Feasibility study on the in-line measurement of pharmaceutical powder mass flow rate and charging characteristics using an electrostatic powder flow sensor (EPFS).

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Introduction

- Electrostatic induction sensors are widely used to measure in-line particle flow parameters in pneumatic conveying processes [1], but are rarely utilised in pharmaceutical flow regimes.
- Triboelectrification may result in powder adhesion to processing equipment [2]. Material charging differences are typically measured using tribo-series and Faraday Cup [3]. However, tribo-series only qualitatively ranks charging behaviour specific to the conditions at which the measurements were performed, whereas the Faraday Cup cannot be integrated into processes.
- In this study, an electrostatic powder flow sensor (EPFS) was developed to directly measure in-line flow parameters and charging behaviour of powders conveyed in a pharmaceutical process.

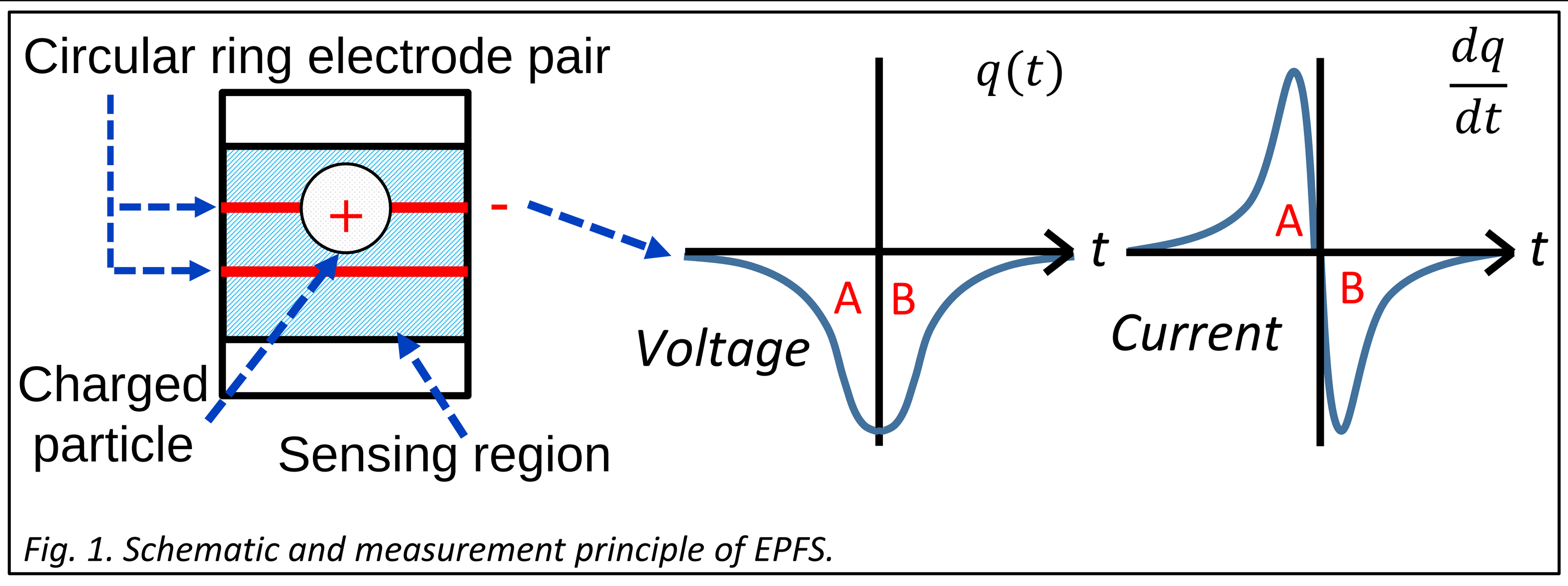

Fig. 1. Schematic and measurement principle of EPFS.

Materials & Methods

- Electrostatic and gravimetric measurements were recorded for five "as received" powders and one oven-dried powder, which were conveyed using a twin screw feeder.
- Particle velocity was obtained via cross-correlation algorithm (1), using the upstream and downstream electrostatic signals.

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (1)$$

- RMS signal was calculated by averaging values across consecutive 0.05s (20Hz) intervals over the entire electrostatic dataset.
- Charging behaviour was analysed by normalising the RMS of the electrostatic signal against the mass flow rate.

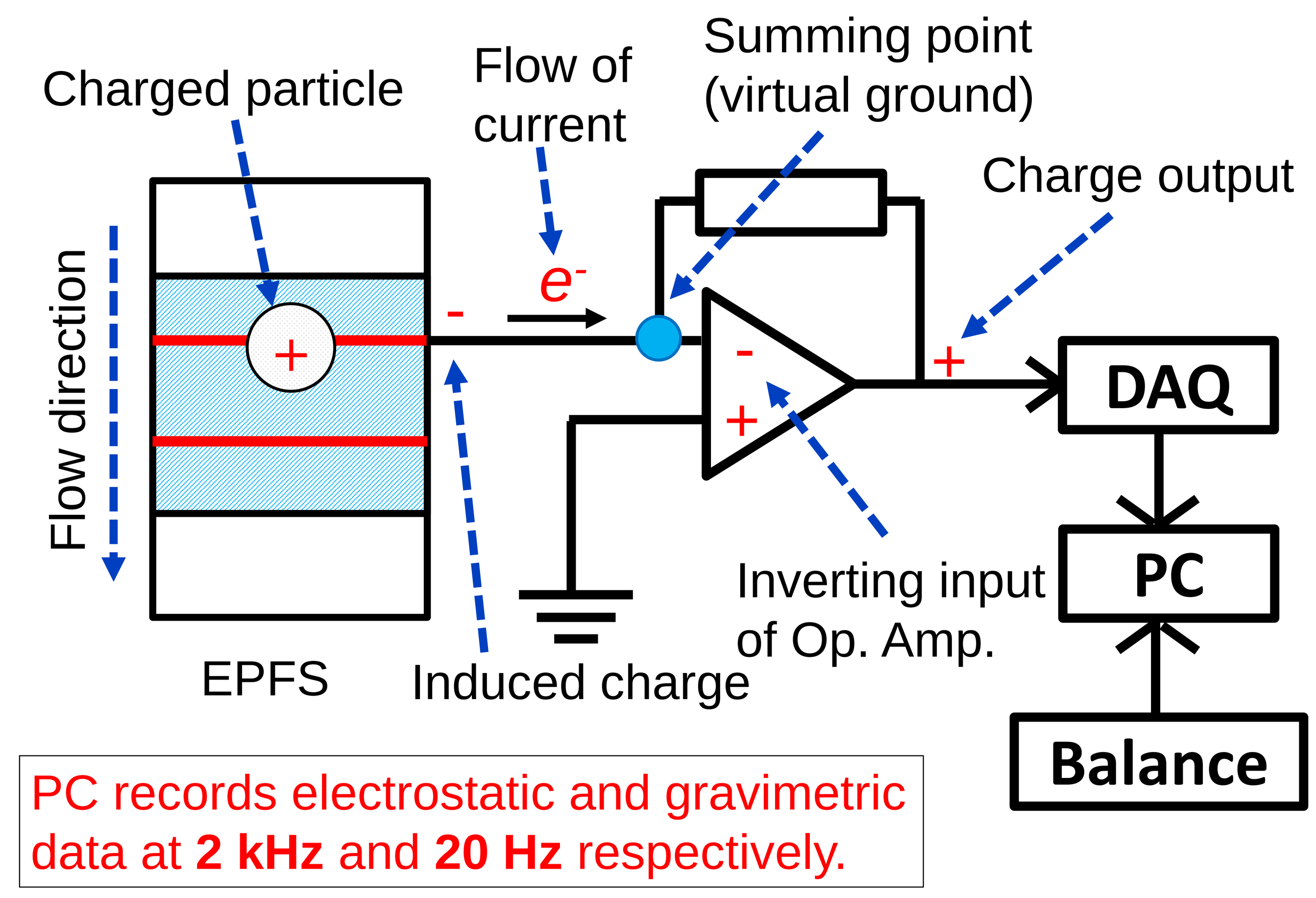

Fig. 2. EPFS and measurement electronics principle of operation.

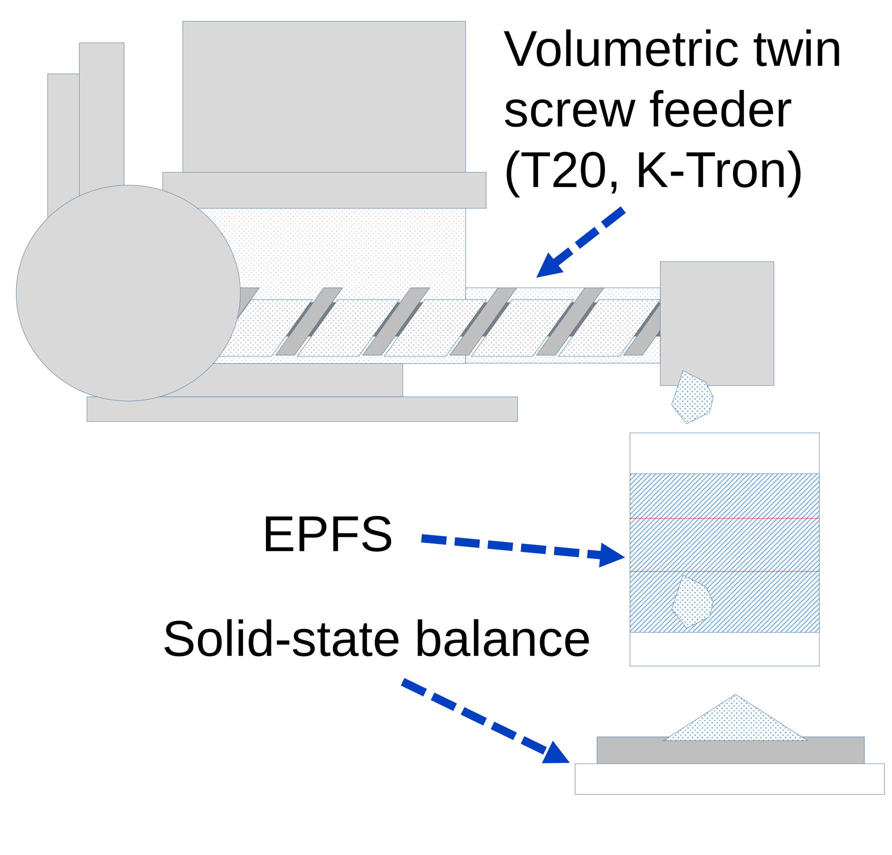

Fig. 3. Lean phase conveying system, (measurement electronics not shown).

Results

Powder mass flow rate vs powder velocity

Table 1. Mean particle velocities recorded for each screw conveyed powder.

Material	Mean powder velocity (m/s)				
	100 rpm	120 rpm	140 rpm	160 rpm	All screw speeds
Avicel PH102	1.68 ± 0.02	1.69 ± 0.02	1.7 ± 0	1.69 ± 0	**1.69 ± 0.01**
Lactose #316 Fast Flo	1.76 ± 0.22	1.71 ± 0.17	1.69 ± 0.02	1.68 ± 0.01	**1.71 ± 0.04**
Avicel PH101	1.73 ± 0	1.73 ± 0.02	1.74 ± 0.01	1.74 ± 0.01	**1.74 ± 0.01**
Lactose 200M	1.78 ± 0.01	1.77 ± 0.01	1.77 ± 0.01	1.77 ± 0.01	**1.77 ± 0**
Maize Starch	1.77 ± 0	1.75 ± 0.02	1.78 ± 0.02	1.80 ± 0.01	**1.77 ± 0.02**

Free-flowing powders ↕ Cohesive powders

Table 2. Powder specific energy (SE), compressibility and permeability characterisation using an FT4 Powder Rheometer.

Material	Mean SE (mJ/g)	% Compressibility @ 15 kPa	Pressure drop (mBar) @ 15 kpA
Lactose #316 Fast Flo	4.5 ± 0.2	5.3 ± 0.2	0.6 ± 0
Avicel PH102	5.2 ± 0.5	11.3 ± 0.2	0.4 ± 0
Avicel PH101	7.2 ± 0.2	15.7 ± 0.2	1 ± 0
Maize Starch	7.8 ± 0.7	18.2 ± 0.7	8.8 ± 0.07
Lactose 200M	6.2 ± 0.3	34.4 ± 0.3	9.3 ± 0.3

Free-flowing powders ↕ Cohesive powders

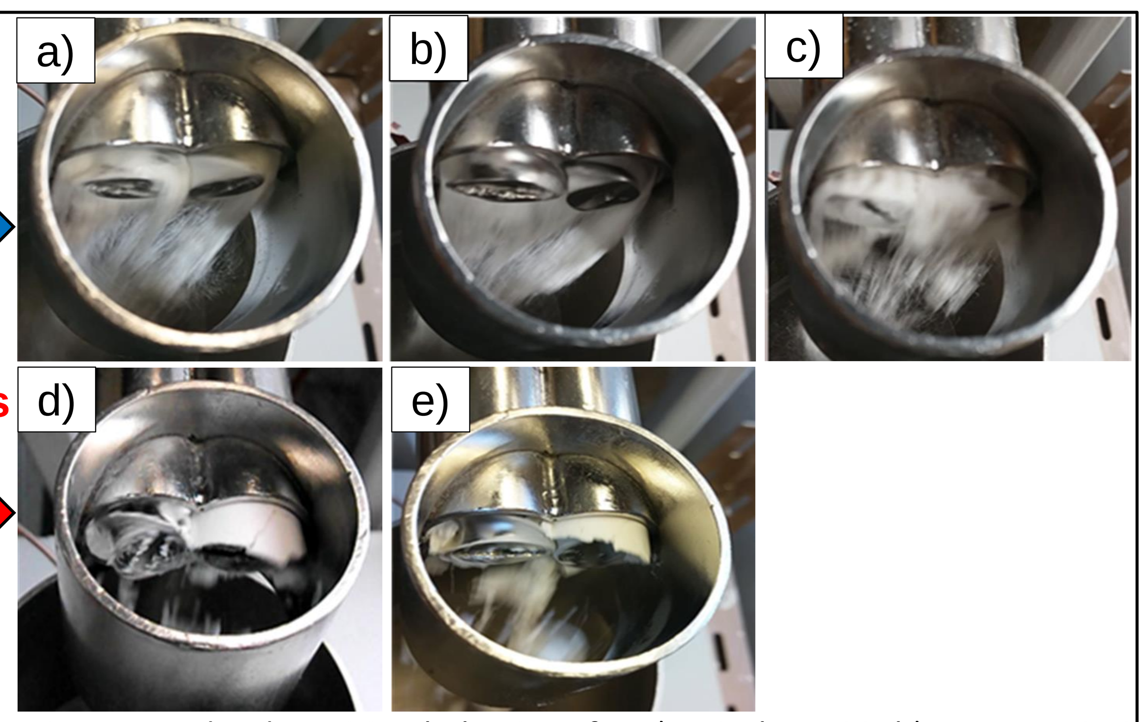

Fig. 4. Powder deposition behaviour for a) Avicel PH102; b) Lactose #316 Fast Flo; c) Avicel PH101; d) Lactose 200M and e) maize starch.

Powder mass flow rate vs RMS signal

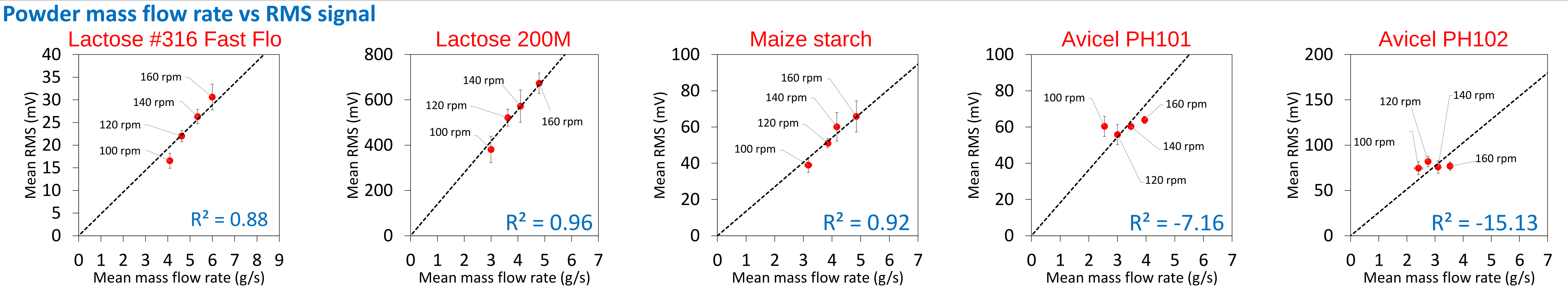

Fig. 5. Mean powder mass flow rate and mean RMS signal correlation, recorded for five pharmaceutical powders conveyed using the twin screw feeder across a range of screw speeds.

Electrostatic charging characteristics

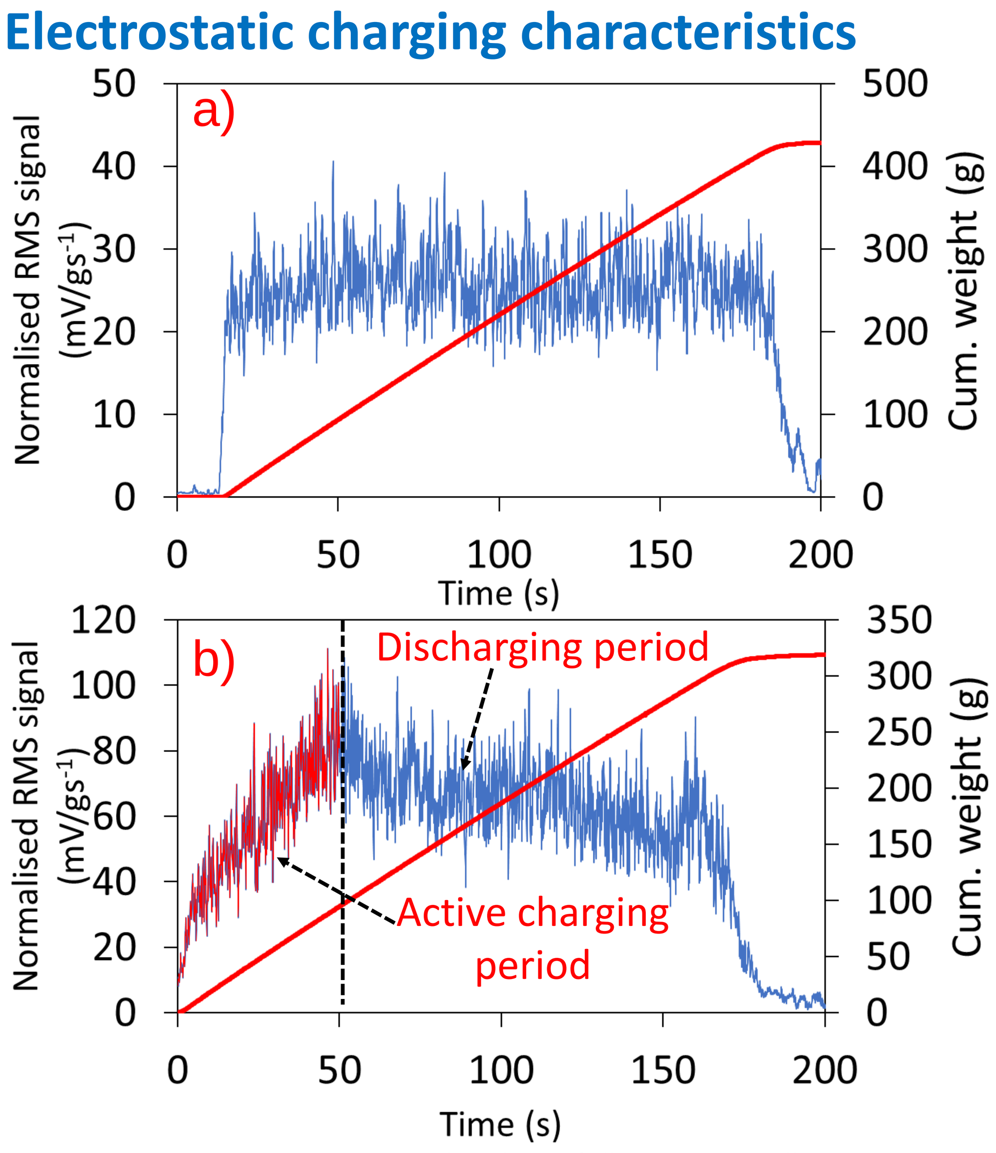

Fig. 6. Normalised RMS profile for: a) "as received" Avicel PH101 and b) "oven-dried" Avicel PH101, conveyed using the twin screw feeder at 100rpm.

Table 3. Ranking in the normalised charges recorded for five pharmaceutical powders conveyed at 100rpm.

Material	Normalised RMS ($mV/g^{-1}s$)
Lactose 200M	121 ± 15%
Avicel PH102	30 ± 3%
Avicel PH101	23 ± 8%
Maize Starch	12 ± 7%
Lactose #316 Fast Flo	4 ± 7%

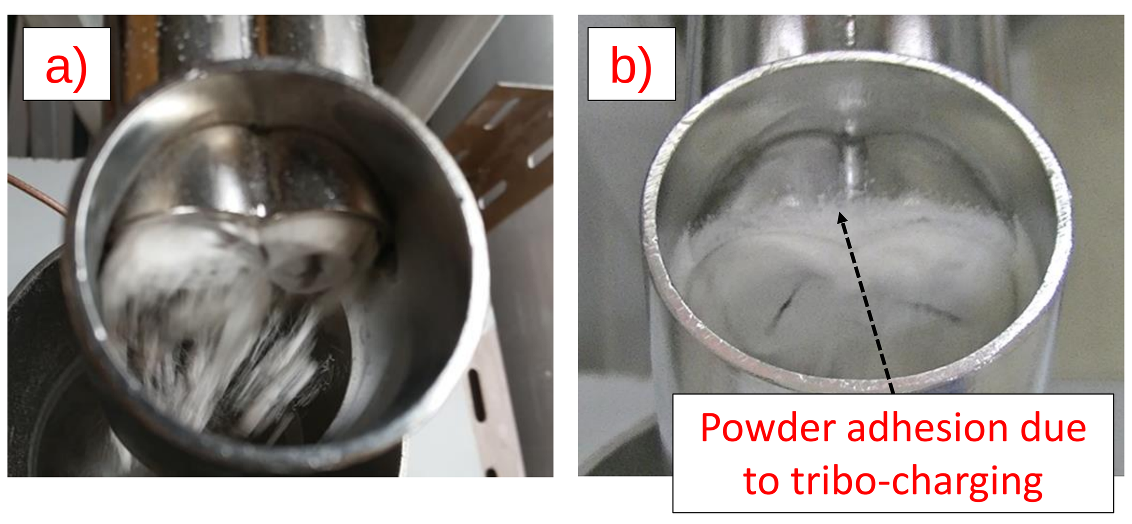

Fig. 7. Images of the feeder outlet during the conveying of: a) "as received" Avicel PH101 and b) "oven-dried" Avicel PH101.

Conclusions

- Particle velocity was independent of the screw speed (Table 1).
- Differences in the particle velocities were thought to be influenced by powder deposition sizes (Fig. 4), which resulted from differences in the cohesivity of the entrained powder.
- Similar rankings were shown between particle velocity and the cohesivity dependant FT4 parameters (Table 2).
- Reasonable correlation was shown ($R^2 > 0.88$) between the mass flow rate and RMS obtained for Lactose #316 Fast-Flo, Lactose 200M and maize starch, but not for other powders (Fig. 5).
- RMS standard deviation was as high as 15%, which rendered the EPFS unsuitable for direct measurement of mass flow rate.
- The powder charge carrying capacity could be indicated by normalising the RMS values against the mass flow rate (Table 3).
- The EPFS could measure the time dependent tribo-charging behaviour of a conditioned powder (Fig. 6).

References

[1] Qian, et al., 2014. Pulverized coal flow metering on a full-scale power plant using electrostatic sensor arrays, Flow Meas Instrum, 40, 185-191.
[2] Samiei, et al., 2017. The influence of electrostatic properties on the punch sticking propensity of pharmaceutical blends. PowderTech, 305, 509-517.
[3] Šupuk, et al., 2012. Tribo-electrification of active pharmaceutical ingredients and excipients. PowderTech. 217, 427-434