Measurement of electric fields of charged spray clouds of conductive liquids in free space and in a conductive vessel

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Abstract. The process of spraying liquids generated electrical charges. The question therefore arises as to whether this electrostatic charge represent an ignition hazard when an explosive mixture is present. This hazard occurs when cleaning vessels, in which an explosive mixture is formed by residues of easily flammable liquids or the cleaning medium itself. Although measurement techniques and methods exist for detecting this electrostatic charging process, they have not been sufficiently scientifically proven. The Chilworth JCI 131 adverse conditions field meter is to be used to measure the electrostatic charging of sprayed liquids. It shall be validated by measuring the electric field strength of a flat spray water jet in low-pressure range (8 bar) charged by contact charging and accumulation of free electrons of a commercial, insulated arranged electrostatic spraying system (up to -90 kV). A flat-jet nozzle is selected which atomizes the spray jet, which serves as the measuring surface, sufficiently large. This arrangement is further investigated in a 1 m³ stainless steel IBC. The investigations presented are part of a project aiming to extend the scope of the German Technical Rules for Hazardous Substances (TRGS) of TRGS 727, which regulate avoiding ignition hazards resulting from electrostatic charging. The aim is to reach an understanding that allows provisions for safe cleaning of “small” and “medium-sized” containers up to 50 m³. This project is funded by DGUV (German Social Accident Insurance) and partners from the industry.

1. Introduction

The spraying of liquids is a highly charge generating process [1]. To measure the electric field strength of sprayed liquids suitable methods are required. In a previous research project [2] the electric field strength of tap water (water) sprayed at high-pressure (up to 500 bar) was measured. The measurement device used was a field meter of the type JCI 131 (JCI 131) obtained from the firm Chilworth Technology Ltd. [3]. The JCI 131 was either mounted in the shell surface of a cylindrical 1 m³ stainless steel IBC (Intermediate Bulk Container) or was manually approached in the vicinity of the free water jet. These measurements demonstrated the general applicability of the JCI 131 for measurements at a high humidity and in close vicinity to the water jet. The previous research project [2] could not verify whether the measured electric field strength corresponds to the real field strength of the water jet. The aim of this research is to transfer the applicability of the field strength measurement from rigid surfaces to charged dynamic flat jets and to verify the generated field strength with the measured field strength of the charged flat jet of water. An insulated installed commercial electrostatic spraying system of J. WAGNER GmbH, type GM 2000 EAF-EN was used to generate a
charged flat jet. It is equipped with a standard nozzle which charges the water in the low-pressure range (8 bar) via a high-voltage cascade (up to -90 kV) with direct contact to the interior of the standard nozzle and emits free electrons from the valve needle, which is also under high voltage, which are accumulated to the flat jet. The charged flat jet generates a defined electric field and is independent from the before mentioned parameters of high-pressure of the previous research project. The negative electric field strength of the flat jet is measured by the JCI 131. A flat jet nozzle was chosen in order to generate a sufficiently large area of measurement. As in [2] the experiments are conducted in free space and in a 1 m³ stainless steel IBC.

2. Measurement of the electric field strength of sprayed liquids in free space

Tap water is sprayed in a flat jet under negative high voltage (up to -90 kV) in the free space by a commercial but insulated installed electrostatic spraying system. The high-voltage of the electrostatic spraying system is measured with an electrostatic voltmeter Trüb & Täuber of type Gt-sv calibrated according to ISO 17025 by the National Metrological Institute of Germany. The charged flat jet leads to a suppression of a corona discharge at the nozzle and valve needle. The water pressure is held constant at 8.0 bar at a flow rate of 52 l/min. The pressure of the atomised air provided by the spraying system inside the nozzle is set to either 2.0 bar or 3.8 bar. The flat jet that fans out from the nozzle in an ellipsoid manner and reaches a height of up to 1.12 m and a width of up to 0.40 m in a distance of 1.25 m from the nozzle. The JCI 131 is aligned towards the fanned out flat jet. The JCI 131 measures the negative electric field strength (in kV/m) of a circular area that increases in size with increasing distance from the measurement object. The JCI 131 operates at a measuring angle of (40 ± 5)° [4] and is positioned at a distance R of 0.40 m to the middle of the flat jet. From this setup results a circular area of measurement of 0.365 m² with Ø 0.68 m (Figure 1). In order to homogenise the electric field between the high-voltage spray jet and the JCI 131 according to [4], the measuring port of the JCI 131 is integrated into a conductive, grounded 0.01 m thick metal plate with Ø 0.40 m. Further than 1.25 m away from the nozzle the widening of the water jet is no longer accurately determinable due to strong turbulences.

![Figure 1: Area of the water jet, area of measurement of the JCI 131](image)

The area of the flat jet completely covers the measurement area of the JCI 131 at a distance of approximately 0.75 m from the nozzle at a pressure of 2.0 bar and at a distance of approximately 0.50 m at a pressure of 3.8 bar. At a pressure of 2.0 bar large water droplets formed in the middle of the inhomogeneous flat jet (Figure 1 left photo down). These droplets quickly fall to the ground resulting in a reduced density of water droplets compared to a pressure of 3.8 bar with a homogeneous flat jet (Figure 1 left photo up). The ellipsoid at the right side of Figure 1 show the direct view to the cross section (height and width) of the flat jet in the direction of spraying.
The flat jet generates a nearly homogeneous volume charge density. Based on the constant distance $R$ of 0.40 m, between the JCI 131 and the middle of the flat jet, and the voltage $U$ applied to the flat jet equal to the voltage $U(0)$ in the middle of the flat jet, the electric field strength $E(R)$ can be calculated for the geometry of an ideal cylinder (equation 1). According to this equation the field strength should increase by 50 kV/m with each increase of the applied voltage of 10 kV (Figure 2 (left), Figure 3 (left), ideal cylinder). The basis of this calculation is a homogeneous volume charge density in a cylindrical volume. In practise the volume of the flat jet in the direction of spraying forms an elliptical cone. The electric field strength $E(R, R_E)$ is calculated for distances to the nozzle ranging from 0.25 m to 1.25 m for an elliptical cone (equation 2) and is shown in Figure 2 (left) and Figure 3 (left). Based on the constant distance $R$ of 0.40 m, between the JCI 131 and the middle of the flat jet, and the radius $R_E$ (semi-major axis) of the elliptical flat jet (ordinate of Figure 1).

Cylinder (see [5]):

$$E(R) = \frac{2}{R} \cdot U(0) \quad (1)$$

Elliptical Cone (see [5] & [6]):

$$E(R, R_E) = \frac{1.5 (R + R_E) - (R - R_E)^2}{R R_E} \cdot U(0) \quad (2)$$

Figure 2: Calculated (left) and measured (right) electric field strength at a pressure of 3.8 bar

Figure 3: Calculated (left) and measured (right) electric field strength at a pressure of 2.0 bar

At a pressure of 3.8 bar the measured electric field strength does not correspond with the calculated electric field strength up to a distance of 0.50 m from the nozzle. The problem that arises with this setup is that the area of measurement of the JCI 131 is larger than the area of the flat jet and, therefore,
fractions of the surroundings are also measured. Due to this the electric field strength is reduced for high volume charge densities. At a distance to the nozzle ranging from 0.75 m to 1.00 m the measurement area of the JCI 131 is smaller or equal to area of the flat jet. Under these conditions and with this droplet density and volume charge density the measured electric field strength corresponds well with calculated field strength. When the distance to the nozzle surpasses 1.25 m the droplet density, the volume charge density and the measured electric field strength decrease.

At a pressure of 2.0 bar there are less droplets in the area of measurement of the JCI 131 than at a higher pressure of 3.8 bar. This is due to the larger fraction of big droplets that quickly fall to the ground. Furthermore, the fanned-out area of the flat jet is reduced. The measured electric field strength roughly corresponds to calculated ideal electric field strength only at a distance to the nozzle of 1.00 m and up to a voltage of 20 kV (Figure 3 (right)). At voltages above 40 kV, the electric field lines respectively the trajectories of the charged droplets are deflected to nearby grounded objects. These "grounding paths" ensure that droplets are discharged, and the electric field strength measured by the JCI 131 is reduced.

3. Measurement of the electric field strength of sprayed liquids in a 1 m$^3$ stainless steel IBC

The electrostatic spraying system is mounted insulated in the lid opening of a cylindrical earthed 1 m$^3$ stainless steel IBC (IBC, Ø 1.07 m, height 1.00 m). This installation sprays a flat jet of tap water under negative high voltage (up to - 90 kV) into the IBC. The JCI 131 is mounted in the shell surface of the IBC at a height of 0.50 m with the opening of the measuring head flush with the inner shell surface. According to equation 1 the idealised calculated electric field strength should increase by 37.38 kV/m, when the voltage is increased by 10 kV (Figure 4 (left), Figure 5 (left), ideal cylinder). The flat jet oriented either parallel or in a right angle to the opening area of the JCI 131. The measured electric field strength only correlates with the idealised calculated electric field strength up to a voltage of approximately 10 kV. At higher voltages the measured field strength reaches a maximum at approximately 50 kV/m. This correlates to a voltage $U(0)$ in the IBC of nearly 15.0 kV. To confirm the results of $U(0)$, the JCI 131 was replaced by a rod electrode that was inserted into the shell surface of the IBC in an insulated manner and connected to a field meter type EMF 58 (EMF 58) with a ± 40 kV voltage measuring head which operates as an electrostatic voltmeter [7]. The rod electrode protruded 0.300 m, 0.450 m or 0.535 m into the IBC from the inner shell surface. Using this setup, the 10 kV set by the electrostatic spraying system were measured (Figure 4 (right), Figure 5 (right)), validating the results obtained with the JCI 131. Increasing the voltage applied to the spraying system led to maximum voltages in the IBC of less than 15.2 kV (Figure 4 (right), Figure 5 (right)), confirming the voltage of nearly 15.0 kV derived from the measured electric field strength. The turbulence in the earthed IBC forces the trajectories of the charged droplets to the earthed container wall at an early stage.

Figure 4: Measured electric field strength (left) and measured voltage (right) at a pressure of 3.8 bar
4. Summary

This research paper proves that the field meter JCI 131 is suitable for traceably measuring the electric field strength of dynamic surfaces such as sprayed liquids. The main parameter is the measurement area of the JCI 131, which must be smaller or equal to the area of the fanned water jet. The equations (equation 1, equation 2) for calculating the field strength from the maximum potential $U(0)$ in the middle of a cylindrical volume or elliptical cone volume can be applied for water jets in free space and in a 1 m$^3$ stainless steel IBC. This calculation is also reversible.

It is proven that an increase of the voltage at the electrostatic spray system up to 90 kV does not lead to voltages in the IBC exceeding 15.2 kV. The turbulence in the earthed IBC forces the trajectories of the charged droplets to the earthed container wall at an early stage. This leads to a continuous voltage drop, which limits the resulting voltage.

In the charge-generating process of spraying conductive liquids in a conductive, grounded 1 m$^3$ vessel, this maximum voltage of 15.2 kV may be an upper limit. This limit value must be confirmed in further investigations with the values from spray tests for tank cleaning in the high-pressure range, which are considered to be strongly charge-generating but highly turbulent.

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