Experimental investigations of the influence of charging on droplet dynamics in high-speed rotary atomization

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Abstract

In this contribution, the results of experimental investigations of direct-charging high-speed rotary bell atomizers used in high-quality painting are presented. On the one hand, detailed PDA measurements have been performed to investigate the local properties of the spray as a function of the applied voltage, on the other hand, an electrical setup was realized allowing the time dependent detection of all relevant currents during spray operation. In the future, the combination of these results should allow the development of an improved droplet charging model, that accounts for both, the application parameters of the atomizer and the relevant material properties of the sprayed fluid.

Keywords

Spray coating, Rotary atomization, Droplet charging

Introduction

High-speed rotary atomizers are widely used in high-quality organic coating applications. Based on several independent operational parameters such as bell speed, bell diameter, shaping air etc., the spray quality and, hence, the coated surface quality can be easily adapted to specific requirements. Furthermore, a high paint transfer efficiency is achieved by installing a high voltage (HV) supply system to obtain both, a strong electrical field between atomizer and grounded target and a charging of the formed paint droplets.

In recent years, several scientific investigations considered high-speed rotary atomizers, many of them intending to model and simulate the complete spray coating process, see e.g. [1], [2]. A common disadvantage of these simulations is the requirement to have either experimental or empirical inlet and starting conditions for the droplet phase, such as local velocities, mean diameters and droplet number fluxes, but also the initial droplet charge distribution which heavily influences the droplet dynamics and, thereby, the film thickness distribution on the target and the transfer efficiency. To improve this situation detailed efforts with respect to modelling and simulation of the film disintegration process at the bell edge and the further droplet formation have been performed already in detail [3], [4], however there is only little work on the initial charging and the resulting charging distribution on the droplets.

In case of direct charging atomizers high voltage is applied directly to the bell. Hence, it follows that most charges should be directly transferred from the bell surface to the attached thin liquid film. It may also be assumed that the effect of ionization at the bell is only of minor influence and can therefore be neglected. From the latter assumption it can be deduced that the total current between atomizer and target is completely produced by the transporting total number flux of the charged droplets. Therefore, it should be possible to derive an overall mean droplet charge or even a size dependent mean droplet charge from detailed measurements of the droplet size distributions and the overall current as a function of the application parameters and the electrical properties of the sprayed fluids.

Material and Methods

The direct charging high-speed rotary bell atomizer ECOBELL 2 (Dürr Systems) with unserrated bell edge has been used for the measurements. Various fluids have been applied, delivering a certain range of relevant fluid properties such as viscosity, surface tension, conductivity, and permittivity. The parameters of the fluids together with the application parameters are listed in **Table 1**.

Table 1 – Investigated experimental conditions

Fluids							
		Butyl acetate	Butyl acetate with 2 % additive	Butyl glycol/ Water (20/80 %)			
Viscosity	*mPas*	1,1	1,2	2,1			
Surface tension	mN/m^2	24,5	25,1	27,2			
Conductivity	*µS/cm*	< 0,1	1,9	331			
Rel. permittivity	-	1,7	1,7	60,4			
Application parameters							
Liquid flow rate	*ml/min*	100	200	300	400	500	600
Shaping air flow rate	*Nl/min*	50					
Bell speed	*1/min*	20 000	30 000	40 000	50 000	60 000	
Voltage	*kV*	0	30	60	80		
Painting distance	*mm*	150	200	250	300	350	

For detailed investigations of the spray properties (local droplet size, velocity and flux) a DANTEC phase-Doppler system has been used, consisting of a 2-component fiber probe and a 112 mm fiber-based receiver, both equipped with 500 mm lenses (**Figure 1**). At a scattering angle of 72°, which was appropriate for all fluids to obtain 1^{st} order refracted scattered light, the size range was around 130 µm. This setup was chosen as a compromise between a maximum spatial resolution and the need to perform measurements at voltages up to 60 kV. Measurements were performed at 50 and 100 mm axial distances from the bell edge plane.

In **Figure 2**, the experimental setup for the global earth current measurements is shown. It consists basically of a mesh-type arrangement around the spray cone attached to a metallic substrate isolated from ground, equipped with an appropriate termination and a digital oscilloscope to store the time dependent current with high accuracy. The porosity of the mesh was chosen as a compromise between minimum impact on the air flow, and, hence, on the overall spray propagation, and maximum transfer efficiency. The transfer efficiency was assumed to be higher than 98 % with mostly very small droplets missing the wire mesh.

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i \cdot \dot{n}_i \cdot A_i}{\sum_{i=1}^{n} \dot{n}_i \cdot A_{tot}} \qquad (1)$$

To achieve global results from local PDA measurements, e. g. global droplet mean diameters, an integration procedure was performed according to Eq. 1. Here, d_i stand for any local mean diameter, e.g., the volume weighted mean diameter d_{30} that has been measured at the location i which is representative for a whole doughnut with a mean radius r_i.

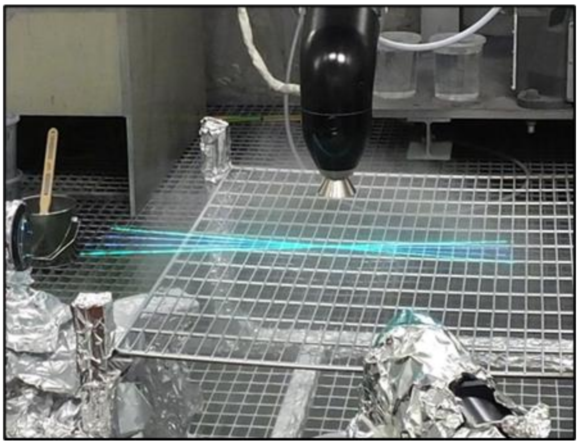

Figure 1: Optical setup of PDA system

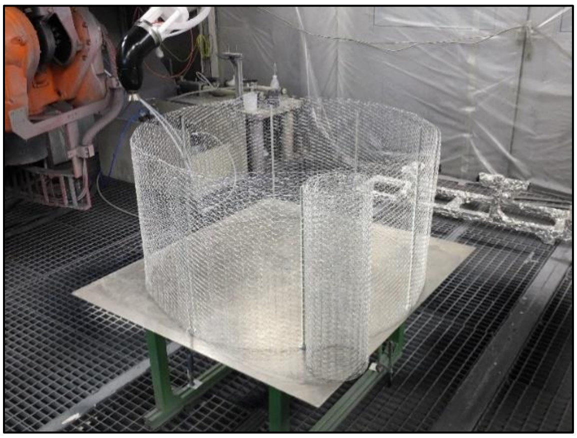

Figure 2: Experimental arrangement for current measurements

Results and Discussion

Out of the huge amount of data from the PDA measurements useful information must be condensed. Below, typical results are shown for butyl glycol/water mixture at a bell speed of 40 000 1/min, a fluid flow rate of 200 ml/min and a distance of 50 mm from the plane of the bell edge. The size distributions shown in **Figure 3** were obtained at 0 kV voltage and a radial distance of 210 mm (peak position of the local droplet number flux). The corresponding number mean diameter was 16.0 µm, the Sauter mean diameter 24.4 µm.

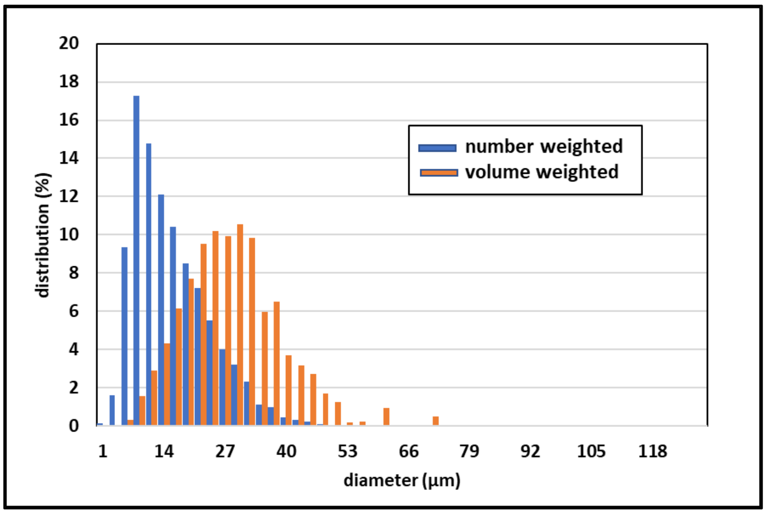

Figure 3: Measured local droplet size distribution at r = 210 mm and z = 50 mm

For the same fluid and application conditions, **Figure 4** shows the corresponding radial profiles of the local volume flow rates as a function of the applied voltage, which can also be derived from the PDA measurements. The volume flow rate integration values, which should be consistent with the overall flow rate, vary between 194 and 212 ml/min, which indicates a certain consistency of the measurements. However, due to optical limitations of the PDA technique, there might be still some probability of having missed a certain number of very small droplets, which do not contribute to the volume flow. In contrast to initial expectations, the spray cone extension reduces with increasing applied voltage. Obviously, the effect of the electrical force directing charged droplets towards the target in axial direction exceeds the repulsive effect of the Coulomb forces between the charged droplets.

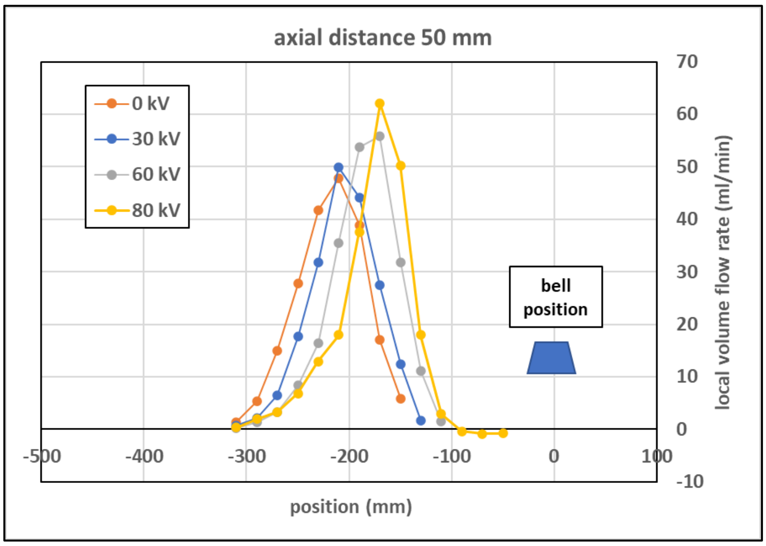

Figure 4: Radial profiles of the local volume flow rates at z = 50 mm

A typical result of the time dependent charging process at a voltage of 80 kV and a liquid flow rate (butyl acetate) of 200 g/min is shown in **Figure 5**. Liquid flow starts at t = 8.7 s and stops at t = 18.7 s. Within this operational period the mean current from target to earth is around 40 µA. Obviously, the current without liquid flow immediately before and after liquid flow trigger is much higher (around 160 µA), confirming the assumption of a corona discharge effect at the edge of the bell. This corona is extinguished by the liquid film formed on the bell surface.

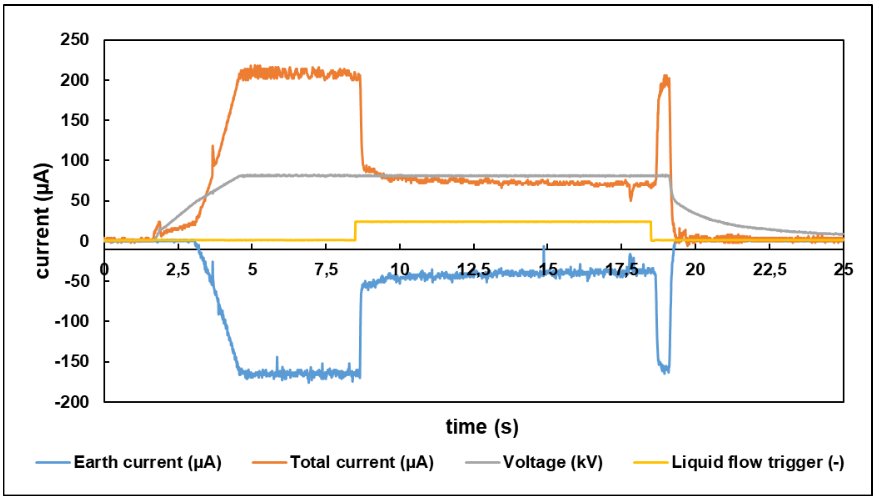

Figure 5: Time dependent charging process during on/off operation

Through an area and number flux weighting of local results (see Eq. 1), cross sectional values of the spray characteristics can be derived. **Figure 6** indicates the influence of the applied voltage on the volume weighted mean diameter in case of butyl glycol/water mixture. Consistently, D_{30} decreases with increasing voltage. Interestingly, the strongest effect occurs in case of minimum bell speed (20 000 1/min), producing the largest mean diameters. This might be due to the disrupting forces of the droplet charges mainly acting on the initial stability of the large droplet fraction.

Finally, **Figure 7** shows the dependencies of the obtained current from substrate to earth on the applications conditions. The current from the isolated target to ground is mainly influenced by the applied high voltage divided by the application distance, which is roughly the electric field strength in the vicinity of the bell. The application parameters like fluid flow rate or rotation speed (and with that the paint thickness on the bell surface) are of minor importance. A similar effect was found for all the other fluids varying in conductivity and permittivity. As the next step, these dependencies and effects will be further evaluated by introducing more detailed characteristics such as droplet mean diameters and droplet fluxes.

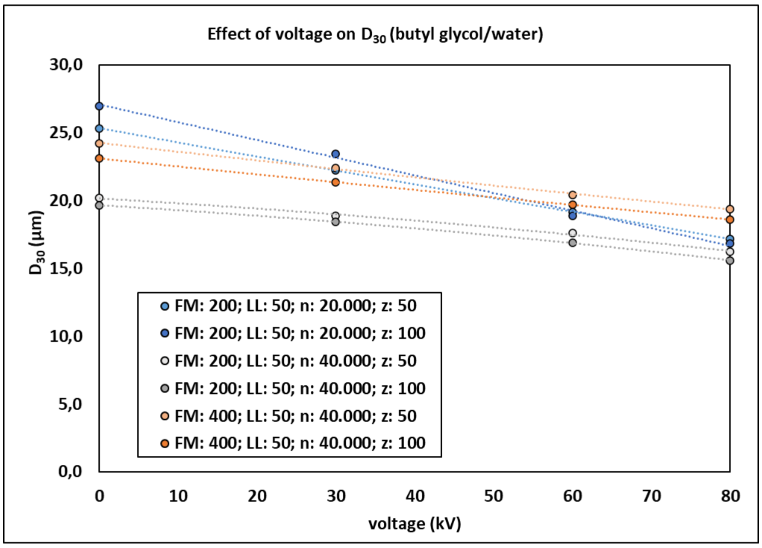

Figure 6: Integral volume mean diameter as a function of applied voltage

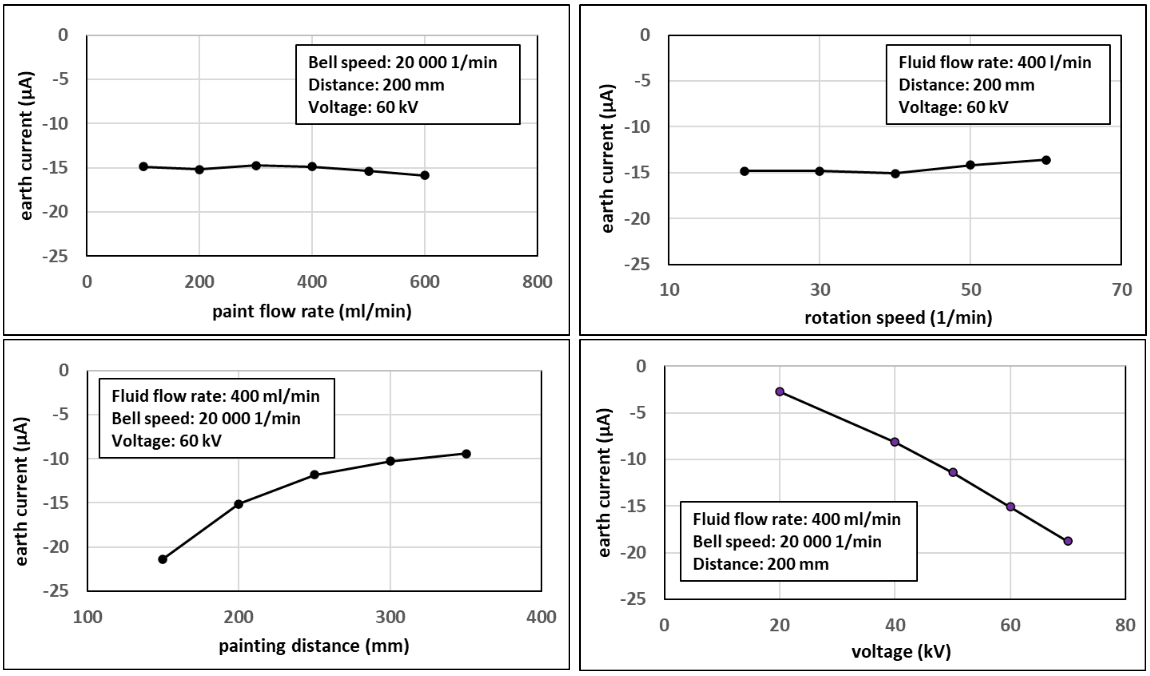

Figure 7*:* Dependency of earth current on painting parameters (Butyl acetate with additive)

Conclusions

The aim of the presented investigations is to develop a model for the droplet charging process of direct charging rotary bells, improving an already existing CFD program that allows to calculate the whole coating process as a function of existing and known application parameters, including the resulting film thickness distribution on the target and the transfer efficiency. Such a program represents the core component for the implementation of a ‘digital painting process tool’ that can be used for planning and improvement of automated painting processes.

As a first step comprehensive measurements of the spray characteristics and the electrical process dynamics have been performed, already indicating some very interesting results, e.g. a reduction of the global droplet mean diameters with increasing voltage. Also, the obtained earth currents are mainly affected by the applied voltage and the distance between atomizer and target. Next, the existing results will be processed using a DoE scheme to allow a further evaluation of main effects and interdependencies, also considering the different conductivities and permittivities of the investigated fluids.

Acknowledgments

The financial support of the German Federal Ministry for Economic Affairs and Climate Action through the AIF-IGF project 21873/N is gratefully acknowledge.

Nomenclature

A	area of doughnut [m²]
A_{tot}	total measurement cross section [m²]
d_i	characteristic mean diameter [µm]
FM	fluid flow rate [ml/min]
n	bell speed [1/min]
$\dot{n}$	droplet number flux [1/(m². s]
r	radial distance from centre [mm]
z	axial distance [mm]

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