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Effectiveness of Increase of Relative Humidity as a Measure to Reduce the Ignition Probability of Explosive Atmospheres by Static Electricity

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It is a well-known fact that the relative humidity of air may have an influence on the build-up of static electricity on equipment, installations, packages, personnel, etc.. However the questions arise whether in industrial practice the increase of the relative humidity of air is sufficiently effective to prevent ignition of explosive atmospheres by static electricity, whether at high relative humidity earthing is no longer required and what are the limit values. In the present paper comprehensive measurements and results are presented, which clearly show that even an increase of the relative humidity of air above approximately 70% does not reduce the build-up of static electricity to such a degree that the well-known measures like earthing, use of conductive or dissipative materials, etc. are no longer required.

1. Introduction

In most Standards and Codes of Practice TRBS 2153 (2009), IEC/TS 60079-32-1 (2013) and NFPA 77 (2014) the increase of relative humidity to reduce the ignition hazards of explosive atmospheres due to static electricity is recommended. Limit values are however rarely available. It is not clear at all, which additional measures like earthing, abdication of insulating plastics, etc. can be omitted, if the relative humidity is increased above a certain limit. In particular the following questions should be answered:

- What is the influence of relative humidity on the charge build-up on equipment, materials, packages and personnel?
- How effective is this measure to avoid ignition hazards due to the build-up and accumulation of static electricity?
- What are the demands on relative humidity and what are the limit values?
- Is it possible to omit measures like earthing, exclusion of insulating plastics, etc.?

In view of all these uncertainties of the real effectiveness of this method applied in production areas the question arises, whether this method is reasonable to apply. All the more when the numerous disadvantages and problems associated with this method in practice are considered, like

- Uncomfortable working conditions for the operators leading to uneasiness and human errors
- Bacteria infestation of equipment, installations and buildings
- Significant increase of corrosion of equipment and installations
- Very high energy costs for the water evaporation, particularly during winter time

In order to get reliable answers to all these questions comprehensive experimental investigations have been performed. At relative humilities from 20% to 80% and temperatures from 15°C to 30°C the surface resistance, the charge relaxation as well as the charge transfer after corona and tribo-charging have been measured. Samples from different materials typically used in process industry like different types of glasses, insulating and dissipative plastics, wood used for wooden pallets, etc. have been included. In addition ignition experiments with a gas ignition probe and typical charging currents arising during the filling of drums or containers with liquids or powders have been performed.
In the following the measurements, the results as well as the conclusions are presented.

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2. Samples

Sample plates with a surface area of 300x300 mm^2 and a thickness of 10 mm in case of plastics and 15 mm in case of glass made from the substances listed in Table 1 have been tested

Table 1: Substances used in the measurements and abbreviations used in result records.

Substances and abbreviations	Substances and abbreviations
Polytetrafluoroethylene (PTFE)	Polyethylene (PE)
Polypropylene (PP)	Polyvinylidene fluoride (PVDF)
Borosilicate glass with insulating coating (BG&IC)	Borosilicate glass with dissipative coating (BG&DC)
Borosilicate glass without coating (BG)	Polyoxymethylene dissipative (POM-D)
Polyethylene dissipative (PE-D)	Wood (WOOD)

Wood was tested in form of a part of a wooden pallet with dimensions LxWxH 500 mm x 600 mm x 60 mm used at Merck Darmstadt and called Chemiepalette CP5.

3. Climates and Conditioning

The measurements of the surface resistance and the charge transfer have been performed at 15°C, 20°C, 25°C and 30°C and for each temperature at 20%rh, 40%rh, 60%rh and 80%rh.
The ignition tests have been performed at 23°C and at 40%rh, 60%rh and 80%rh
Prior to all measurements the samples have been conditioned during 24h in the corresponding climate.

4. Measurements and Results

4.1 Surface resistance

The surface resistance was measured according to the method described in TRBS 2153 (2009) with two parallel electrodes of 100 mm length and 10 mm distance positioned on the sample surface with a measuring voltage between 100 and 1000 V depending on the resistance range with the Megohmmeter Sefelec Type M 1501 P in the climate chamber. The reading was taken 60 s after application of the measuring voltage. For each climate and sample the surface resistance was measured at 5 different places. From these measurements an average value and a standard deviation was derived. Since from the point of view of safety a differentiation of values above 10^{15} Ω is no longer relevant but is associated with huge metrological effort, all readings above 10^{15} Ω have been set to 10^{15} Ω. Figure 1 shows the results of surface resistance measurements for different sample plates at different climates. The effect of temperature and relative humidity on the surface resistance shows the expected behaviour:

- The temperature has no significant influence on the surface resistance.
- The effect of relative humidity on the surface resistance depends on the type of substance: Whereas in case of the hydrophobic substances PTFE, PE, PP, PVDF, POM and BG&IC it remains still above the limit value of 10^{11} Ω for the exclusion of brush discharges up to and including 80%rh, it significantly drops with relative humidity in case of hydrophilic substances like BG, BG&DC, PE-D and WOOD.
- It is a comprehensible behaviour, that relative humidity has a minor effect on the surface resistance if the substance lies already in the dissipative or even conductive range like PE-D.

4.2 Charge Transfer - Tribo Charging

The charge transfer was measured according to the method described in the standard IEC 60079-32-2 (2015). The samples have been charged by friction (tribo charging). As friction partners rags made from cotton wool and leather as well as a cat fur were used. Since highest values for the charge transfer after friction with the cat fur have been obtained, results from these experiments are reported.
During the charging procedure and during the immediate subsequent charge transfer measurement the probes have been earthed by attachment of a small piece of aluminum foil folded over the rim of the sample plate (contact area about 400 mm^2) and connection of an earthing clip.
Immediately after the charging procedure the charge transfer was measured by approaching the electrode of a hand Coulomb Meter Type HMG of the company Firma Schnier towards the charged probe surface. The detection threshold of the Coulomb Meter was 6 nC. For each climate and sample the charge transfer was measured 5 times. From these measurements an average value and a standard deviation was derived.
Figure 2 shows the results of charge transfer measurements after tribo charging for different sample plates at different climates.

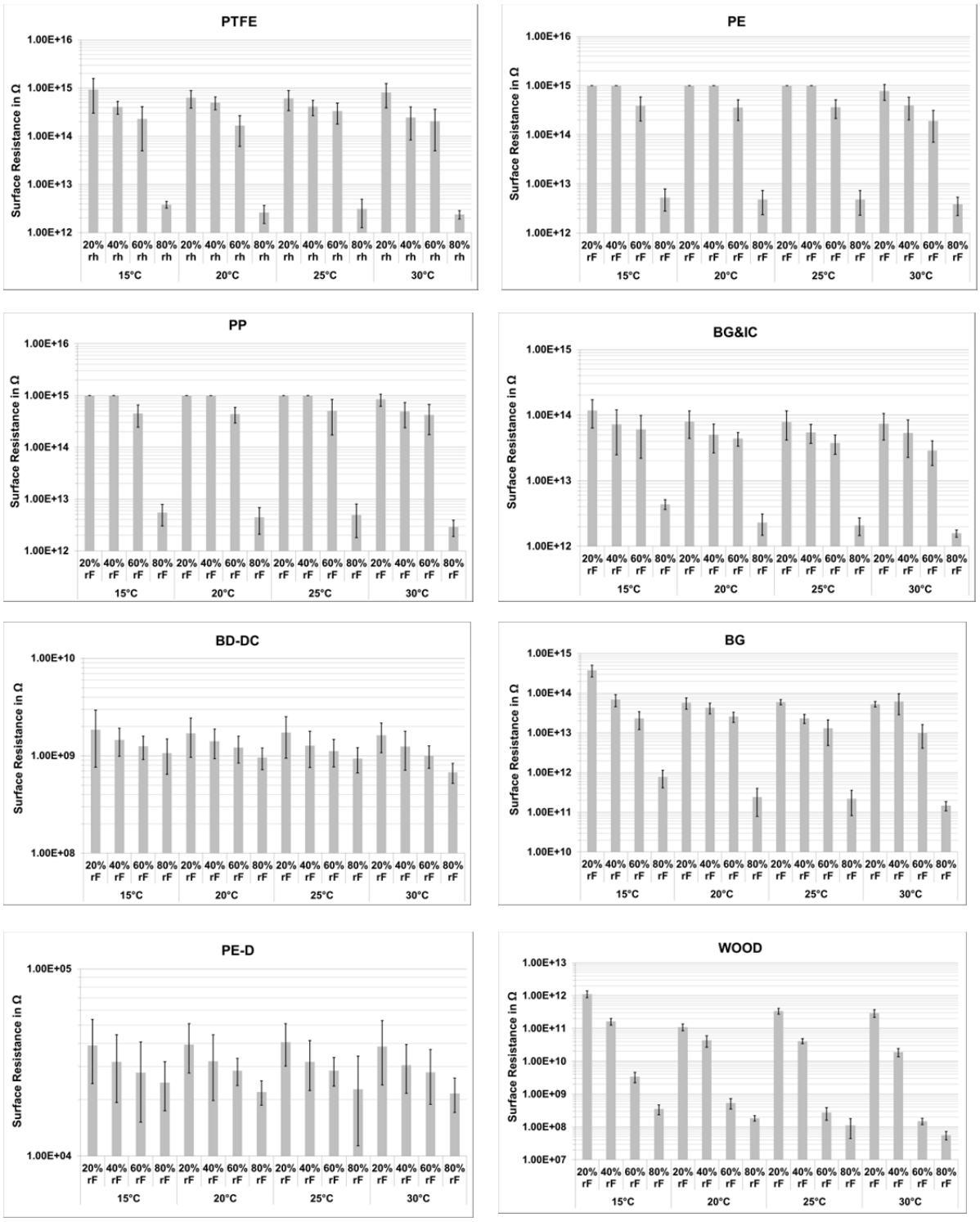

Figure 1: Surface resistance of different sample plates at different climates

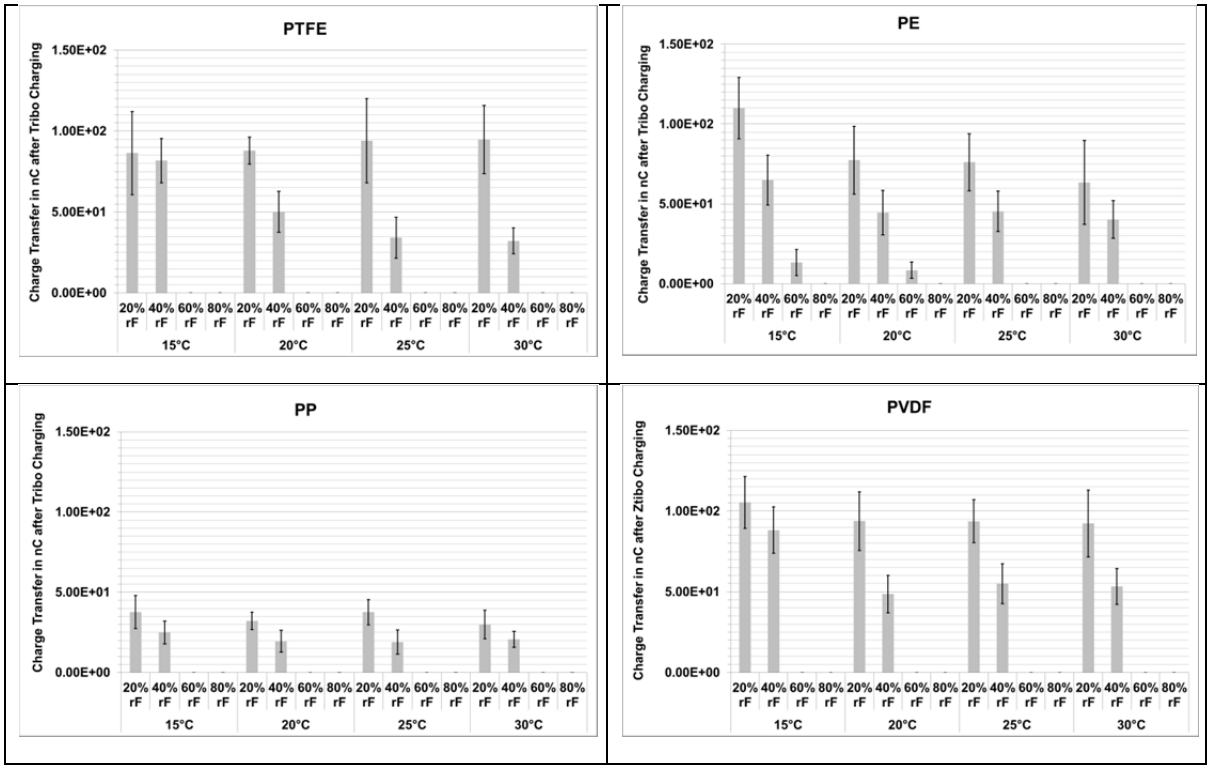

Figure 2: Charge transfer from different sample plates after tribo charging at different climates. The sample plates from the substances BG-DC, BG, POM-D, PE-D and WOOD did not show any charge transfer after tribo charging in all climates.

The discussion of the results of charge transfer measurements after tribo charging will be combined with the discussion of the results obtained after corona charging at the end of section 4.3.

4.3 Charge Transfer – Corona Charging

In addition to the charge transfer measurements after charging the samples by friction as described in section 4.2 the charge transfer was also measured after corona charging the samples as described in the standard IEC 60079-32-2 (2015).

For corona charging of the sample plates a hand-held spraying equipment of Maag Flockmaschinen GmbH with variable negative high tension between -30 kV and -70 kV was used. The spray gun was moved across the surface of the earthed (see section 4.2) sample plate for about 10 s. Immediately afterwards the charge transfer was measured as described in section 4.2.

Figure 3 shows the results of charge transfer measurements after corona charging for different sample plates at different climates.

The charge transferred in a discharge is a much more direct measure to assess the ignition probability by electrostatic discharges compared to the surface resistance. According to the relevant standards IEC/TS 60079-32-1 (2013) and TRBS 2153 (2009) the following amounts of charge transferred is required for ignition of gases and vapors of the different explosion groups:

- 60 nC for explosion group IIA
- 25 nC for explosion group IIB
- 10 nC for explosion group IIC

The effect of temperature and relative humidity on the charge transfer after tribo and corona charging shows the following characteristics:

- The temperature has only a minor influence on the charge transferred for both tribo and corona charging as in case of the surface resistance.
- The amount of charge transferred does not for all samples correlate with the height of the surface resistance.

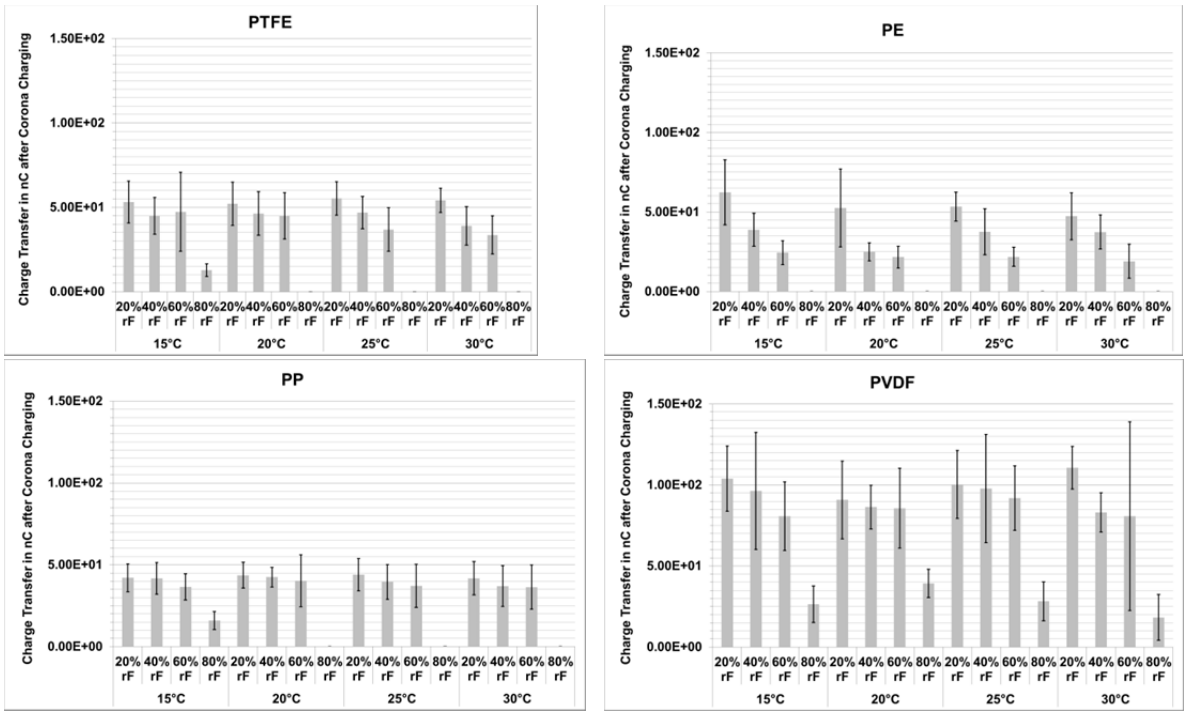

Figure 3: Charge transfer from different sample plates after corona charging at different climates. The sample plates from the substances BG-DC and PE-D did not show any charge transfer after corona charging in all climates

- In case of low relative humidity the charge transfer is for most samples higher with tribo charging, whereas at high relative humidity where no charge transfer can be measured after tribo charging, a substantial charge transfer can still be measured after corona charging. This is most probably based on the fact that the friction partners are hydrophilic and become rather conductive at high relative humidity.
- It must be pointed out that regarding the threshold values for the charge transfer mentioned above ignition of substances of the explosion group IIB and IIC may even occur at 60%rh by brush discharges from all substances except BG-DC, POM-D, PE-D and WOOD.

4.4 Ignition Tests

With ignition tests it should be checked whether an electrically insulated conductive object like a metal drum may become charged in a given climate to such an extent that an explosive gas or vapor atmosphere can be ignited. For this purpose a 20 liter metal drum was put on top of the sample plates or the wooden pallet, which were in contact with earth on the other side. In order to simulate a 200 liter drum standing on an approximately 100 mm thick wooden pallet on a conductive or dissipative floor additional capacitances were added in order to reach a total of about 200 pF to 300 pF.

The charging mechanism of the drum, which typically occurs in practice by filling the drum with a liquid of low conductivity or a powder of high resistivity, was achieved in the experiments by corona spraying with a constant well defined current. The corona current was varied by adjusting the spray voltage and the geometrical set-up and measured with a Keithly 2700 Multimeter / Data Aquisition System. From TRBS (2009) a charging current of approximately 1 µA to 3 µA can be derived when filling a drum with a liquid of low conductivity through an earthed metallic pipe. In case of filling the drum with a highly insulating powder charging currents up to 10 µA have to be anticipated, see Fath et al. 2013, Glor (2013a) and Glor et al. (2013b).

The actual ignition trials have been performed according to the standard IEC 61340-4-4 (2012) using a standardized gas ignition probe with a mixture of 5.4 vol.% Ethylene in air resulting in an ignition energy of 0.14 mJ, corresponding to the lower region of minimum ignition energy of explosion group IIB substances.

In Table 2 the results from the ignition tests are listed. These results show the following characteristics:

- There is only a small difference between the ignition probability at 40%rh and 60%rh.
- At 40%rh as well as at 60%rh ignitions occurred with all sample substances except BC-DC and PE-D.

Table 2: Results from ignition tests.

Climate	40 % rh				60 % rh				80 % rh			
Charging current	1 µA		10 µA		1 µA		10 µA		1 µA		10 µA	
No Ignition NI, Ignition I	NI	I	NI	I	NI	I	NI	I	NI	I	NZ	I
PTFE	0	2			0	5			3	2	0	5
PE	0	2			1	2			5	0	2	3
PP	0	2			1	3			4	1	0	5
PVDF	0	2			0	3			3	2	0	5
BC-IC	0	2			1	3			3	2	0	5
BC-DC	3	0	3	0	3	0	3	0	5	0	5	0
BC	0	3			1	3			4	1	0	5
POM-D	1	3			4	1	0	3	5	0	3	2
PE-D	3	0	3	0	3	0	3	0	5	0	5	0
WOOD	0	2			4	0	0	3	5	0	2	4

- With the exception of WOOD these ignitions occurred with a charging current of only 1 µA. Only in case of WOOD a charging current of 10 µA was required for ignition
- Even at 80%rh ignitions occurred with all sample substances except BC-DC and PE-D. These ignitions occurred already at a charging current of 1 µA except for PE, POM-D and WOOD, where a charging current of 10 µA was required.
- For 70% of the tested sample substances ignition occurred already with a charging current of 1 µA at 60%rh. At 80%rh this was the case for 50% of all tested samples.

5. Conclusions

The results clearly show that increasing relative humidity is of limited effect to reduce the ignition probability of explosive atmospheres in process industry. Of course the effectiveness depends a lot on the material of the equipment. But for instance even at 80% relative humidity a drum without direct earth connection on a wooden pallet on concrete floor being filled with an insulating organic powder accumulates sufficient charge to ignite a flammable vapour. This example shows definitely that even if earthing is omitted accidentally, increasing relative humidity does not significantly decrease the ignition hazard.

Acknowledgments

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