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Safety of Old Centrifuges in ATEX Environment, How Can You Insure Safe Working Conditions?

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Process safety is one of the oldest priorities in process industry. With time, the ignition source mechanisms are more and more understood and the current standards are much more accurate than their first versions. Due to this evolution, some characteristics that were allowed in the past may not be tolerable any more. Besides due to the ageing of the devices, it can happen that some properties do not comply with the last versions of the concerned standards. In that case, the end user has few choices and usually end up changing its device.

This presentation describes the study of old centrifuges (more than 30 years old) whose some characteristics appeared to be out of the ranges defined by the current standards. In that case, the centrifuges were supposed to be coated with a dissipative coating but some showed values of resistances to the ground several orders of magnitude higher than the values defined in the IEC 60079-32-1: 2013 (IEC, 2013). As resistance to the ground is a key parameter to avoid spark discharges, the user should change the centrifuges or recoat them with a proper coating. However, this standard describes that the threshold values for resistance were assessed to avoid that the electric potential du to static electricity build up exceeds 100 V.

The basket of the centrifuge was then modelled through an RC circuit and based on measured data on the centrifuges and on the specifications of the handled products, the voltage across this circuit was defined as a function of time. It was then possible to assess the required waiting time to let the voltage decrease below 100V.

The model was then tested against a real case experiment using the worse centrifuge. The results of the test were predicted by the model.

1. Context

1.1 Legislation

Since 2003, when the ATEX directives came into effects, all new electrical and mechanical devices installed at a place where a flammable atmosphere is expected, must be certified. The certification helps to ensure that the design of the device and a proper maintenance ensure that it cannot become an effective ignition source. Thirteen families of ignition sources that could be produced by the device were defined (Secteur interdisciplinaire de normalisation, 2012)**.** The IEC defined the frame of acceptance of most of them (IEC, 2012). Depending on the expected frequency of occurrence of the flammable atmosphere, the requirements to fulfill differ. Three frequencies are defined:

- 1: areas in which explosive atmospheres caused by mixtures of air and gases, vapours or mists or by air/dust mixtures are present continuously, for long periods or frequently.
- 2: areas in which explosive atmospheres caused by gases, vapours, mists or air/dust mixtures are likely to occur occasionally.
- 3: areas in which explosive atmospheres caused by gases, vapours, mists, or air/dust mixtures are unlikely to occur or, if they do occur, are likely to do so only infrequently and for a short period only.

Based on the European directive 2014/34/UE – the updated version of the directive 94/9/CE – a supplier must exclude an efficient ignition source under normal process conditions for category 3 devices, under normal process conditions and foreseeable malfunctions for a category 2 device and under normal process

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conditions, foreseeable malfunctions and two simultaneous malfunctions for category 1 devices. This approach is summarized by the table below (Table 1):

Table 1: Risk acceptance matrix for ATEX certified devices

		Device category			
		No	3	2	1
Effective ignition source frequency	A: can occur under normal process conditions	YES	NO	NO	NO
	B: can occur under foreseeable malfunction	YES	YES	NO	NO
	C: can occur in case of rare malfunction	YES	YES	YES	NO
	D: the ignition is not relevant.	YES	YES	YES	YES

Some issues arise with mechanical devices that were installed before 2003. Indeed, those devices are not certified since it was not a requirement at that time. However, they must comply with the current safety requirements and the user of the device must ensure that those devices fulfil an equivalent safety level as a new equipment. This can be achieved using the same method as for a new equipment.

1.2 Ignition source analysis

The risk analysis to be performed aims to decompose the device of interest into individual parts. Then, for each identified part, the 13 families of ignition sources are analyzed and in case one ignition source could appear, its frequency must be assessed. Based on the maximum value of the frequency, the equivalent category of the device can be defined (Table 1).
Static electricity is one of the 13 families of ignition source. It 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:

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

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 (Glor & Schwenzfeuer, 2003) 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 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 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.

Depending on the device and the ATEX zone defined, the ignition source analysis can be straightforward. One difficulty can arise when the hazard of spark discharges from a dissipative surface must be assessed. In that case it occurs that the resistance to the ground far exceeds the threshold values defined in the IEC 60079-32-1. In that case, to comply with the standards, the device should be changed for a new one or a deeper study should be assessed.
This paper deals with the case of dissipative coated vertical axis centrifuge. During routine check up, it appeared that the properties of the coating evolved with time. The resistance to the ground was 2.10^{10} Ω .

2. Theory

According to the IEC 60079-32-1: 2013, the maximum resistance to the ground of any conductive object should not be higher than 10^6 Ω while the one for dissipative ones should be lower than 10^8 Ω .Those two values ensure that no spark discharges can arise. Those values assume that the maximum tolerable voltage on a conductive or a dissipative part should not be higher than 100V.

3. Methodology

The basket of the centrifuge is considered as a real capacitor and is defined by its capacitance and its leakage resistance. The hypotheses behind this model are the following:

- The centrifuge or its basket has a high resistance to the ground.
- The basket can be assimilated to a plate of a parallel plate capacitor
- The product inside obeys the local Ohm law.

The electrical potential of the basket is a function of the inflowing current:

$$\frac{du(t)}{dt} + \frac{1}{RC}u(t) = \frac{1}{C}i(t) \tag{2}$$

Where u is the electric potential (V), R the resistance to the ground of the basket of the centrifuge (Ω), C the capacitance of the basket (F) and i the current (A)
This current comes from the product that slowly dissipates the electrical charges. Based on Maxwell Gauss equation, conservation law and local Ohm law, the space charge density follows equation 3:

$$\rho(t) = \rho_0 \times e^{-\frac{t}{\epsilon_0 \epsilon_r \rho_{el}}} \tag{3}$$

Where ρ(t) is the charge to mass ratio of the product (C/m^3), ρ_0 is the initial charge to mass ratio (C/m^3), ϵ_0 is the vacuum permittivity (F/m), ϵ_r is the product permittivity (-) and ρ_{el} is the electrical resistivity of the product (Ω.m).
Assuming the charges dissipate, the can be deduced from the time derivative of the amount of charges

$$\begin{aligned} i(t) &= m \times \frac{d\rho(t)}{dt} \\ i(t) &= -\frac{m \times \rho_0}{\epsilon_0 \epsilon_r \rho_{el}} \times e^{-\frac{t}{\epsilon_0 \epsilon_r \rho_{el}}} \end{aligned} \tag{4}$$

Where m is the mass of product inside the centrifuge (kg). The other parameters are defined in the previous equations.
Eq. 2 is a first order differential equation presenting non constant coefficients. The shapes of the potential curves depend on the characteristics of the centrifuge (resistance to the ground and capacitance) but also from the properties of the product inside. As the charge density, the current is a function of the resistivity of the product and of its permittivity.
The model was used for old centrifuges whose characteristics are the following (Table 2). During process operation the centrifuge works under inert conditions.

Table 2: characteristics of the centrifuge

	Resistance the ground	toCapacitance	Mass product	ofProduct resistivity	Product permittivity	Initial space charge density
Centrifuge	2.10^{10} Ω	$2.17.10^{-9}$ F	50 kg	1.10^{8} Ω.m	2 (-)	1.10^{-5} C/kg

4. Results

4.1 Voltage evolution

Figure 1 presents the expected evolution of the voltage on the basket of the centrifuge. The plain line represents the voltage on the basket. the dashed line represents the 100V threshold value as defined in the IEC 60079-32-1. According to this model, the voltage on the basket becomes lower than 100 V after around 400 seconds. This waiting time complies with process time frame and would be a suitable reply in this case.

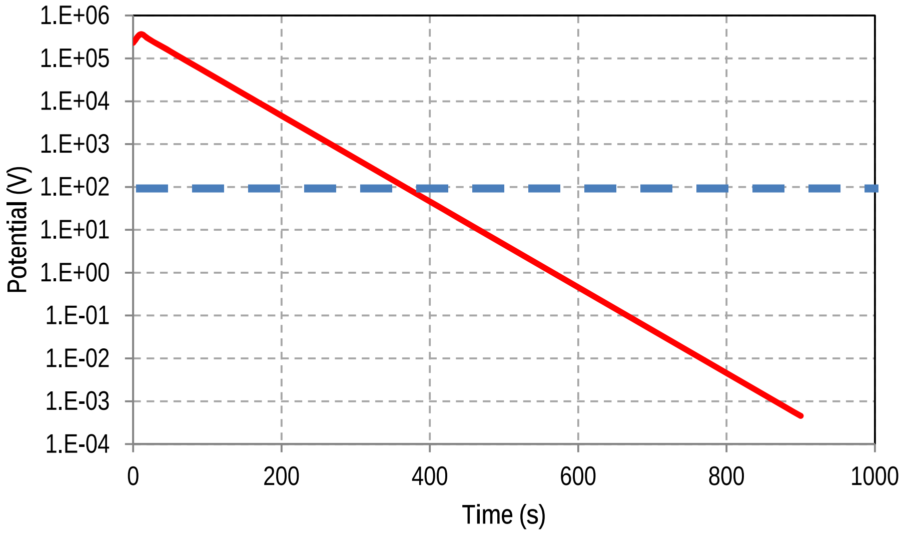

Figure 1: Expected evolution of the voltage as a function of time

A real scale experiment was carried out using non flammable solvent. The aim of this test was to ensure the lack of charges 10 minutes after the centrifuge stopped. Using a coulombmeter, no charge transfer could be measured. This point confirms the lack of charges on the basket.

4.2 Parametric study

To identify the most sensitive parameters, a sensibility study is carried out. The main parameters are

- The resistance to the ground of the centrifuge,
- The mass of product inside,
- The charge to mass ratio
- The resistivity of the product.

The resistance to the ground of the centrifuge is the most sensitive parameter. Figure 2 presents the results for four different case studies. All the parameters are the same as the studied centrifuge except for the resistance to the ground. Four different values are investigated, from 10^{9} Ω to 10^{12} Ω. One higher order of magnitude than the case studies increase the required waiting time by a factor 4. This point can be explained by the fact that the charge dissipation process is driven by the centrifuge and the time constant of the centrifuge depends directly from its resistance to the ground. On the other hand, the mass and the initial charge to mass ratio only have a linear impact on the results. The influence of the resistivity of the cake inside the centrifuge is more important. While the time constant of the product remains lower than the one of the centrifuge, this parameter does not influence the electric potential of the basket. when the time constant of the product is higher than the one of the centrifuge, the charge dissipation is limited by the cake and not the centrifuge itself.

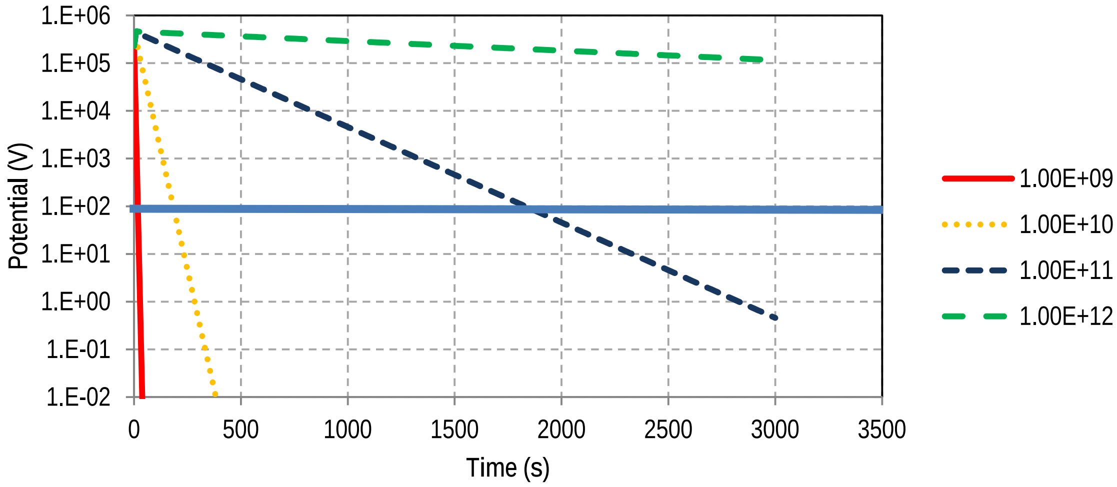

Figure 2: Influence of the resistance to the ground of the centrifuge

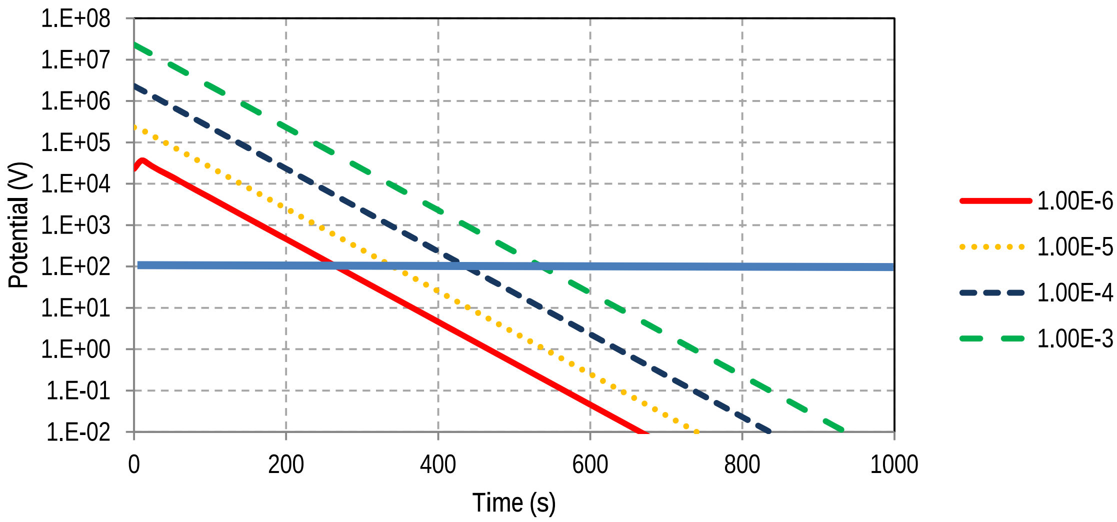

Figure 3: Influence of the initial charge to mass ratio on the electric potential of the basket.

The influence of the product resistivity (figure 4) highlights the interaction between the properties of the centrifuge and of the product. Both owns a specific time constant, (eq 5 for the product, 6 for the device)

$$\tau_{prod} = \epsilon_0 \epsilon_r \rho \quad (5)$$

$$\tau_{centri} = RC \quad (6)$$

Where R is the resistance to the ground (Ω) and C its capacitance (F). the different shape of the green curve on figure 4 occurs because for this value of resistivity, the time constant of the product is higher than the one from the centrifuge. Then, the charges are no longer accumulating on the centrifuge.

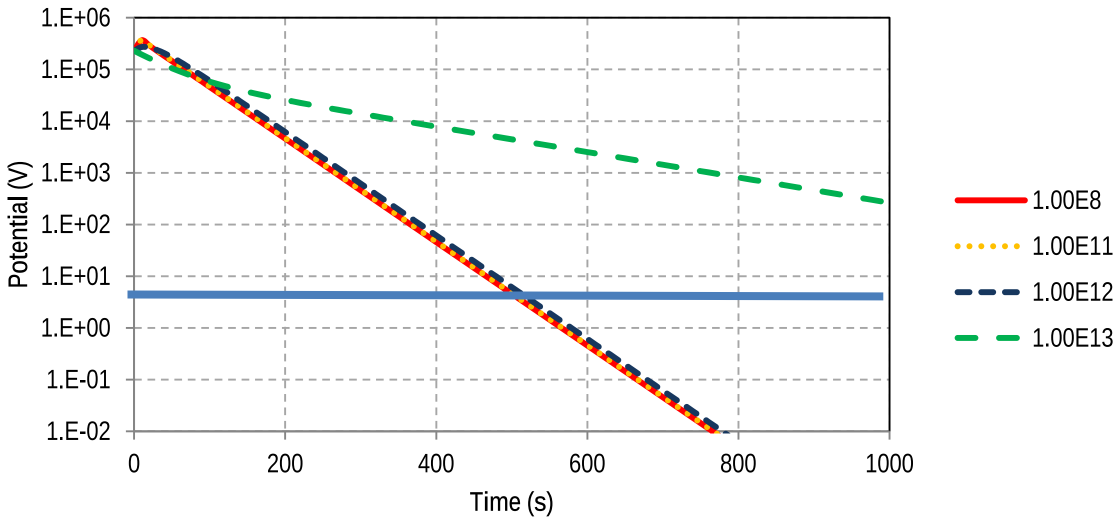

Figure 4: Influence of the resistivity of the product on the electric potential of the basket.

5. Conclusion

This paper presents the methodology followed to justify that a non certified ATEX devices complies with the IEC 60079-32-1 in terms of safety. The main hazard was spark discharges even if the resistance to the ground of the device is two orders of magnitude higher than what is recommended in the standard. Instead of fulfilling the recommendations in terms of resistance to the ground, the situation is considered safe based on the dissipation of the charges that are carried out by the basket. The centrifuge and its product are considered as a RC circuit. The electric potential on the basket is then assessed based on the properties of the product and of the centrifuge. Finally, a specific waiting time is defined for each centrifuge. A parametric study shows that the behaviour of the charge decay differs depending on the values of the time constant of the product and of the centrifuge. Besides, when the time constant of the product is smaller than the one of the centrifuge, the main parameter is the resistance to the ground of the centrifuge. The relationship between this parameter and the time required to reach the threshold value of 100V is exponential

The results in this paper only apply for the studied device. A specific study must be issued case by case. This study only focused on the hazard of spark discharge induced by the basket of the centrifuge. Additional considerations must be taken to ensure a safe emptying of the centrifuge.

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