CHEMICAL ENGINEERING TRANSACTIONS

VOL. 77, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano

ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977130

Assessment of Electrostatic Discharges in Insulating Venting Lines

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In the field of protection against an explosion, every plant where flammable chemicals (liquids, gases, powders) are handled should build an explosion protection document. This document is a powerful tool to assess explosion management on the plant. Among other parts, it must include an ignition source analysis that assess the probability of explosion for every single place where a flammable atmosphere is expected.
The ignition sources to be considered as listed in various standards such as the EN 1127-1 (Secteur interdisciplinaire de normalisation, 2012) and the IEC 60079-0 (IEC, 2012). The trickiest ignition sources are often static electricity and sometimes, the general measures that could be defined for a fully new plant are extremely difficult to implement on an existing plant.
A common case deals with venting lines. Those lines are sometimes made of insulating plastics while a flammable atmosphere remains possible under normal operation. A strong charge build up can be generated on the inside surface of those lines and several hazards might happen. The charge build up in the inside part of the line will generate an electric field in its vicinity and will charge by influence the conductive parts that are not grounded. In that case, a spark discharges can occur in the working area. If a flammable atmosphere takes place at that point, an ignition could occur. The second main hazard would be a propagating brush discharge across the thickness of the venting line. In that case, an ignition of the vapours inside the pipes is possible.
This presentation describes an experimental approach to measure the charge build up generated during the different process steps of one chemical firm. The results showed large differences depending on the process step and a hazard of propagating brush discharge was identified at some point.

1. Context

Since the ATEX directives are implemented, every single plant where flammable or combustible compounds are handled must assess their explosion protection management. This assessment can be issued by the explosion protection document. The European directive 1999/92/CE describes its content. It must include the ATEX zoning of the installation i.e. the assessment of occurrence of a flammable atmosphere and an ignition source analysis where flammable areas are identified.
Basically, all places where a flammable or combustible chemical could transit must be sorted in this document. Three qualitative frequencies of occurrence of a flammable atmosphere are defined depending on its duration and its conditions of occurrence. Besides the EN-1127-1 standard introduces the 13 families of ignition sources to be assessed.
Venting lines are often a difficult part of this assessment because of the possible multiple sources of emission and the presence of air. Besides, for old chemical plants, they are often made of insulating materials for cost and depending on the process to avoid the corrosion of the pipe in case of acidic mixtures. On the other hand, the amount of ignition sources is limited. Among the 13 families listed in the EN 1127-1, open flames, device induced ignition sources and static electricity are most of the time the only ones relevant.

Paper Received: 13 October 2018; Revised: 26 May 2019; Accepted: 19 June 2019

Please cite this article as: Forestier S., 2019, Assessment of electrostatic discharges in insulating venting lines, Chemical Engineering Transactions, 77, 775-780 DOI:10.3303/CET1977130

2. Ignition sources in venting lines

2.1 Trivial ignition sources

Trivial ignition source in a venting line can occur during maintenance operations, in case of welding or grinding. This type of ignition source can easily be removed when an efficient work permit is assessed and when the line to work on is easily identified. This organizational measure is not always efficient and must be carefully applied even if this task is a daily routine in most of the chemical plants. Indeed, in 2016, a company well known in the field of safety for their strict, efficient and endorsed safety policy knew a catastrophic accident where four people died. The root cause of this accident comes from a fire during maintenance work on a pipe in a pipe rack. Similar malfunctions occurred in France in 2018 when two accidents occurred in a time frame of a week. Both are due to inconsideration of the extend of flammable atmosphere during maintenance operations

2.2 Device induced ignition sources

Device induced ignition sources are the easiest to deal with as soon as the ATEX zone inside the line is properly defined and when the properties of the chemical products inside are known.
When a device must be installed in a flammable area, its manufacturer or its supplier must demonstrate that the device cannot become an effective ignition source for the considered Ex-zone. To do so, the manufacturer or the seller must go through the ATEX certification process as described in the European directive 2014/34/UE and finally allows a ATEX category to their device. The category directly informs the end-user when effective ignition sources are excluded.

Table 1: Exclusion of ignition sources

Category	1	2	3
Exclusion of ignition sources	Under normal operation, under foreseeable malfunction, under rare malfunction and when two foreseeable deviations occur simultaneously	Under normal operation, under foreseeable malfunction	Under normal operation,

The equipment categories are directly defined by the ATEX zone inside and outside the line. Table 1 presents the type of device to be implemented depending on the ATEX zone defined.

Table 2: Equipment category depending on the ATEX zone

	Zone 0 or zone 20	Zone 1 or zone 21	Zone 2 or zone 22
Category	1	2 (1 still possible)	3 (1 and 2 still possible)

Of course, to keep the certificate valid, the end user must install the device properly and maintain it as defined by the manufacturer.
On top of that, the end user must also choose the devices he installs based on the properties of the product in contact with its equipment. Basically, the maximum surface temperature of the device must remain lower than the autoignition temperature of the product and its tightness must be high enough to avoid that vapours penetrate through the sealings. It means that the temperature class and the explosion group of the device must comply with the products characteristics. Those two last information do not appear on the ATEX marking but on the IEC one.
For instance, assuming a venting line where vapors of acetone and ethanol could be mixed, a zone 2 outside the line and a zone 1 inside, the ATEX marking should contain the following information : II 2/3G. The IEC marking should also contain the information regarding explosion group and explosivity class i.e. IIA T2 in addition the level of protection and the product category.

2.3 Static electricity in venting lines

Static electricity includes five types of discharges:

- the sparks: 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. 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. Brush discharge can ignite vapors/air mixtures (Glor, 2010). To ensure their inefficiency, the maximal insulating surface allowed where a flammable atmosphere is expected under normal operating condition is limited (IEC, 2013).
- 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 10 mm (IEC, 2013)
- the cone discharge: a cone discharge occurs when handling a bulk powder in large capacities such as a silo, or a tank. This discharge is not relevant in this study.
- 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.

2.4 Conductive and dissipative pipes

When a venting line is made of conductive and grounded materials – i.e. the resistance to the ground is lower than 10^6 Ω for conductive pipes and 10^8Ω for dissipative ones – only a brush discharge between the product and the pipe is theoretically possible but requires numerous conditions, the first one being that the product is sprayed in the pipe. This case does not appear clearly in the IEC 60079-32-1 nor in the TRBS 727 but the closest configuration would be tank cleaning by spraying liquid. The IEC recommends to limit the pressure below 50 bar for conductive compounds and 12 bar for insulating compounds. The other ignition sources entailed by static electricity are not relevant, provided the pipes remain clean and do not contain any crust of product.

2.5 Insulating pipes

When a venting pipe is made of insulating materials, brush, propagating brush discharges and spark are of interest. a first solution consists to work under inert conditions to ensure those discharges will not become effective if they occur. Otherwise, their frequency of occurrence must be assessed.
A charge build up is expected in vertical parts of the lines in case of condensation of the product and in case of a spray.

- A spark can take place when an isolated conductive part gets charged. This can be an isolated sensor or an embedded spiral used for thermal welding of the pipes.
- A brush can occur between a charged insulating part of the pipe and a conductive part
- A propagating brush discharge can occur across the insulating part provided its thickness is less than 10 mm. All those discharge can ignite a cloud of flammable vapors.

3. Methodology

In order to assess the possibility of occurrence of the different types of discharges, the charge build up on the line must be measured. To do so, experiments were conducted in a chemical plant to measure the charge build up on their venting lines during their activities. The venting lines are made of insulating material, 5 mm thick and whose different sections are thermally welded by a conductive spiral (Figure 1, the outer surface of the pipe id not represented).

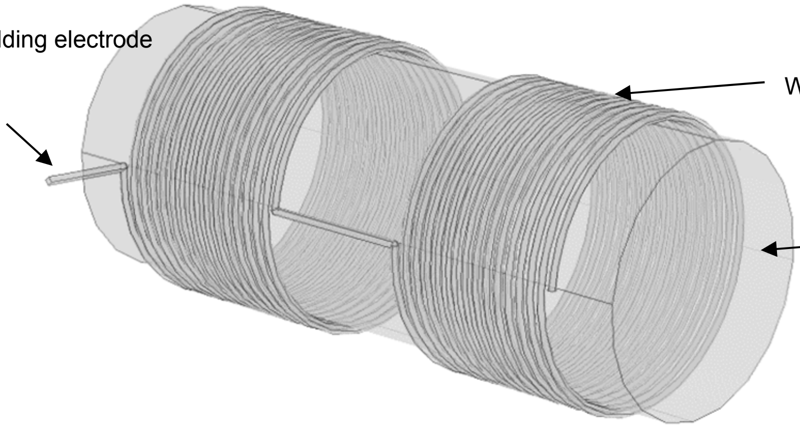

Figure 1: PVC sleeve with welding wire

The experiments aim to measure the surface charge density on the inner surface of a pipe for two different types of operations. A first set of experiments take place on a reactor fed with liquid via a dip pipe. The second set of experiment takes place on a different reactor during a process step where a conductive solution is introduced under 6 bar of nitrogen by the top of the reactor. This set of experiments was measured twice. Both set involved four points of measurement along the line. The measurements took place under normal process conditions and during some deviations when the releases to the vent lines took place after a manual operation.
To measure the surface charge density, the electrical potential values measured on the pipe using aluminum stripes linked to capacitors and to a voltmeter. Since the amount of charges is the product between the capacitance of the circuit and its voltage, this solution offers a direct measurement of the charge density carried out by the aluminum stripe. Then the surface charge density is then deduced from the inner surface of the covered pipe.
Depending on the studied configuration, the overall capacitance of the circuit varied between 1.1 nF and 30.1 nF.
The sampling rate was 10 Hz for every measurement.

4. Results

4.1 Charge build up mechanisms

The two process steps showed strong differences. Figure 2 presents the results on the first reactor that was filled with liquid via a dip pipe. No droplet is expected after the valve due to the introduction method. The red curve
Figure 3 presents the results on the second reactor. The behavior differs from the first one.

1. The maximal charge density measured at the venting valve is twice the first value for both tests. (red curve)
2. The highest surface charge density is reached far away from the venting valve and is above 3×10^{-4} C/m^2. (green curve)

However, like the first set of tests, the surface charge density strongly decreases after the maximum is reached. 50 centimeters away from the point were the highest values are measured, nearly no charge build up occurs. (curves yellow and violet)

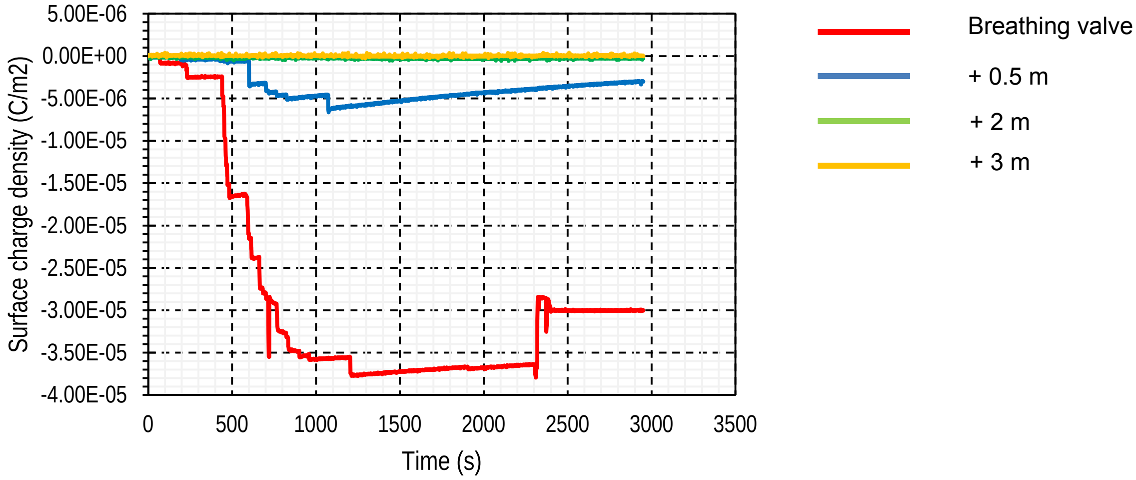

Figure 2: Surface charge density after a breathing valve

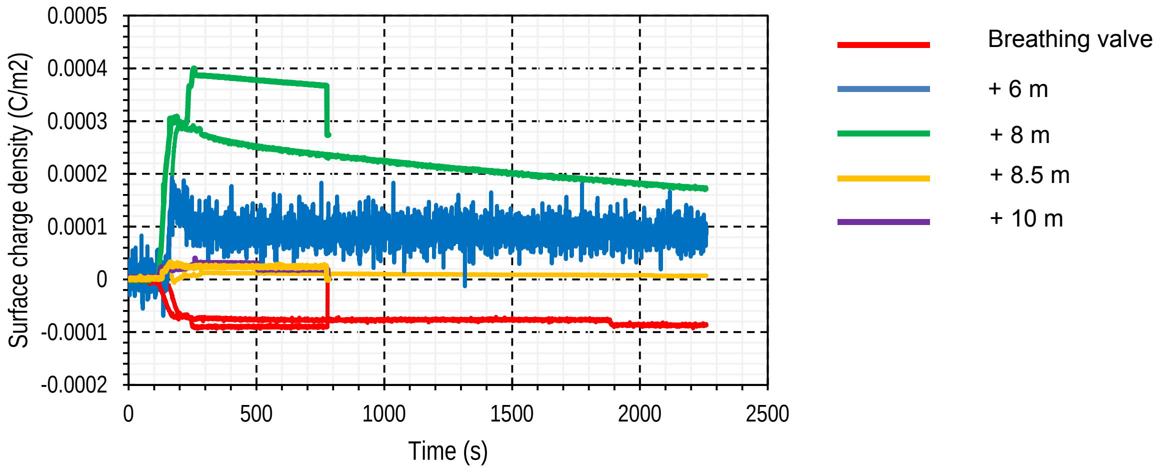

Figure 3: PVC sleeve with welding wire

The hypothesis behind this phenomenon is that some liquid remains inside the lines due to condensation. when a low-pressure flow comes into the vent line, charge build up is very limited since the liquid remains still. However, when the pressure is enough to trigger droplets, much higher values are reached. This hypothesis could not be checked on site.

4.2 Avoidance of brush discharges

Brush discharges can be avoided when no fine and elongated conductive parts are introduced in the pipe. If some are, the hazard for brush discharge appears as soon as the surface charge density is above 1.10^{-6} C/m^2.

4.3 Avoidance of propagating brush discharges

According to the IEC 60079-32-1, a propagating brush discharge can be expected when the surface charge density exceeds 250 µC/m^2. Charge build up by sprays is strong enough to entail this surface charge density. At that point, a propagating brush discharge cannot be excluded and the lack of ignition is probably due to the breakdown voltage of the pipe that remains higher than the electrical potential difference between the two surfaces of the pipe. The safety concept of the plant where the experiments were carried out was then upgraded and new pipes were installed. The pipes are now thicker than 10 mm where the highest surface density were measured. Another solution could have been to replace the insulating pipes by dissipative or conductive ones and to ground them.

4.4 Avoidance of spark discharges

Grounding every conductive part will ensure that no spark discharge can occur. The resistance to the ground should be lower than 10^8 Ω. In case the pipes are thermal-welded through an isolated conductive spiral, grounding every single electrode is extremely time consuming. The IEC 60079-32-1 and the TRBS 727 provide some guidance regarding the maximal capacitance value of the objects that do not need to be grounded. Unfortunately, the measured spirals exceed this value by a factor of 10.
To avoid grounding all electrodes, the maximal distance between an electrode and a grounded part is modelled using basic equations. In order to trigger a spark discharge, the electric field between the two conductive part must be higher than 3.10^6 V/m. Considering a surface charge density of 5.10^{-4} C/m^2 – the highest value measured during the tests -, a pipe length of 20 cm and a pipe diameter of 32 mm, the overall amount of charges induced on the spiral is $1.88.10^{-5}$ C. From Maxwell Gauss law, the distance from the charged part can be expressed using:

$$r = \sqrt{\frac{Q}{4 \times \epsilon_0 \times \epsilon_r \times \pi \times E}} \tag{2}$$

Where r is the distance in m, ϵ_0 is vacuum permittivity (8.84×10^{-12} F/m), ϵ_r is the air relative permittivity (-) and E is the electric field magnitude (V/m). Considering a field magnitude of 3.10^6 V/m, the corresponding distance is 10 cm. Considering the surface charge density induced by condensation on vertical parts of 5.10^{-5} C/m^2, the distance decreases to 3 cm.

5. Conclusions

This article presents the possible ignition sources that can appear in venting lines. Static electricity ignition sources must be closely investigated since they are generated by the process. To assess their possibility of occurrence, experiments were conducted in a chemical plant whose venting lines are made of insulating materials. The results showed that most of the process operations do not lead to high charge generation inside the venting lines. Nearly no charge build up was measured at the bottom of a 5 m height vertical section while reactors were being fed. On the other hand, process steps that generated a spray inside the venting lines showed a much higher charge generation. In the studied configuration sparks and propagating brush discharges are the discharges of interest. Propagating brush discharges can be safely excluded when the pipes are replaced either by a conductive or a dissipative material or when their thickness is increased at 10 mm. Spark discharges were excluded via the grounding of all conductive parts that are initially closer than 10 cm to a conductive grounded part. It is important to notice that this last recommendation is only valid due to the batch processes

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