Charge generation associated with liquid spraying in tank cleaning and comparable processes - preliminary experiments

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Abstract. The BG RCI has initiated investigations in order to improve the data basis for assessing the ignition hazard by electrostatic charging processes associated with the spraying of liquids. On the base of preliminary experiments, we established procedures for measurements of electric field strength and charging current in the presence of aerosol particles. Results obtained with three different nozzle types, variation of pressure and with built-in deflecting plate are presented.

1. Introduction

1.1. Motivation
In Germany the technical guidelines of TRBS 2153 \cite{1} regulate avoiding ignition hazards resulting from electrostatic charging. This document was established and is updated by the Deutsche Gesetzliche Unfallversicherung (DGUV)\textsuperscript{4} under the direction of the Berufsgenossenschaft Rohstoffe und chemische Industrie (BG RCI)\textsuperscript{5}.

Many industries, e. g. chemical, pharmaceutical, petrochemical, and food industry, perform processes in which liquids are sprayed. Therefore those responsible must assess the danger of ignition by electrostatic discharges. In marked contrast to this requirement the guidance given by TRBS 2153 is scarce. One example is the maximum pressure that is still acceptable when cleaning containers with different solvents in order to avoid dangerous charging. The lack of clear guidance is due to limited experimental data for the actual conditions that result in hazardous charging. For the existing statutory provisions it is not known how far the “safe range” of parameters is apart from dangerous conditions.

This is the reason why BG RCI has decided to initiate investigations in order to improve the data basis for assessing the ignition hazard by electrostatic charging processes associated with the spraying of liquids. Two objectives of the preliminary experiments are presented here. First we establish procedures for measurements in the presence of aerosol particles, which is essential prior to

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quantitative investigations. Secondly, we target the most critical parameters among the many that impact charge generation in technical applications.

1.2. Physical context and previous studies

The charging of small droplets in spraying processes is well known as Lenard effect and commonly referred to as “waterfall electricity”, a nickname, which reflects that this effect is not confined to liquids of low conductivity. The fact that discharges resulting from spraying liquids can act as an ignition source was brought to mind in 1969, when within a couple of weeks three supertankers suffered heavy damages due to explosions during the cleaning of empty tanks with seawater. These incidents stimulated extensive studies researching electric fields and potentials generated by liquid jets at 12 bar in tanks of some 20,000 m³ size, e.g. [2]. The findings were that most likely water slugs discharging charged clouds of droplets were the cause of the explosions. While this setup is unlikely to occur in smaller tanks and containers, the question arose as to whether in smaller vessels brush discharges capable of igniting explosive atmospheres can be produced involuntarily. In 1989 Post et al. [3] published results from experiments with combustible liquids and water in a 1 m³ container at up to 50 bar and with water in a 24 m³ container at pressures from 100 bar to 500 bar. They gave safe conditions for operations in the investigated pressure range, which have been implemented in the German regulations. With the advance of technologies the call has intensified for answers extending the scope of permissible conditions.

2. Experimental setup

The tests were performed by spraying industrial and purified water with a commercial high pressure cleaner (HD9/50-4, Kärcher) through the manhole into a modified cylindrical stainless steel 1 m³-IBC. The outlet valve was left open during spraying and the water was collected in an insulated container (not shown in the experimental setup, figure 1). The electric field strength was measured with a field meter (JCI 131, JCI Chilworth). In addition, the temporal progress of charge accumulation on the wall was recorded with a charge amplifier (5011B, Kistler). In all experiments the observed increase of charge during the spraying time was linear (e.g. bottom writing in figure 2). Therefore, we evaluated the gradient dq/dt, which yields the charging current. The nozzle types used were a pencil jet nozzle (.3 mm), a flat spray nozzle (15°, .3 mm), and a rotating nozzle (only 300 bar). The pressure was varied from 100 bar to 500 bar. The IBC could be fitted with a deflecting plate mounted close to the bottom but electrically isolated from the IBC. Two different plates were used, an insulating plate of polyethylene and a metal plate earthed by a cable laid through the outlet valve.

Figure 1. Experimental Setup.

Figure 2. Simultaneous record of field strength (top) and charging current (bottom writing).
3. Results

3.1. Procedures for measurements of electric field strength and charging current

The objective of the experiments was to establish a procedure to measure simultaneously i. the electric field strength of the spray cloud using the induction field meter and ii. the charge generated by droplets arriving at the wall of the IBC – the charging current – using the charge amplifier and the oscilloscope (figure 2). Both methods were suited. The induction field meter worked reliably in the presence of aerosol particles. Furthermore, the measurements of charging currents produced correct results. Since charge accumulation on the wall can only be determined if the vessel is electrically isolated against earth, simultaneous measurements could not be continued, because in the course of the measurements the water fog shorted the insulating installation of the field meter, draining the charge via the casing. So the electric field strength and the charging current had to be measured consecutively maintaining constant parameters.

3.2. Pressure dependence and influence of installations

As anticipated, charging currents and electric field strength increased with pressure (figure 3). The differences in charging between the pencil jet nozzle and the flat spray nozzle were less marked (figure 4). Introducing the deflecting plate lead to a lower charge on the wall. The currents measured at the wall and from the earthed metal plate had similar values (figure 4 bottom lines), summing appropriate values almost exactly equals the currents measured for the polyethylene plate.

3.3. Conductivity of the sprayed water

The purified water and the industrial water used differed in conductivity by approximately one order of magnitude. This was the most important parameter giving the most significant differences in measured field strengths and currents. At identical conditions, the charging current using purified water was found to be up to eight times that of the value measured using industrial water. When spraying into the grounded container only spraying with purified water yielded a measurable electric field of the spray cloud.

3.4. Grounded container

In practical applications containers are grounded rather than isolated against earth. With respect to the objective of assessing the danger of ignition by electrostatic charging the electric field strength was also monitored when spraying into a grounded container. Table 1 gives the results obtained for spraying purified water with a pressure of 500 bar (flat spray nozzle and pencil jet nozzle) and 300 bar (pencil jet nozzle and rotating nozzle) without deflecting plate and using a polyethylene deflecting plate. This shows that the field strength increased from flat spray to pencil jet and was highest.
employing the rotating nozzle. Also the introduction of a polyethylene deflecting plate increased the field strength considerably.

**Table 1.** Electric field strength – container grounded.

| Nozzle     | Pressure [bar] | Deflecting plate | E [kV/m] |
|------------|----------------|-------------------|----------|
| flat spray | 500            | no                | 4        |
| flat spray | 500            | polyethylene      | 16       |
| pencil jet | 500            | no                | 6        |
| pencil jet | 500            | polyethylene      | 25       |
| pencil jet | 300            | no                | 0        |
| pencil jet | 300            | polyethylene      | 16       |
| rotating   | 300            | no                | 12       |
| rotating   | 300            | polyethylene      | 20       |

4. Discussion and conclusions

When a liquid is sprayed into a container charging occurs at the phase boundaries in the feed pipe and the nozzle bringing charged liquid into the container and also if the jet breaks up and when it hits the wall of the container. As we collected the water draining from the container in an insulated vessel, while the container itself was electrically isolated against ground, our measurements of the charging current of the wall give the total net charge reduced by the charge of the cloud of droplets. Thus a total charge of the liquid of 71 µC/kg is calculated from the measured current of 17.8 µA and a flow rate of 15 l/min (values for industrial water, 500 bar, flat spray nozzle, no deflecting plate).

The charging currents we measured for flat spray resp. pencil jet nozzles at 500 bar are one order of magnitude higher than the value found by [3] for industrial water sprayed at 50 bar into a 1 m³ container. Taking into account different nozzle geometries and sizes the values match fairly well.

In order to arrange conditions close to practice and to allow validation by calculations, we measured the electric field strength with the container grounded. Using the same parameters as given in the first paragraph, we obtained a field strength of 4 kV/m. Assuming a homogeneous space charge density in the cylindrical container and using Gauss law, we can derive a space charge density of 133 nC/m³. This estimate is about a factor 2 smaller than the value of 240 nC/m³ given by [3] for their experiments with a pair of nozzles in a 24 m³ container.

The measured field strengths in the grounded container were far from the physical limit given by the uniform breakdown field of air of 3 MV/m. For this reason there is no ignition hazard from electrostatic discharges under conditions comparable to our tests.

Installations reduced the measured charge of the liquid and increased the measured field strength. It appears that fewer droplets arrive at the wall resulting in a higher charge of the cloud of droplets. Since the geometry is more complex, further model calculations of the potential and the resulting electric field could help in clarifying the contributions of the different charging mechanisms.

The preliminary tests have shown that the procedure outlined above procures valid information on charging in spraying and related processes. It can be used to obtain experimental data in application-oriented setups, e. g. bigger containers and higher pressures. Thus the conclusion of [3] that the space charge density is converging at pressures above 100 bar to an upper limit of approx. 240 nC/m³ can be put to the test. Eventually this is a step on the way to safe operation conditions based on a better understanding of the underlying physical processes.

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References

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