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Ignition of a Cloud of Dry Powder Using Super Brush Discharges

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Ignition of a cloud of dry powder is a major concern in the field of industrial process safety. The different types of discharges are already defined (spark discharges, brush discharges, propagating discharges, cone discharges, corona discharges) such as their ignition properties in a gas or a dust atmosphere. For example, it is known that a classic brush discharge cannot ignite a cloud of dry flammable dust (Glor & Schwenzfeuer, 2005; Schwenzfeuer & Glor, 2001). Glor and Schwenzfeuer performed direct ignition tests using brush discharges and defined that even if the energy released by this kind of discharge equaled the one of a spark, the power released by the brush discharge is too low to trigger an ignition.
However, some doubts remained for super brush discharges. A brush discharge as a super brush discharge occurs between a charged insulating object and a conductive electrode. The main difference lies in the surface charge density reached on the insulator that is much higher for a super brush discharge than for a brush discharge. A high charge density can be reached for example using pipes of polyethylene individually charged by tribo-charging piled one above another. Such a configuration was evocated by Lüttgens (Lüttgens & Wilson, 1997) and tested by Larsen (Larsen, Hagen, & van Wingerden, 2001) who performed direct ignition tests in oxygen enriched atmospheres.
This study is relevant with the actual safety problems since pharmaceutical and chemical powders are well known to generate electrostatic charges during their transport or handling and since the same configuration of independent polyethylene fibers can be found in flexible bulk containers that are one of the most common solutions to package this kind of powder.
This paper presents the experimental set-up and the results of direct ignition tests performed with a polyethylene wax whose MIE is lower than 1mJ at ambient conditions. The electric field reached at 1 meter and the charge transfer were also registered and are described. Finally, numerical simulations are carried out to define the original surface charge density in order to help to understand the phenomenology of this discharge and its frequency of occurrence in industry.

1. Introduction

Explosion protection is of a major concern in the field of process safety and remains an ongoing process. The French office of technological accident feedback took an inventory of 61 explosions in chemical or petrochemical facilities in 2014 (ARIA, nd). In order to harmonize all the different methods in the different European countries, the so called ATEX legislation was developed and applied in 1999 (European parliament, 1999). Since then, an explosion protection document is required in each plant where a flammable atmosphere is susceptible to appear (IEC 2009 and IEC 2015). This assessment entails that an ignition source analysis was carried out for every defined flammable area. It aims to define if the frequencies of an explosive atmosphere and of an associated ignition source remain reasonably low enough. Two domains are thus defined: a safe one and one where corrective actions should be carried out (figure 1).

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		A flammable atmosphere…			
		… is not expected to be present in quantities such as to require special precautions for the construction, installation and use of equipment	is not likely to occur in normal operation but, if it does occur, will persist for a short period only	… is likely to occur in normal operation occasionally	… is present continuously, or for long periods or frequently.
The ignition source…	Zone	HZ	2 / 22	1 / 21	0 / 20
	A… happens frequently under normal conditions				
	B… happens during rare deviations				
	C… happens during very rare deviations				
	D… can be ruled out or is not an effective ignition source				

Figure 1: Hazard matrix, the configuration in the grey area must be improved.

The EN 1127-1 (CEN, 2011) states that 19 different ignition sources should be investigated and among them, five are related with static electricity.

1.1 Static electricity hazards in the industry

The hazard of static electricity in the process industry has been widely studied (Glor and Lüttgens, 1989, Lüttgens, 1977). Six types of discharges are identified:

- the spark discharge: a spark discharge occurs between two conductive parts whose at least one of them is not grounded. This discharge is a capacitive discharge and the released energy can be computed by the following equation:

$$E = \frac{1}{2} C U^2 \tag{1a}$$

And since

$$Q = C \times U \tag{1b}$$

Eq(1a) can be written as

$$E = \frac{1}{2} \frac{Q^2}{C} \tag{1c}$$

Where E is the released energy (J), Q is the amount of charges (C), C is the capacitance of the system (F) and U the potential different between the two armatures of the capacitance (V).
A spark discharge can ignite a flammable atmosphere made of gas or made of dust.

- the brush discharge: a brush discharge occurs between a charged insulating surface and a conductive electrode this discharge is a so called one electrode discharge. Extensive researches were carried out to define whether or not such a discharge could ignite a cloud of dry powder. Schwenzfeuer and Glor (2005) carried out ignition testing and showed that even if the energy of a brush discharge could be of the same magnitude of a weak spark, it could not ignite a cloud of powder. Schwenzfeuer concluded that the powder of the discharge is too low to do so. To the authors' knowledge, there is no explicit expression of the energy released by a brush discharge. The only approximation would be to use Eq(1c) if the amount of charges transferred is known.
- the propagating brush discharge: A propagating brush discharge is a surface discharge and only appear under specific conditions involving a continuous rubbing against an insulating surface. This kind of discharge occurs if the breakdown voltage of the material is reached or if a grounded electrode approaches the charged layer. This kind of discharge is very energetic and can ignite a gas or a dust explosive atmosphere. Some

preventive measures can be put in place in order to avoid this discharge: for instance conveying the products in grounded conductive pipes or using insulating pipes thicker than 8mm (IEC, 2013)

- the cone discharge: a cone discharge occurs when handling a bulk powder in large capacities such as a silos, or a tank. This discharge can ignite a gas or dust explosive atmosphere
- the corona discharge: a corona discharge is too weak to ignite most of the flammable gas. This discharge is hazardous only in presence of IIC gases (IEC, 2013)

The thunder-like discharge is also mentioned but was never observed in the process industry.

1.2 Super brush discharges

Such as a brush discharge, a super brush discharge involves only one conductive electrode. However, the charge build up mechanism differs from the others discharges. Brush and propagating brush discharges only involve a piece of equipment while a super brush discharge requires several. Lüttgens (1989) describes the phenomenology of this discharge. He states that such a discharge requires a very high surface charge density. This point can be achieved by superimposing several individually charged insulating pipes. Each pipe should be rubbed using a cat fur. In that way, all the pipes are carrying charges of the same polarity. Glor (1988) noticed a similar configuration in industry during the filling of large capacities such as silos or FIBCs.
Two opposite actions take place simultaneously:

- the pipes repeal each other since the charges are of the same polarity
- gravity brings the pipes closer

This results in a redistribution of the charges at the surface of the pipes and an enhanced surface charge density. Since the electric field is a function of the surface charge density (Maxwell Gauss law) such a configuration raises the field. The available energy also increases since this quantity is a function of the electric field Eq(2)

$$W = \frac{\epsilon_0 \epsilon_r}{2} \int_V E^2 dV \quad (2)$$

Where W is the total energy (J), ϵ_0 is the relative permittivity (8.85×10^{-12} F/m), ϵ_r is the relative permittivity (-), E is the norm of the electric field (V/m) and dV is an elementary volume (m^3).
Since the energy of the discharge is increased and that this configuration can be found in production plants under normal operation, it is relevant to investigate the characteristics of the field and of the charge transfer. This approach helps to define whether or not this kind of discharge would be able to ignite a cloud of dry dust.

1.3 Direct ignitions using brush or super brush discharges

To the author's knowledge, no direct ignition tests have been carried out using super brush discharges. On the contrary, direct ignition with brush discharges is well described. Larsen (2001) uses a device close to the description made by Lüttgens but replaced the wall of pipes by a large plate of insulating material charged by corona.

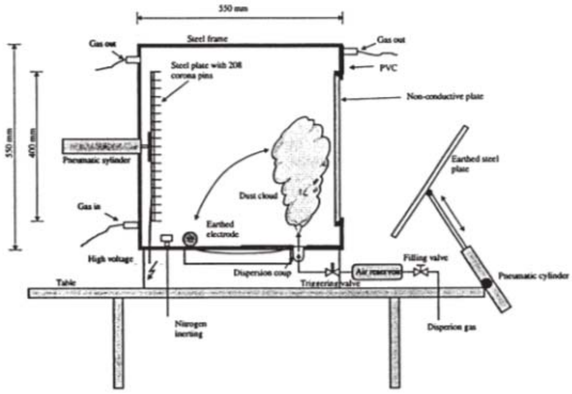

Figure 2: Larsen experimental device (Larsen, 2001).

One can see that the dust injection probe is at the bottom of the device and that the electrode strikes the upper part of the plate. It means that the gradient of concentration is high since the powder is not confined. He reported that he managed to get three ignitions on 300 trials. He used sulfur powder and the dust air mixture only ignited under enriched oxygen conditions.

2. Experimental approach

The experiments are carried out under controlled climatic conditions at 23 °C and (20±5) % relative humidity. These are the standard conditions for testing electrostatic properties of FIBCs (IEC, 2012).

2.1 Dust and dust injection probe

The chosen dust is a polyethylene wax whose Minimum Ignition Energy is lower than 1 mJ under normal air conditions. Several tests of minimum ignition energy under reduced oxygen concentration have been carried out and by extrapolation, the MIE under normal oxygen concentration in air could be lower than 0.1 mJ. Dust is pneumatically injected towards the experimental device.

2.2 Experimental device

The experimental approach is based on the drawing of Lüttgens but the number of pipes is extended. Twenty five polyethylene pipes are used instead of five. These pipes are maintained by a highly insulating polypropylene device in order to fully isolate the pipes. The pipes are 70 cm long and their diameter is 16 mm (figure 3).

Figure 3: Experimental device.

For each experiment the pipes are rubbed with a cat fur. The fur is put in contact with a grounded surface after rubbing each pipe.
The electrode triggering the discharge is a 4 cm diameter sphere. In order to reduce its electrical potential at a maximum a huge set of capacitances is linked to the electrode. The overall capacitance reached 100 nF. The voltage during the discharge is measured thanks to this capacitive circuit (figure 4).

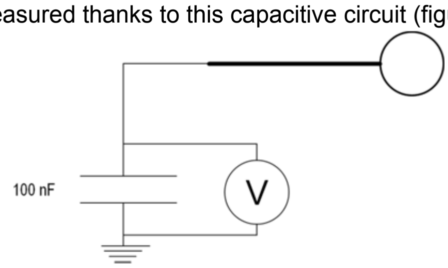

Figure 4: Electrode and electronic circuit.

The electrode is fixed on a pneumatic linear actuator. The dust injection and the actuator are synchronised.
The discharge is triggered less than 200 ms after the dust was injected.

2.3 Acquired data

Several data are registered before and during the tests. The electric field is monitored at 1 m from the wall via an Eltex field meter. The sampling rate is one second and the range of measure is manually set up at 200 kV/m. The voltage during the discharge is monitored via a fast acquisition oscilloscope (Fluke 190-204 Scopemeter). The sampling rate differs depending on the discharge but was never higher than 40 ms per division.

3. Results

The following paragraphs present the obtained results. Several set of experiments were carried out in order to adjust the injection probe and the synchronization between the electrode and the dust injection. The field and the charge transfer were always recorded and the presented results are the measures of the last set. Five trials were carried out

3.1 Electric field

The electric field reaches - 84 kV/m before a discharge was triggered. Figure 5 presents the electric field before the discharge. The observed oscillations are due to the superimposition of the pipes and of their displacement in the vicinity of the field meter. Care was ensured to keep a frequency higher than one pipe every 10 seconds. This figure shows that the electric field increases linearly when a pipe is added. This point shows that the overall device is fairly ungrounded. During the superimposition of the pipes several brush discharges could be heard and a pipe levitated at least once on each experiment. Due to their weight, this phenomenon disappears as soon as another pipe is added.
The measured field was always negative for all the trials.

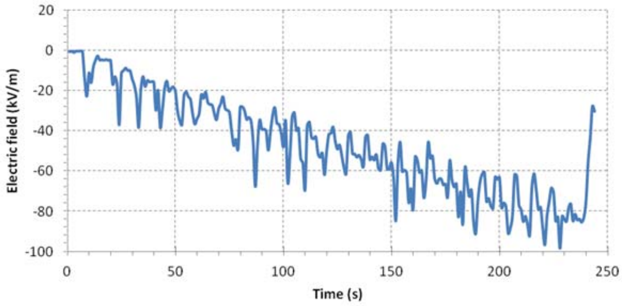

Figure 5: Electric field registered before the discharge (Exp 1).

At the far right, the fast increase of the field represents the discharge. The amplitude of the field remains positive since only a part of the polyethylene wall is discharged. Table 1 presents the main characteristics of the other trials during this set of measurement. The preparation time stays lower than a stick every 10 seconds and the highest amplitude presents a mean deviation of 3 kV/m. This represents 3% of the average value of the reached fields. The deviation of the values of the field after the discharge is higher but may be due to the stick adjustments.

Table 1: Summary of the results of the electric field

Trial	Preparation time	Highest amplitude	Field after the discharge
1	240 s	- 84 kV/m	- 23 kV/m
2	220 s	- 88 kV/m	- 15 kV/m
3	235 s	- 91 kV/m	- 19 kV/m
4	220 s	- 84 kV/m	- 19 kV/m
5	250 s	- 88 kV/m	- 7 kV/m

3.2 Charge transfer results

The voltage measurement also showed an acceptable reproducibility. The highest voltage values were close to 15 V for each trial. This is consistent with the low standard deviation of the registered field. Figure 6 presents the full charge and discharge of the capacitive circuit of the 1st trial. Attempts were made to reduce the time scale in order to visualize the charge transfer but it was not successful.

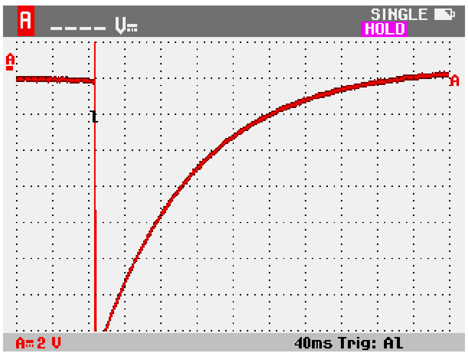

Figure 6: Charge and full discharge of the capacitive circuit.

The amount of charges transferred during the discharge can be computed from Eq(1c) where C is 100 nF and U is 15 V. The overall charge transfer reaches 1.5 µC. The equivalent energy of the discharge reaches (Eq(1c)) 110 mJ. This order of magnitude of energy should be enough to trigger an ignition. It should however be kept in mind that this charge transfer was measured without any dust cloud present.

3.3 Ignition results.

Several injection probes have been tested but none of them allowed to reach a satisfactory concentration homogenization. This means that we could not trigger an ignition. The discharges were heard after the cloud of dust was dispersed or dust accumulated on the electrode due to its movement. Figure 7 presents the apparatus after a discharge. A circular area of 32 cm diameter appears. After measurement, this area is fully discharged.

Figure 7: Unloaded area.

4. Conclusion

These first results show that highly energetic super brush discharges can be created. Even if an ignition could not have been observed, the released energy should be enough to trigger an ignition, The modification of the injection probe to ensure a more confined cloud should be of help in the aim of this study.

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