GROUND'2014

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6th LPE

International Conference on Grounding and Earthing
&
6^{th} International Conference on Lightning Physics and Effects

Manaus, Brazil May, 2014

LIGHTNING PROTECTION OF ABOVE GROUND FUEL STORAGE TANKS

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Abstract: This paper presents a study on protection of above ground fuel storage tanks against direct lightning strokes, including the preliminary tests results on metallic sheets subjected to direct current pulses simulating continuing currents and its measured temperatures over the inner face. These tests provide suitable tools to improve the future mounting tests in the IEE High Power Laboratory, i.e., in DC and impulse current.

1 - INTRODUCTION

Lightning discharges to earth may be hazardous to structures, individuals and also to services such as electricity supply, wired telephone, wired computer networks, gas and water metallic pipes, industrial activities, processes involving oil and other fuel types, etc.

The dangers to a structure can result in damage to it and its contents, electronics systems failure and damage to living beings in or near the structure.

The effects from damage and failure may extend to the vicinity of the structure or affect the environment.

Dangers to services can result in damage to the service itself and failures of associated electronic equipment's.

If a lightning strike fuel tanks, explosions may occur as well as onset of fire. Then, the harm can be irreparable, beyond environmental problems as the risk of life to living beings nearby.

As examples, in January 2013, in Brazil, two ethanol storage fuel tanks had exploded after being struck by lightning: São Luiz plant in Ourinhos, in the state of São Paulo on Jan/6^{th} and Rio Claro plant, in the state of Goiás on Jan/16^{th}.

First, this paper presents a digest of the main aspects related to the protection of fuel storage tanks as described in various standards [1][2][3]; presents a risk analysis of this kind of tanks; shows preliminary results of a direct current pulses tests (simulating continuing currents) performed straightly on metallic sheets and a system for measuring the inner face hot spot temperature for analysis.

2 - BASIC CONSIDERATIONS

In Brazil, several types of fuels are used, mainly by the automotive industry: various types of gasoline, ethanol and diesel. These fuels are stored in large tanks in plants and also in the distribution terminals. There are still some differences between the tanks used in the plants and terminals: dimensions, maintenance procedures, lightning and fire protection systems, among others.

This paper analyzes these tanks and the protection against the effects of lightning.

Initially, a study of the various existing standards and a comparison between the main recommendations of these standards for the protection of fuel tanks was done.

Then, an analysis of the various tanks in plants and distribution terminals was taken in order to specify a tank that can be considered as standard and an analysis of the main products (fuels) that are stored in them.

A third stage concerns to specification, testing using a testing device for sheet metal used in these tanks that aimed to checking for any holes in the plates and, especially, checking hot spots inside the plates when struck by currents that simulate atmospheric discharge.

Another step was the development of a worksheet based on IEC 62305-2 [3], for the analysis of specific risk for tanks for fuel storage.

3 – DEVELOPMENTS

3.1 – Analysis of the various fuel storage tanks

Initially 360 tanks of fuel distribution terminals and 235 tanks plants were analyzed in order to characterize a typical tank for the study. In this review, the existence or non-floating membrane were observed; the ceiling type (fixed or floating); capacity in m³ of fuel; types of fuel stored; the diameter and the height of the tanks. The results of this analysis were considered as typical tanks:

- Typical Tanks for terminals:
  - Diameter: 14 meters
  - Height: 12 meters
  - Fixed roof (with and without membrane)
- Typical Tanks Plants:
  - Diameter: 22 meters
  - Height: 12 meters
- Most relevant products:
  - Anhydrous ethanol
  - Hydrous ethanol
  - Gasoline (A type)

Various thicknesses of metal sheet in the construction of these tanks, depending on the dimensions and locations (top, side or base) are used.

These tanks considered typical and the most relevant products will be the object of study.

3.2 – Preliminary tests on metal sheet

Preliminary tests for defining the methodology and check the order of magnitude of the parameters to be measured were performed on steel plates. As these steel plates are not provided by the tank manufacturers, then they are used only for preliminary tests.

The lightning is conducted primarily through the air (gaseous medium). This is driving the ionized medium (plasma) whose temperature is extremely high, near to 30000℃ [4].

When this discharge comes into contact with the wall of the fuel tank, it is now considered that the heat transferred is usually not enough to cause perforation of the plate subject to complying with the standard conditions. Although the lightning current has high values, near to 30 kA [4] in mean, the energy involved in the process is limited by the exposure time that is usually very short, on the order of microseconds.

On the other hand, often accompanying the process of high intensity discharge (return stroke), the low-intensity discharge (continuing current) occurs between the first and subsequent strokes, but with a greater length that can reach a few milliseconds duration and amplitude of hundreds of Amperes.

The whole process can be insufficient to cause perforation in a sheet with a thickness greater than 4 mm, under the conditions normally found in the technical literature, but the temperature on the inner face of the plate may reach a value such that ignition of the mixture occurs within the tank, in the case of an adequate mixing between fuel gas and oxygen.

The test of this hypothesis is the purpose of the experiment. A machine of this arc welding with coated electrode (SWAW Shielded Metal Arc Welding), as showed in Figure 1, was used. Due to limitations of this equipment, the test has limited scope in terms of conclusions, but indicates the potential for developing a more accurate test, that will be done in the High Power Laboratory at the IEE-USP.

Being a machine which provides direct current, the negative electrode was attached at the plate and the positive electrode produced the arc.

As the electrode was operated manually, driving time can not be precisely controlled, but its value was determined by the measurement system as well as the amount of current applied to the test

Figure 1: Welding Machine.

The measurement system comprised of an oscilloscope and a shunt resistor, as shown in Figures 2 and 3 below.

Figure 2: Oscilloscope used in the preliminary test.

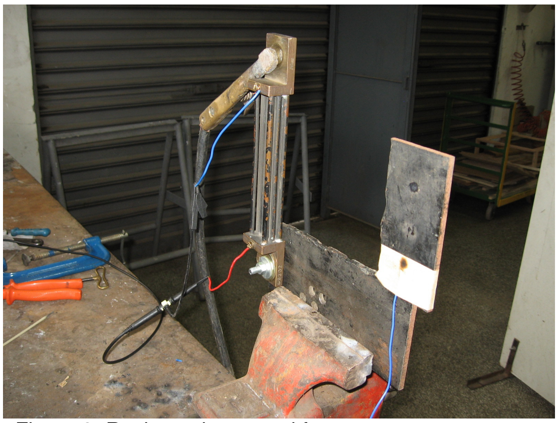


Figure 3: Resistor shunt used for current measurement.

In addition, two instruments were used to estimate the temperature: a multimeter capable of operating thermocouples K type and a registration system, with internal memory and an acquisition rate of one sample per second and an infrared camera.

Figure 4: Temperature Measurement.

Figure 5: Infrared Camera.

The thermocouple was installed at the back of the plate, corresponding to the point where it would be applied to the bow on the front in order to monitoring the temperature gradient. The infrared camera allows observing the expected gradient distribution of the heat on the plate.

The plate used in the test has a thickness of 6.3 mm and the steel material as showed in Figure 6.

Figure 6: Sheet steel used in the tests caught in the vise.

Two applications were performed. The first was applied with a current of 242 A, conduction time of 400 ms, which corresponds to an offset load (charge) of 97 C. The temperature gradient observed in the thermocouple is illustrated in Figure 7.

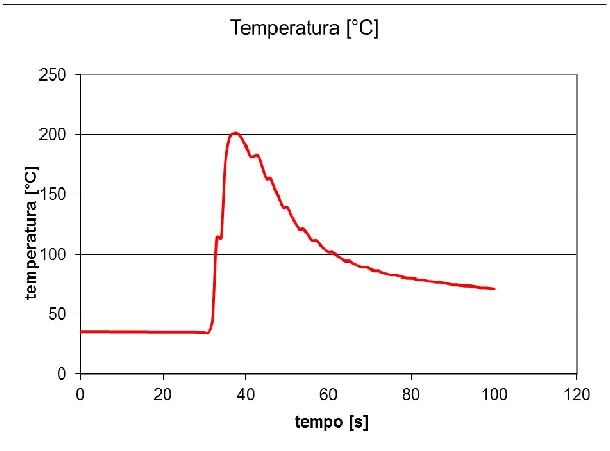


Figure 7: Evolution of temperature during application nº 1.

Starting from environment temperature, the gradient of temperature was observed due to the application of the arc on the other side of the plate. The time to reach the maximum temperature was approximately 6 seconds. The value of the maximum temperature recorded was 201 ºC.

The second application was made with a current of 286 A, conduction time of 864 ms, which corresponds to an offset load (charge) of 247 C. The temperature gradient observed in the thermocouple is illustrated in Figure 8.

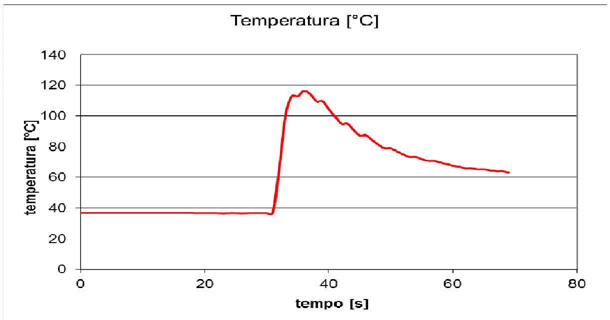


Figure 8: Evolution of temperature during application nº 2.

Starting from environment temperature, the gradient of temperature was observed due to the application of the arc on the other side of the plate. The time to reach the maximum temperature was approximately 6 seconds. The value of the maximum temperature recorded was 116 ºC.

Although there was greater displacement loads, the maximum temperature observed in the second application was less than the first. This is explained by electrode position relative to the point of the thermocouple, as illustrated in Figures 9 and 10.

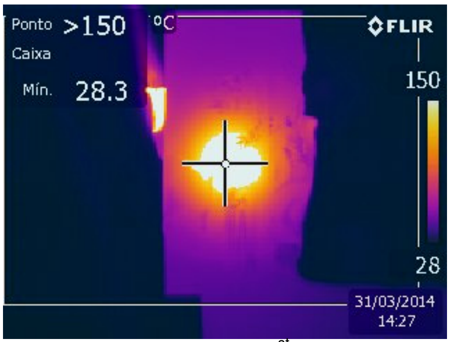


Figure 9: Thermal image of 1st ap. - Front face.

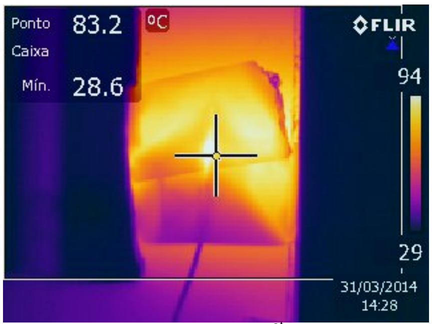
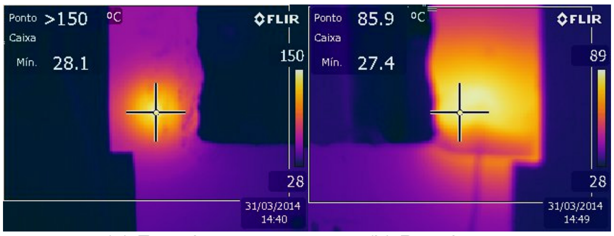


Figure 10: Thermal Image of 1st ap. - Rear panel.

As can be seen, the thermocouple was fixed on a point just where the electrode was applied in the first application.



(a) Front image (b) Rear image
Figure 11: Thermal Image of 2nd application.

As can be seen, the thermocouple was fixed at a point slightly displaced from that to which the electrode was applied.

This underlines the importance of aligning the points in future tests.

The use of thermal imaging in this case was not to determine the temperature, but to give a more comprehensive view of the process of temperature distribution on the metal sheet and check the best position of the thermocouple.

The effects produced on the plate by the applications are illustrated in Figure 12.


Figure 12: Damage in the surface of the plate.

In the Figure 12, only the two lower points with blackened edges must be considered, because the top spot was used for system calibration. The first application corresponds to the central point and the second to the lower point, both points are showed in red circles in the Figure 12.

In this preliminary test, none temperature near the ignition point of the alcohol (363 ℃) was observed, but at a temperature of about 200 ℃ observed in the test, approaches the ignition temperature of the gas (246 ℃).

There are questions related to the design of the arc to simulate lightning in the tank and as noted in the test positioning of the measuring system is important. This only emphasizes the need for a more comprehensive investigation in a more controlled environment.

Yet it was clear that the contact with the plate of the arc increases the risk of internal temperature rises to critical value and it would be best to avoid this occurrence. Even to discuss the precise value of determining, this temperature is very unlikely that this value is too low to be considered innocuous, even using a sheet of 6.3 mm.

On the other hand, there are ways to prevent direct contact with the plate of the tank, and since the capture of lightning takes place outside of the radius of the plate (using, e.g., rod air terminals fixed in the cover plate of the tank) in principle, not should be problem for the transportation of charge by tank.

Such research may provide grants to improve risk assessment in structures, in that it enhances the assessment of the probability of failure due to localized heating due to lightning.

For more accurate results, specific device was developed to perform various tests on metallic sheets used in storage fuel tanks as shown in Figure 13.

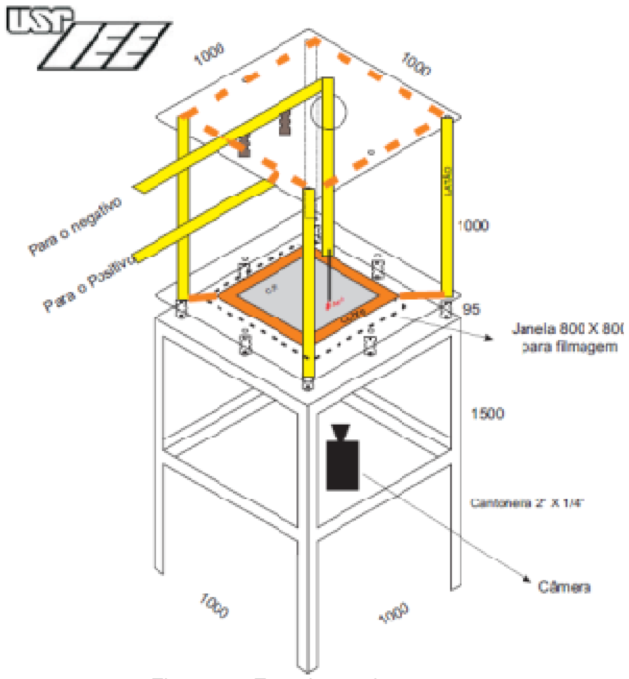


Figure 13: Experimental set-up

The main objective of this test is to check any perforations in the metallic sheets (both new and corroded) and check the hot spots on the inner face of the sheets. These temperature values can be compared with the values of flammability limits of the various types of fuels typically stored in these tanks.

The continuing current test will be simulated from pulses of direct current obtained by three-phase bridge rectifier adjusted to reach a 600A (RMS) and duration of 500ms, thus obtaining charge of 300C pulses.

Current pulses will be applied to the upper side (external) of new and used metallic sheets and of different thicknesses and also in soldered sheets used in with tanks.

In the lower (internal) face of the metallic sheets, hot spot temperatures were measured with different methodologies: thermocouples, thermal imaging, sensitive paints and optical interrogators.

These tests shall be performed on metal plates that are used in the construction of fuel storage tanks.

The results of these tests will be presented in future work.

3.3 – Risk analysis

This study also included a risk analysis based on IEC 62305-2/2010 [3] with some adaptations taking into account that we are dealing with protection of fuel tanks.

One of the first points to be introduced into the analysis was the question of the formation of fuel environment due to possible leakage of fuel and exhaust gases.

In the case of areas with explosion hazard is associated with the formation of explosive atmospheres and the time when the risk condition persists. According to IEC600079-10/1996 [5], mode or the degree of an explosive medium may be:

- ✓ Continuous, permanently occurring, frequently or for a long period;
- ✓ Primary, occurring periodically or occasionally during normal operation of the equipment;
- ✓ Secondary, occurring only sporadically and briefly and not in the normal operation of the equipment (e.g., in case of loose elements or operation of safety devices).

As a result of these degrees and considering the ventilation parameters, three types of areas at risk of explosion, where the explosive mixture (flammable gas, vapor or mist in the air) occurs can be distinguished as follows.

- ✓ Zone 0 (Z0), where the explosive mixture is present continuously, frequently or for long periods (greater than 1000 hours per year);
- ✓ Zone 1 (Z1), where the mixture can occur only occasionally under normal operating conditions (between 10 and 1000 hours per year);
- ✓ Zone 2 (Z2), which is more common in the explosive mixture does not occur, but if it occurs only persists for a short period (up to 10 hours per year);

I.e., zones 0 and 1 should be minimized in number and scope in the design and operation of appropriate procedures and facilities were to be mainly in zone 2.

Another point that has been adapted for fuel tanks has been the determination of the collection area (Figure 14).

As these are compositions of circles around about set points can be applied to geometry and trigonometric relationships to create calculation algorithms.

Based on the model of the tank.

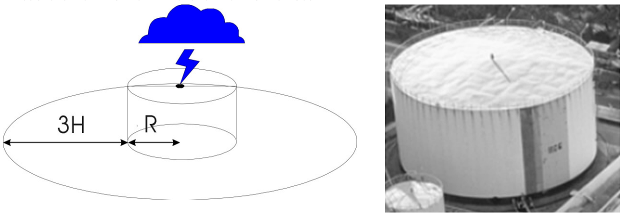


Figure 14: Collection area of a tank.

Whereas a tank of height H, draw the collection area A_D by a concentric circle with radius equal to the sum of the tank radius R with three times the height.

$A_D = \pi (R+3H)^2$

In case of Lightning Protection Systems (LPS) with towers, the collection area increase.

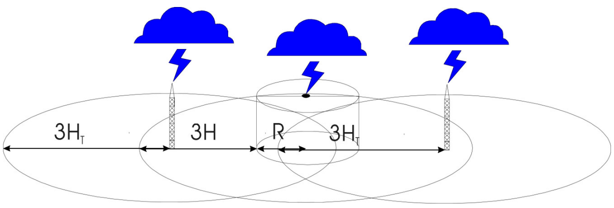


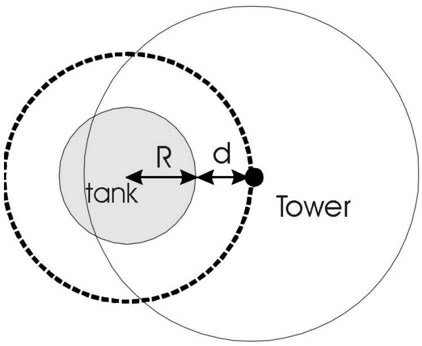
Figure 15: Collection area of a tank and 2 towers.

As shown in the Figure 15 at the center of the tank, where there is an overlap of collection areas of each object and the space shall not be replicated in the calculation, since this way the calculated area of A_D exposure would be oversized.

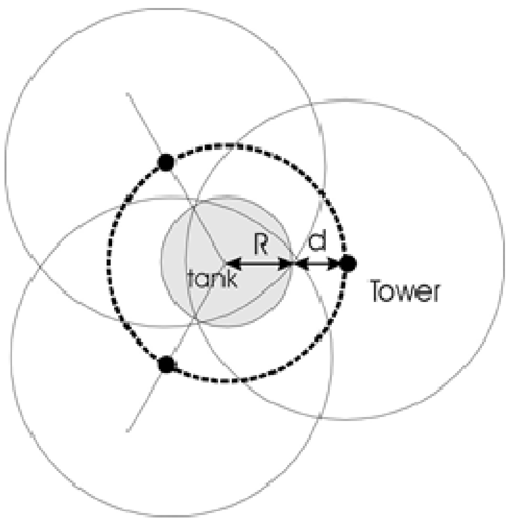
The calculation of the area should be equal depending on the composition of the figures, whereas the outer perimeter created and thus the central area is counted only once. Thus, it is avoid an excessive scaling the collection areas A_D.

The reasoning can be developed assuming three towers are used with height H_T uniformly arranged around the center of the tank.

This determines an imaginary around the tank where you can place towers, whose distance is d circumference of the shell.



As it was assumed that there are three evenly spaced towers next tower must be placed at 120° and another at 240°.



Although apparently more confusing this scheme also enables one to calculate the equivalent area from the dimensions involved using geometry and trigonometry.

In short, the display area equivalent can be calculated by the following steps:

1. Calculate the collection area of a tower $A_{DT}=(3H_T)^2*\pi$. H_T is the height of the tower.
2. Multiply that by the number of towers 3 A_{DT}
3. Calculate the full area of the circular sector of the intersection. (12 β -3D) H_T being $\beta = \text{arc sin} [(D/2)/ (3H_T)]$. D is the distance between the towers.
4. From the value of the calculated area for three towers $3A_{DT}$ subtract the full area of the circular sector of intersection.
5. Repeat step 4 the number of towers least once (n-1).

With these additions and a few others, it was possible to develop an MS Excel® spreadsheet to check the risk in fuel tanks in relation to lightning.

4 - RESULTS

The preliminary tests showed: the molten material for several metallic sheets and the temperatures reached on the opposite face of the sheet application of the pulses.

5 - RESULTS ANALYSIS

Preliminary tests and its results were presented in this paper. These tests were made in steel metal plate and the gradient temperature and thermal image of rear plate were acquired. The acquired maximum temperature values were compared with the ignition temperature of gases, e.g., alcohol and gas. These parameters will provide an elaboration of better setup for tests, as the parameters for calibration, i. e., current, duration and charge. On the other hand, these values can be used to estimate in the risk analyses due to lightning.

6 - CONCLUSIONS

This work presents a fairly comprehensive study on the protection of direct lightning on fuel storage tanks.
Analyzes conditions of self-protected tanks presents a risk analysis of risk for specific conditions of these tanks and also shows the results of a preliminary test on metal sheet to determine the hot spots on the inner part of the plates and checking possibilities these points to initiate the explosions as a function of various types of stored fuels in Brazil.

7 - REFERENCES

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