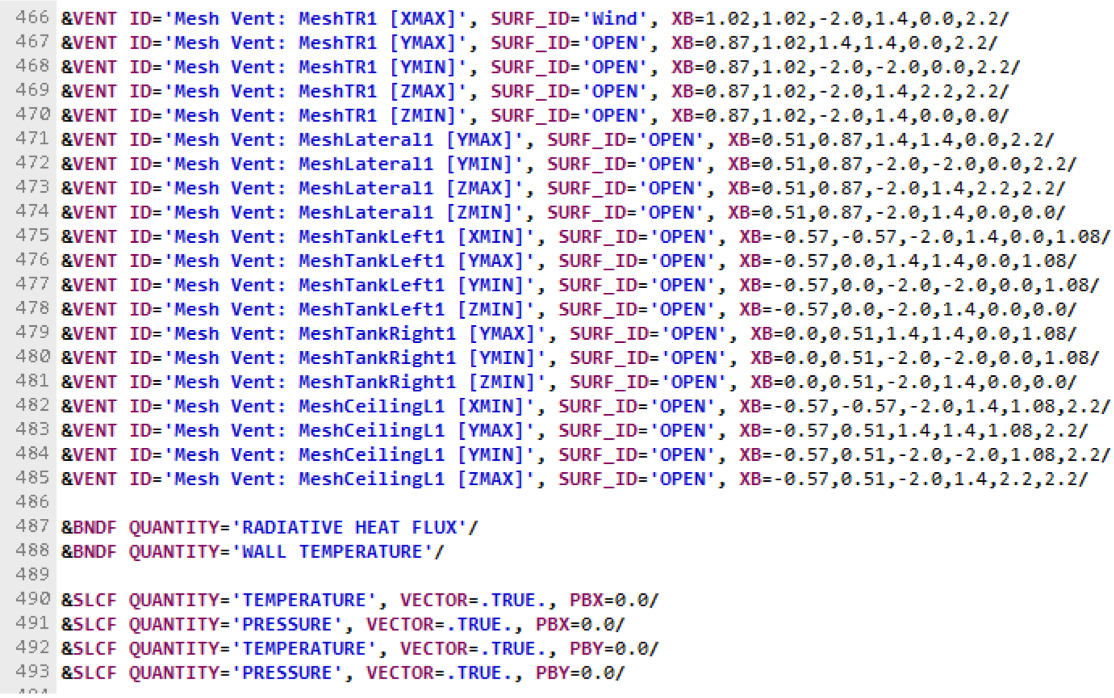

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11.2 Figures List

11.3 Tables List

12.

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