STEP-1
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Soka University, Hachioji, Tokyo JAPAN

Charge Transfer Limited by Gas Breakdown of Air

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Question to be answered:
Which process dominates the amount of charge generation?

(a) before contact

(b) contact
and charge transfer

(c) separation
and charge fixation

(d) charge relaxation
due to gas discharge

(e) charge observation

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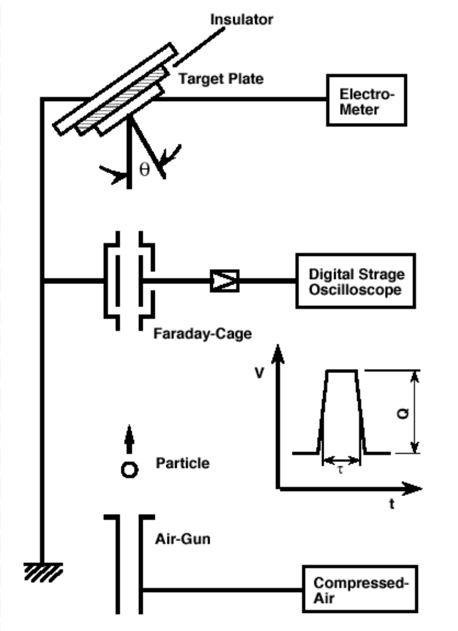
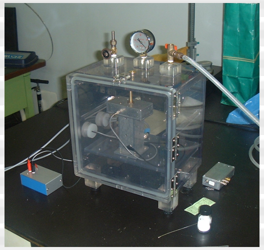
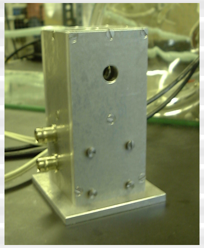
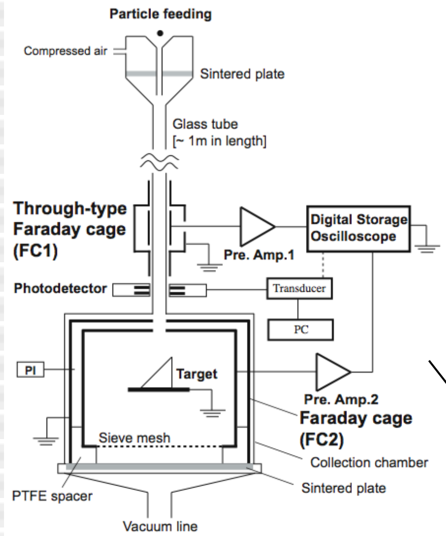
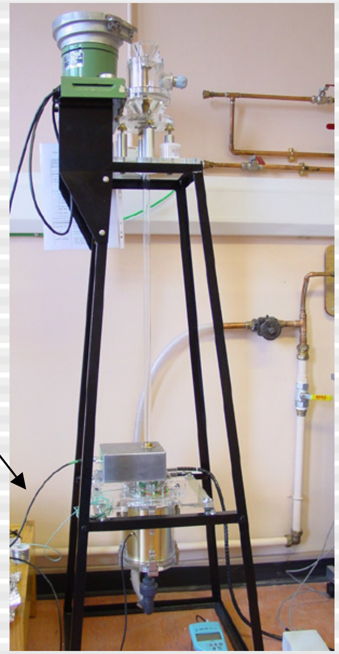
Impact Charging Experiments with single particles

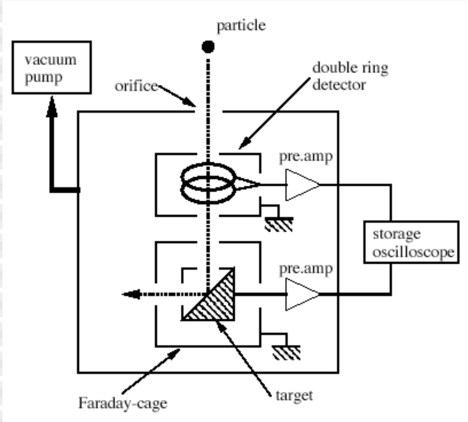


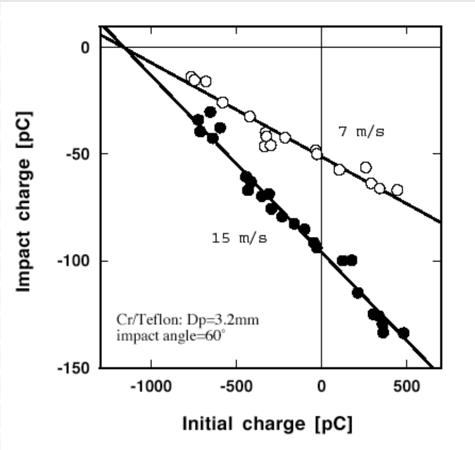


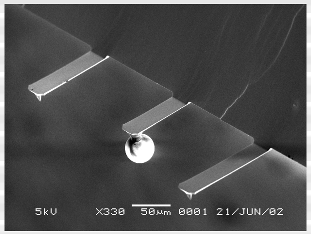


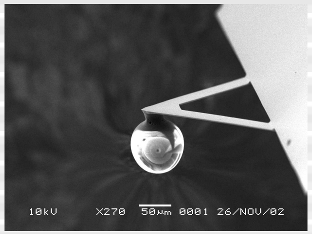


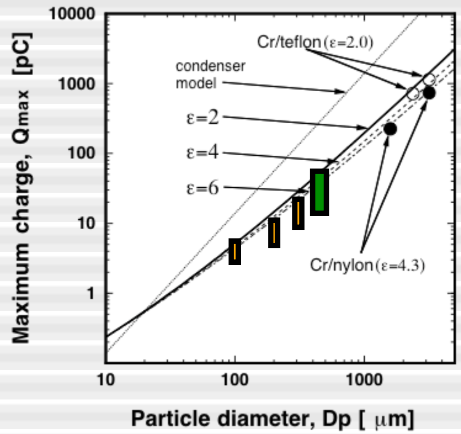












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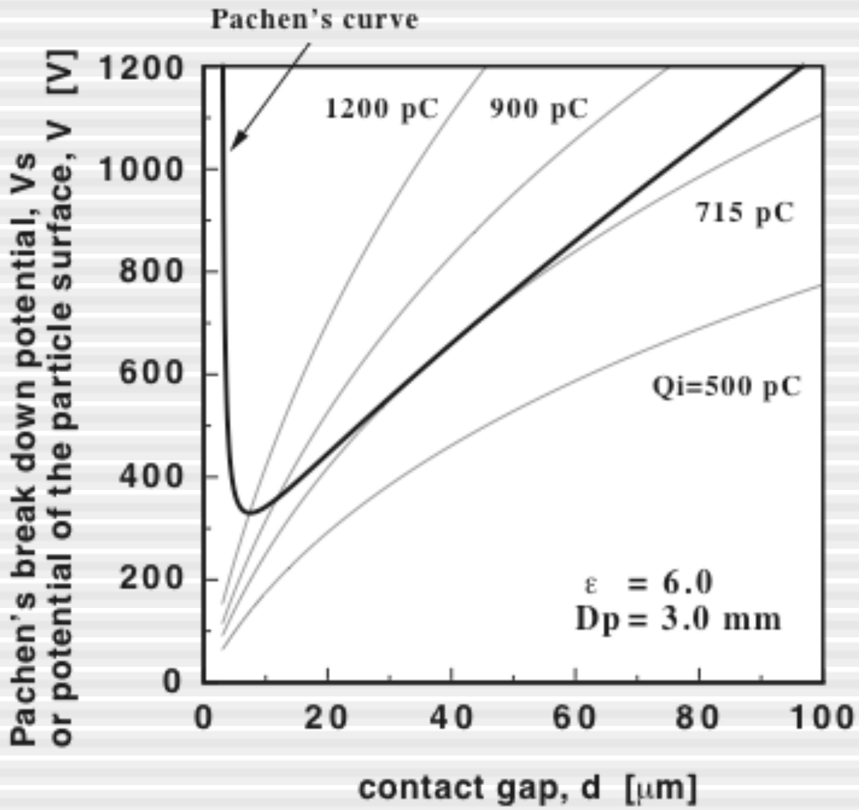
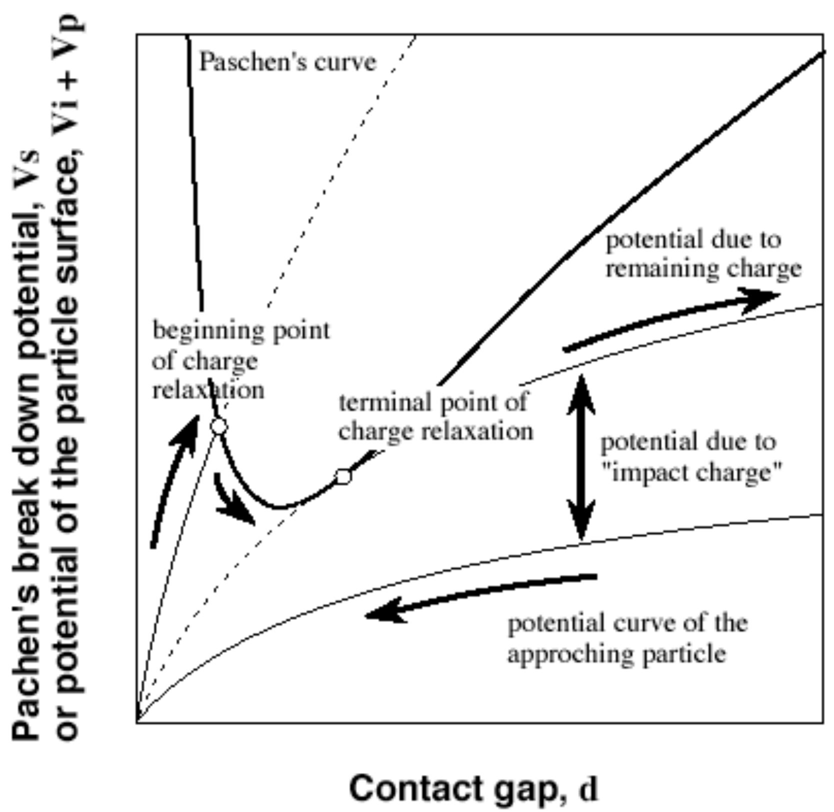
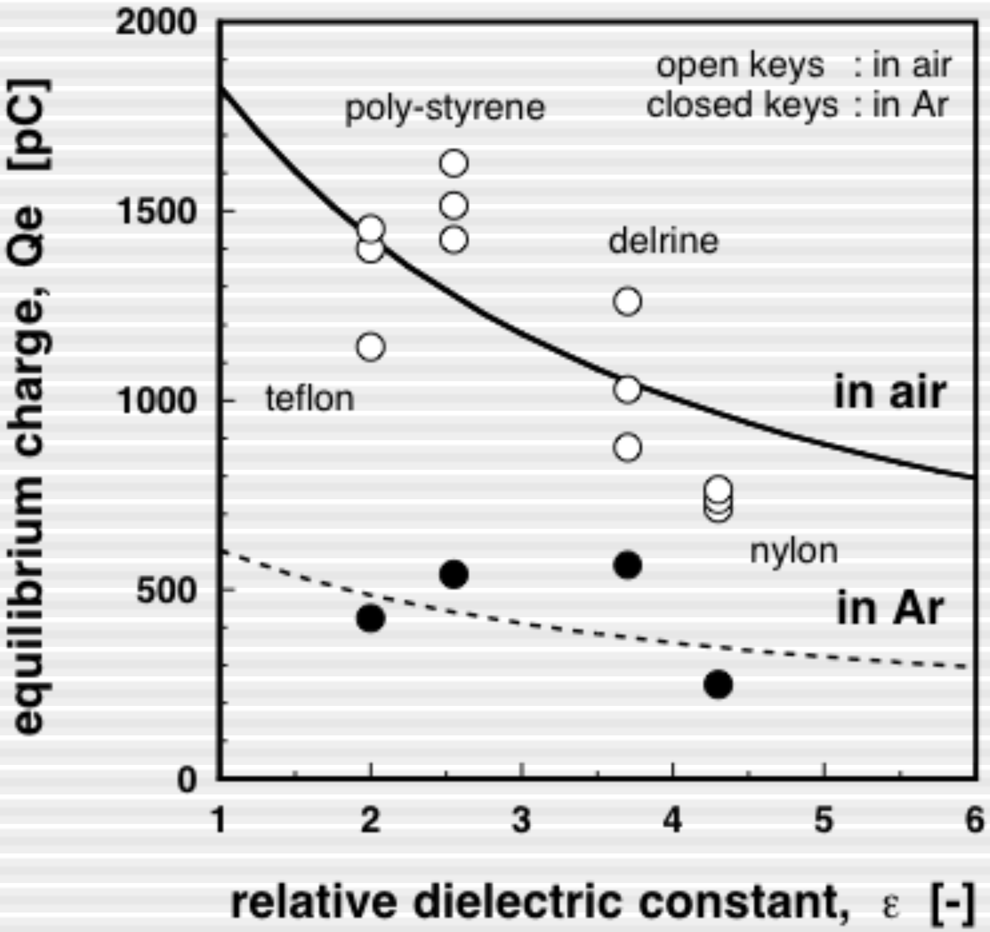
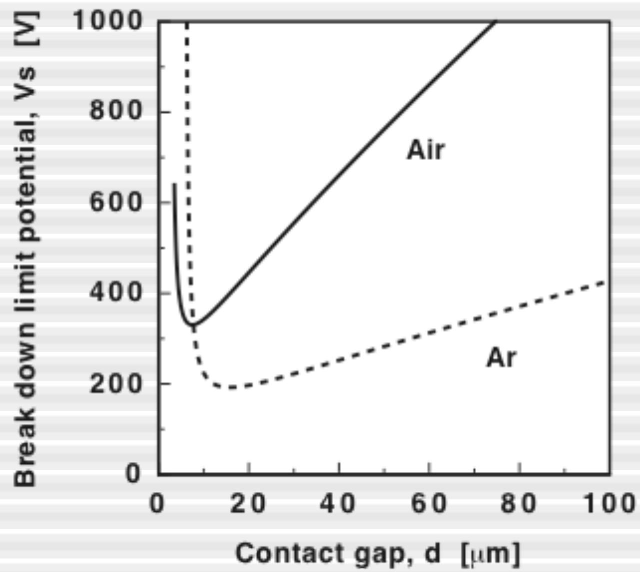
Charge relaxation in separation



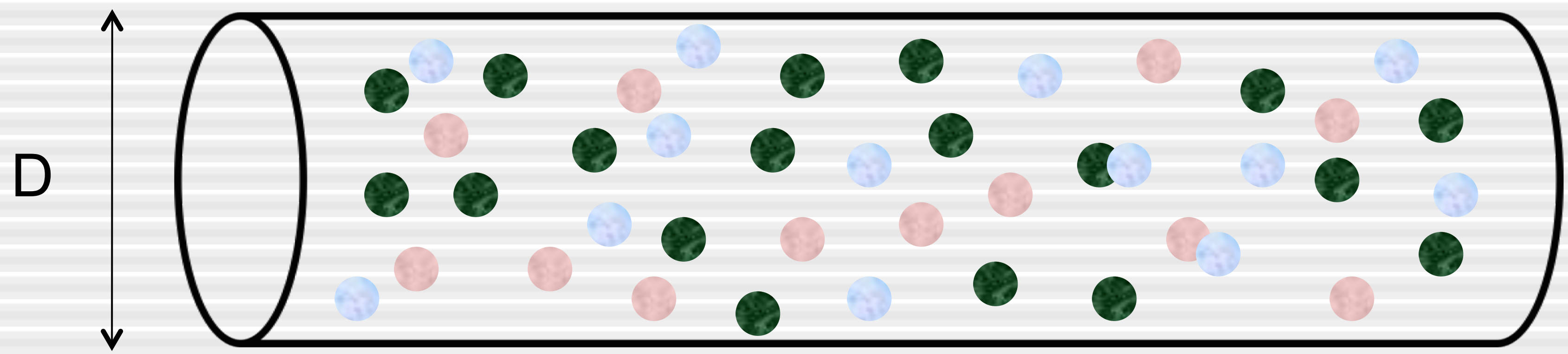


The maximum charge is well explained non-empirically





Extend the concept to pneumatic conveyed particles



- Major parameters:
  - Particle size: d
  - Diameter of pipe: D
  - Volume fraction of particles: ϕ

The scheme of 'charge relaxation' is applied to the bulk powder system in pneumatic conveyer

- Spheres, uniform size
- Uniform charge
- Uniform space distribution in pipe
- Mean field approximation for space charge
- Metal wall
- Air of ambient pressure

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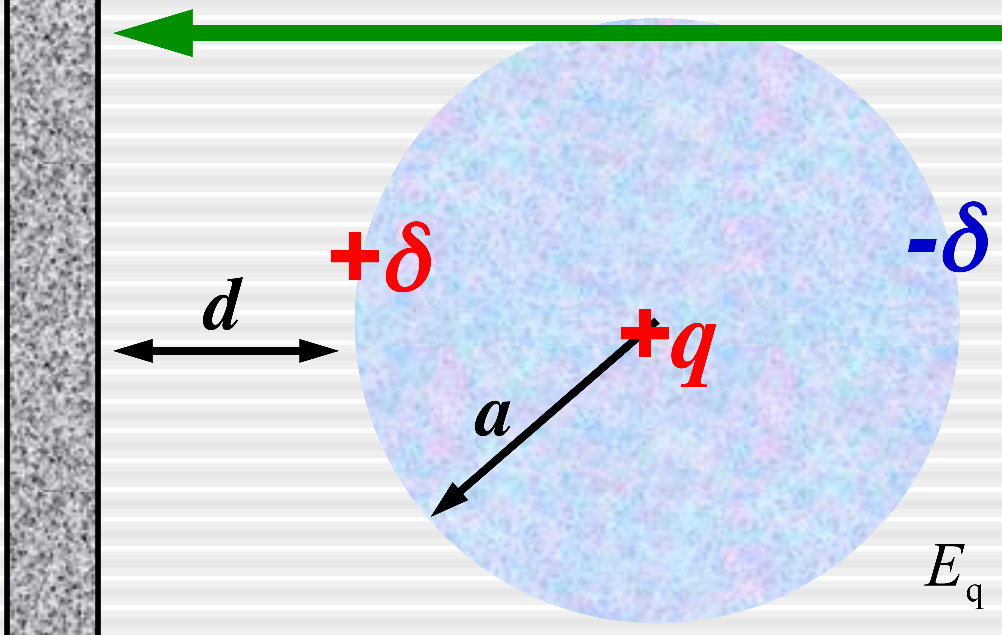
Calculus scheme

$$E_r = \frac{3\phi q}{8\pi\varepsilon_0 a^3} r$$



$$E_0 = \frac{3\phi q}{8\pi\varepsilon_0 a^3}(R - a - d)$$

$$E_p = 2\frac{\varepsilon_p - \varepsilon_0}{\varepsilon_p + 2\varepsilon_0} E_0 \left(\frac{a}{r_p}\right)^3$$

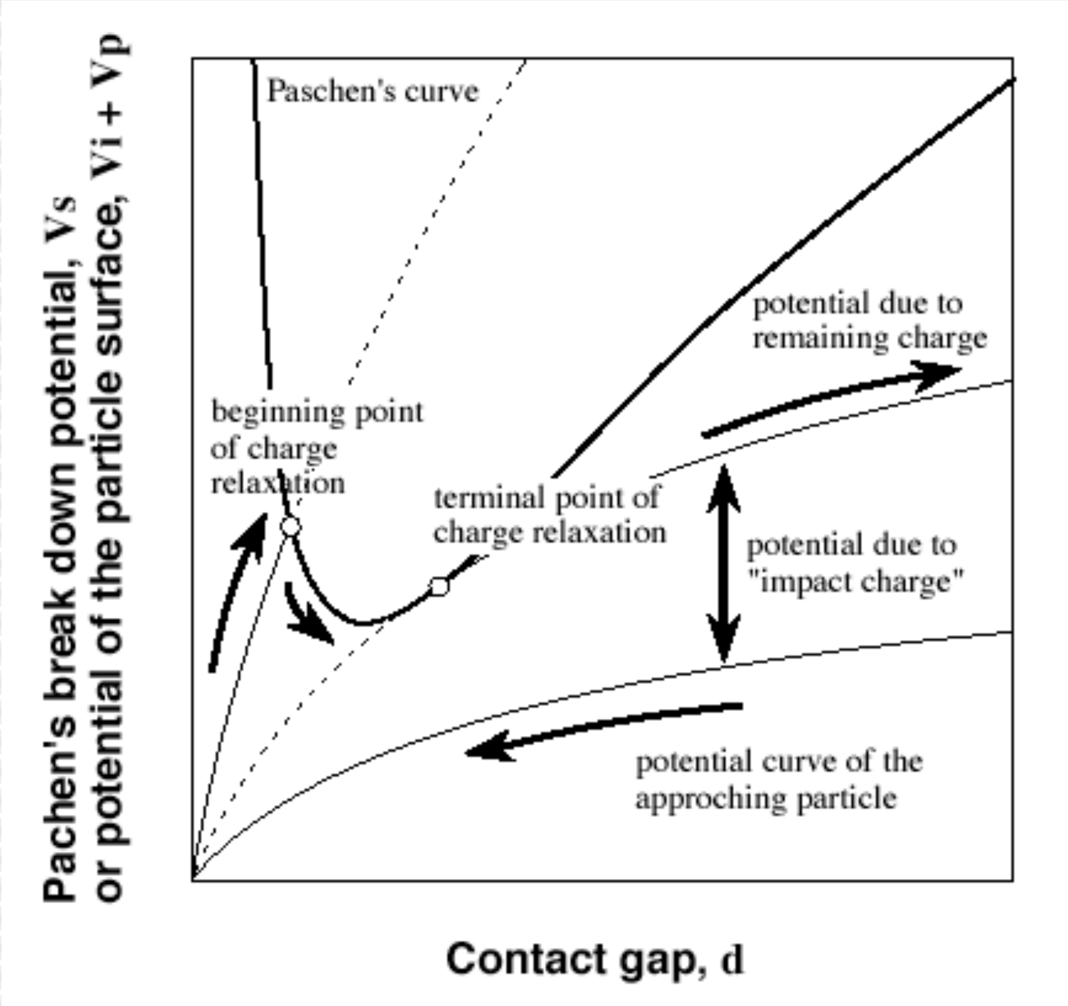
$$E_q = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_p^2}$$

$$r = R - d - a$$

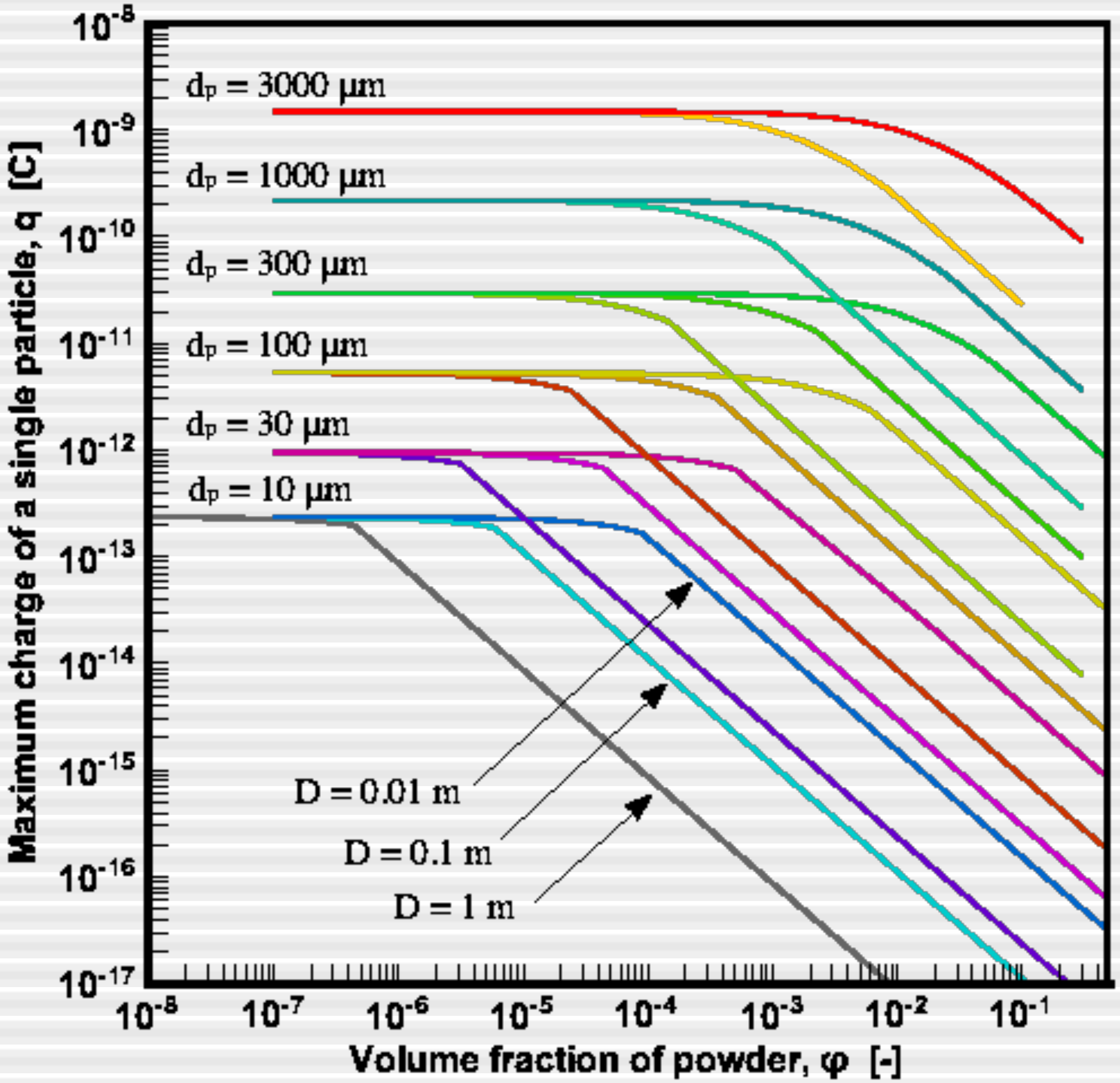
$$V = -\int_R^{R-d} \left(E_q + E_p + E_{Im} + E_r\right) dr$$

$$= \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{a} - \frac{1}{a+2d}\right) + \frac{\varepsilon_p - \varepsilon_0}{\varepsilon_p + 2\varepsilon_0}\left(a - \frac{a^3}{(a+2d)^2}\right)E_0 + \frac{3\phi q}{8\pi\varepsilon_0 a^3}\left(Rd - \frac{1}{2}d^2\right).$$

Charge relaxation model

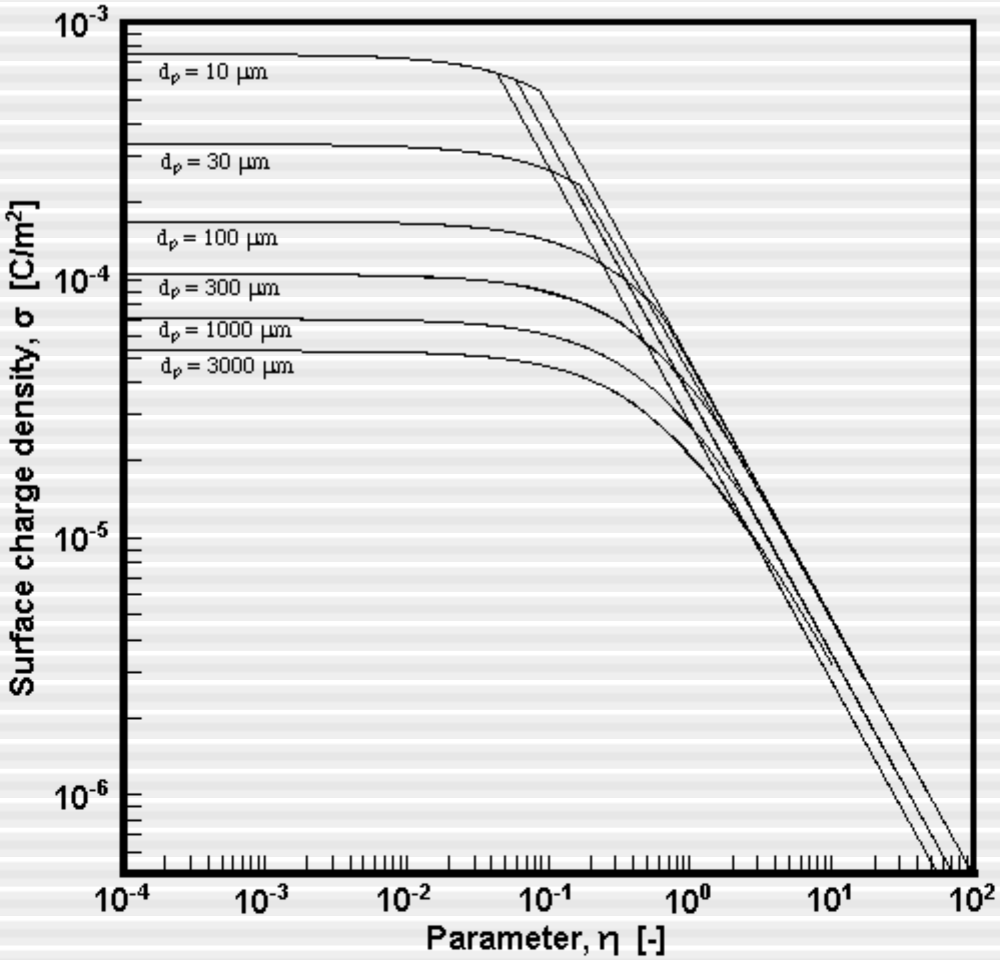


Result



Maximum charge of a single particle, q [C]
Volume fraction of powder, φ [-]
dp = 3000 μm
dp = 1000 μm
dp = 300 μm
dp = 100 μm
dp = 30 μm
dp = 10 μm
D = 0.01 m
D = 0.1 m
D = 1 m

Normalization



$$\eta = \frac{\phi D}{d_\mathrm{p}}$$

$$E_\mathrm{R} = \frac{3\phi D q}{2\pi\varepsilon_0 d_\mathrm{p}^{\ 3}} = \left(\frac{3}{2\varepsilon_0}\right)\left(\frac{\phi D}{d_\mathrm{p}}\right)\left(\frac{q}{\pi d_\mathrm{p}^{\ 2}}\right)$$

$$= \frac{3}{2\varepsilon_0}\eta\sigma \approx \text{const.}$$

$$q = \frac{2\pi\varepsilon_0}{3\phi D} E_\mathrm{Rc} d_p^{\ 3}$$

$$E_{Rc} = 6\ \mathrm{MV/m}$$

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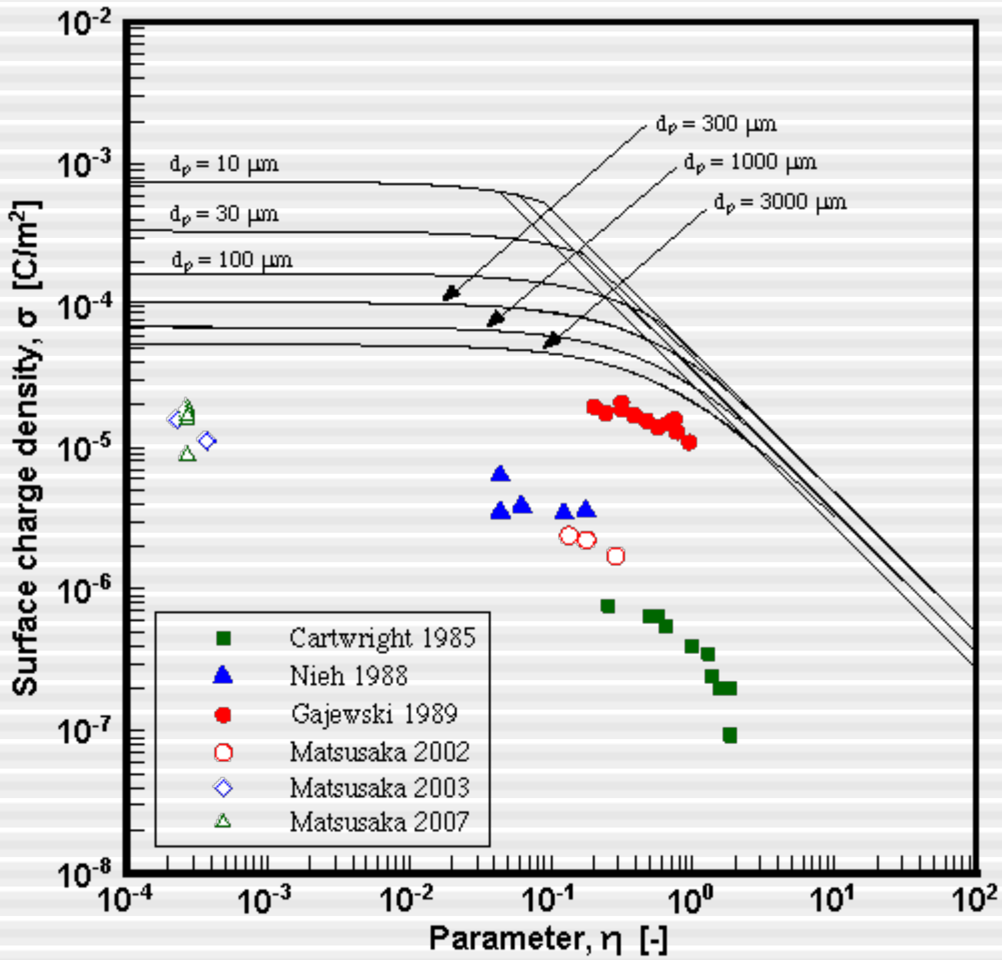
References

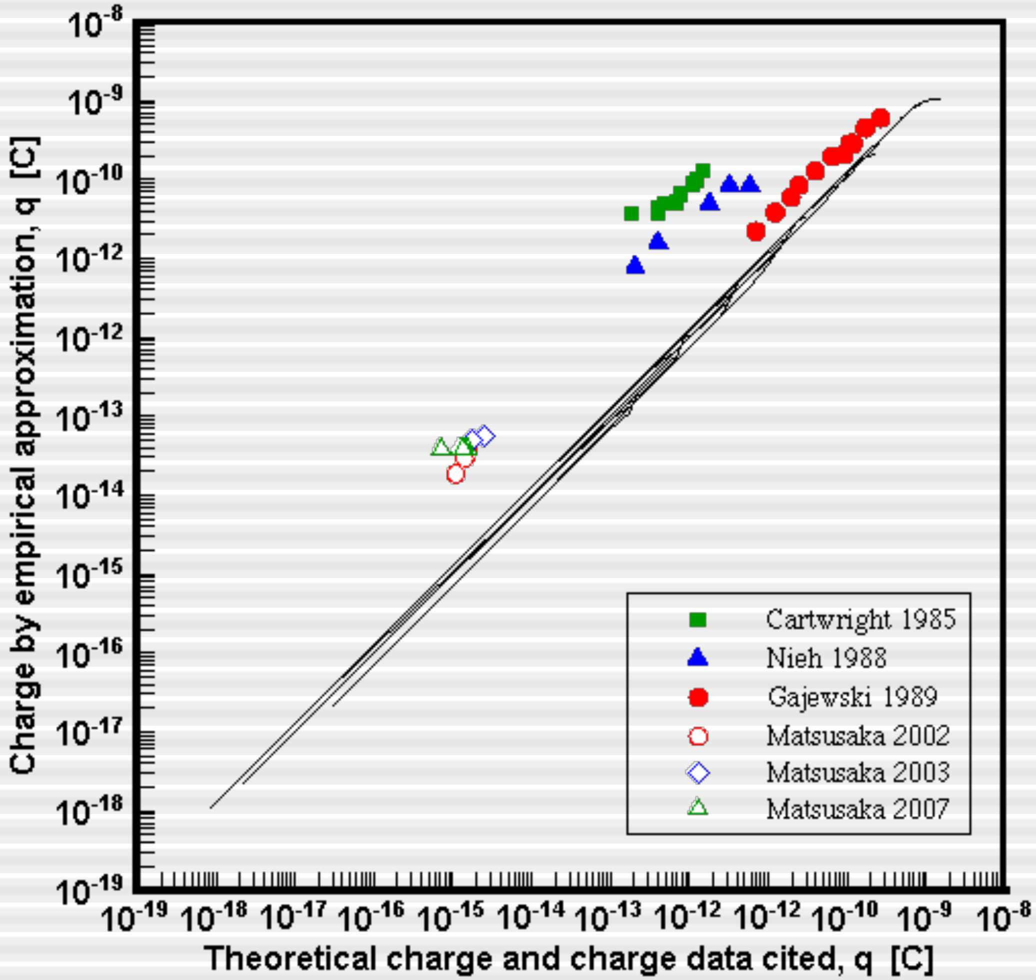
author	Cartwright	Nieh	Gajewski	Matsusaka		
year	1985	1988	1989	2002	2003	2007
particle material	PE	glass	PE	fly ash	fly ash alumina	alumina
particle size	800 μm	130-550 μm	0.4-2 mm	7 μm	4.2 μm 3.9 μm	3.3 μm
pipe material	steel	copper	steel	stainless	stainless	stainless, aluminum, copper, brass
pipe diameter	10 cm	5.1 cm	5 cm	4.7 mm	6.0 mm	6.0 mm
pipe length	35 m	10 m	8.8 m	2 m	3 m	3 m
pipe shape	straight	straight	straight	straight	spiral	spiral
air or solid velocity	30 m/s	5-28 m/s	1.5-12 m/s	35-80 m/s	20-40 m/s	40 m/s
volume fraction	0.2-1.5 %	0.05 %	0.85-2 %	0.02-0.05 %	1.5-2.6 10^{-7}	1.5 10^{-7}
charge on a particle	0.2-1.5 pC	0.2-6 pC	7-270 pC	1-1.5 fC	0.7-1.5 fC	1.5-2.5 fC

Comparison with reported values



Empirical expression to unify all the conditions

$$q/\mathrm{C} = \frac{1.10\times10^{-4}(d_\mathrm{p}/\mathrm{m})^3}{\sqrt{\{\phi(D/\mathrm{m})\}^2 + \{7.1(d_\mathrm{p}/\mathrm{m})^{1.5}\}^2}}$$



Discussion (ad hoc)

- Equilibrium or saturation was not achieved in experiments?
- Spatial distribution is not uniform, especially in the flow direction
- Highly ionic (conductive) in pipe due to small discharges

Question and Discussion

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