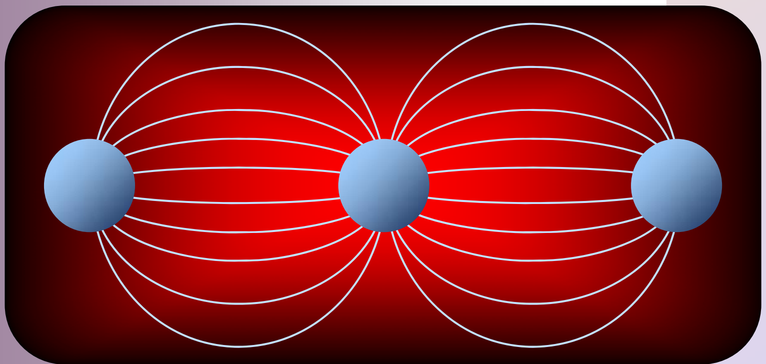
20th December 2014
STEP-1 The first international workshop on
Static-Tribo-Electricity of Powder, Tokyo

Characterization of particles triboelectrically charged in external electric field



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1. Introduction

Powders and particulate solids are handled in air, their surfaces become triboelectrically charged. In pneumatic transport lines and fluidized beds, particles become charged.

In order to analyze particle charging, the measurement of electrostatic charge and the characterization of electrostatic properties are important.

1.1 General particle charging

$$\bar{q}_{\mathrm{m}}(L) = \bar{q}_{\mathrm{m0}} \exp\left(-\frac{L}{L_0}\right) + \bar{q}_{\mathrm{m}\infty}\left\{1 - \exp\left(-\frac{L}{L_0}\right)\right\}$$

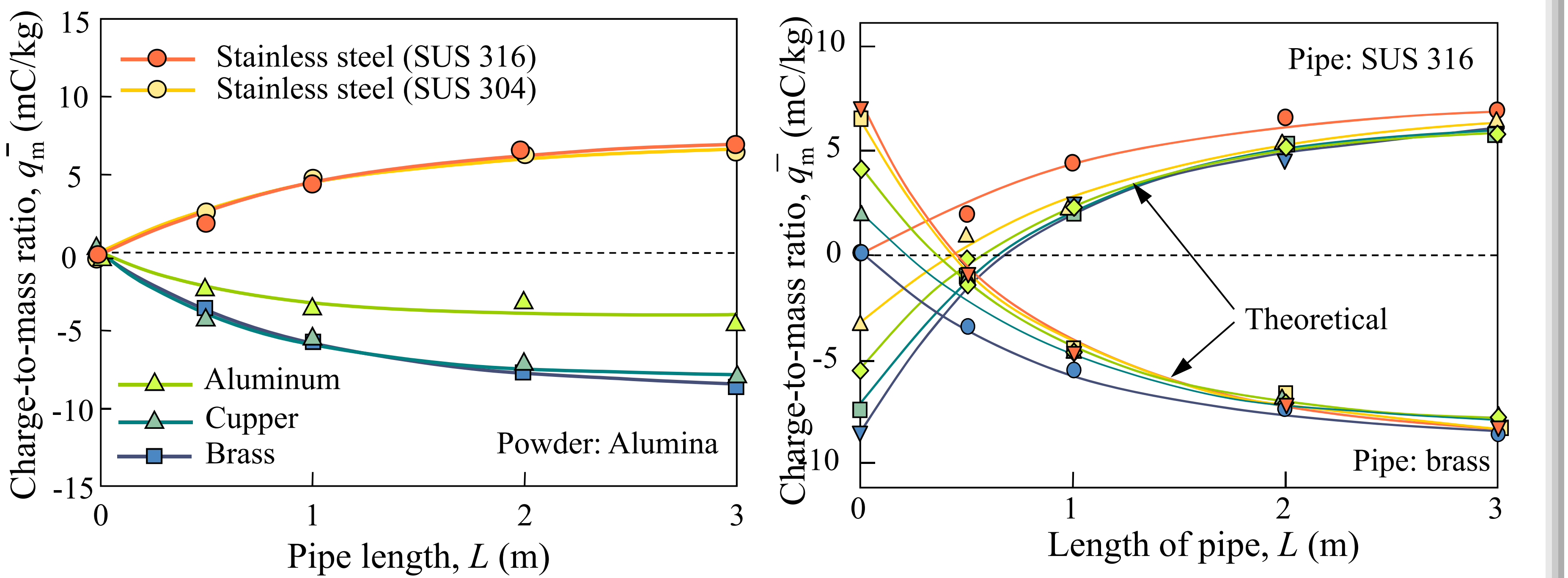
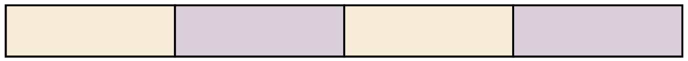
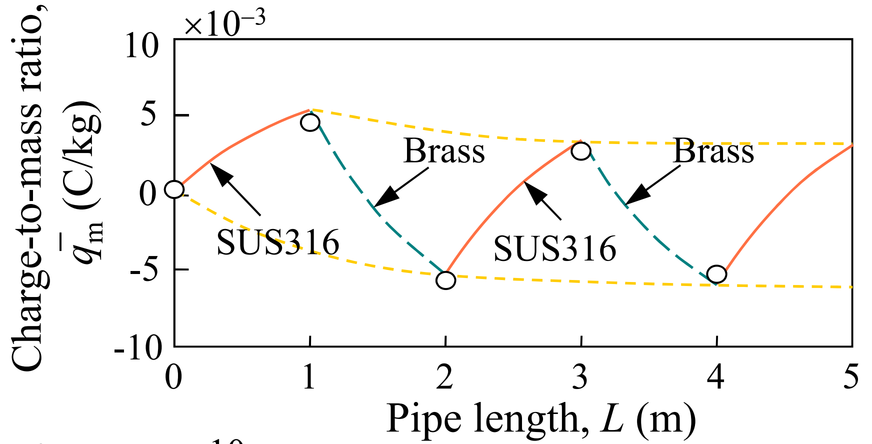


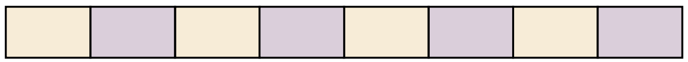
Fig. 1-1. Charge-to-mass ratio of particles passed through in a pipe made of different material.

1.2 Control of triboelectric charging

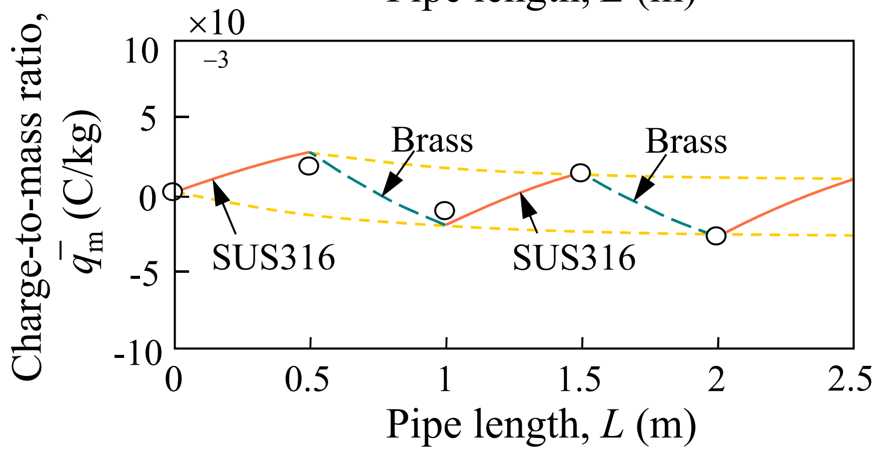


Connection of longer pipes





Connection of shorter pipes



Series connection

Fig. 1-2. Control the particle charge –theory and experiments –

1.3 Various charge control units

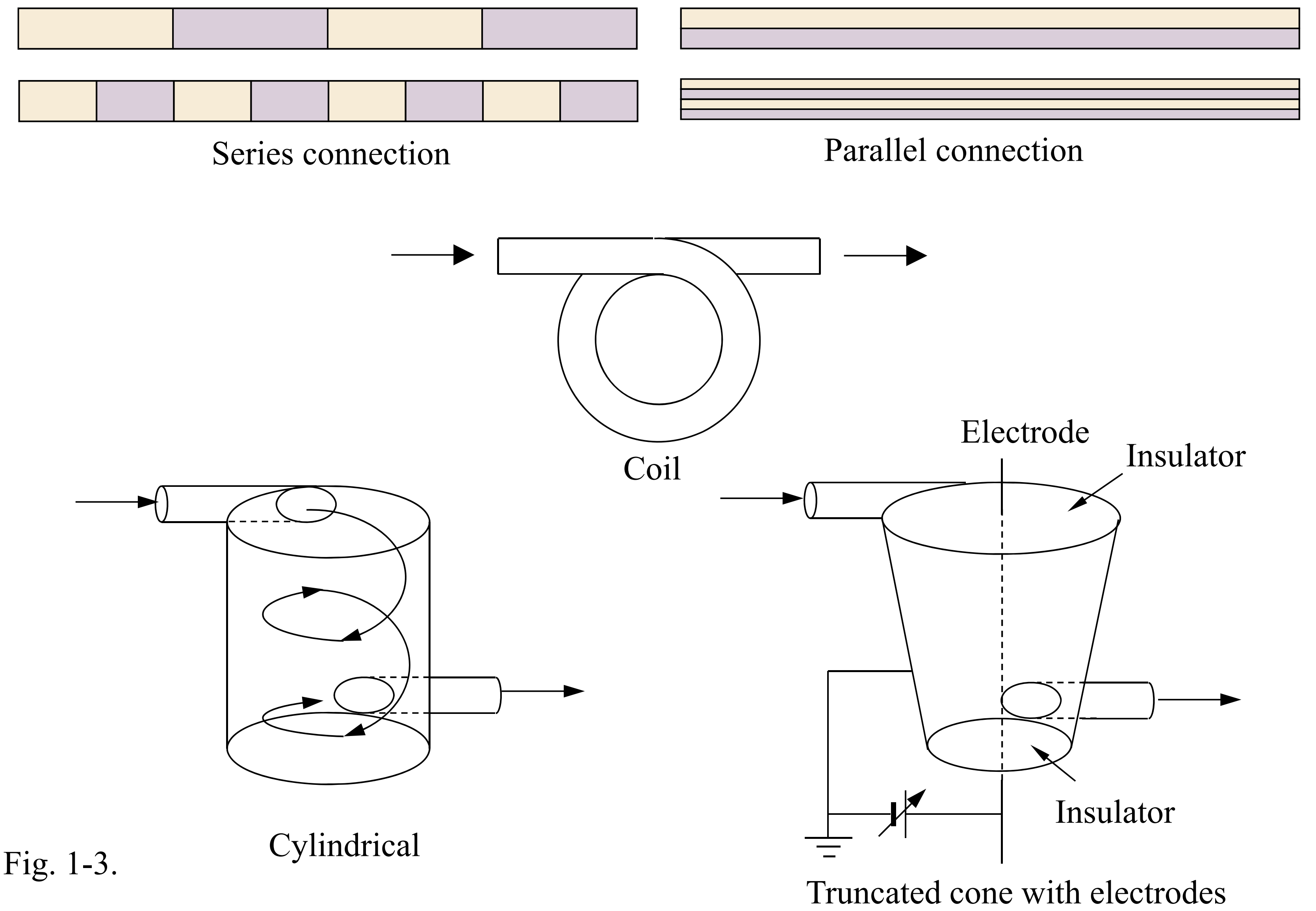


Fig. 1-3.

2.1 Characterization of particle tribocharging in gas-solids pipe flow

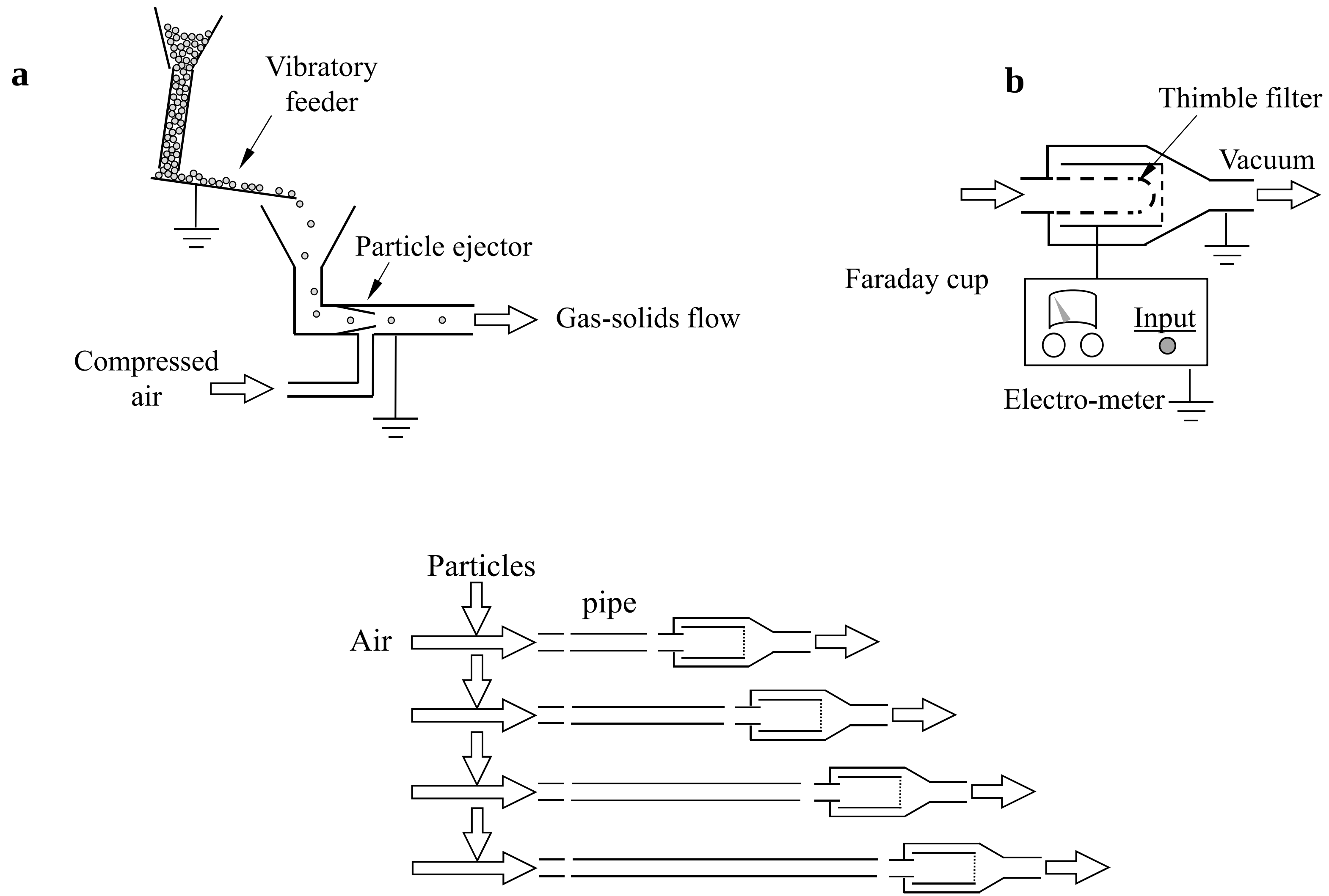


Fig. 2-1. Experimental setup for determining particle charge after different pipe lengths.

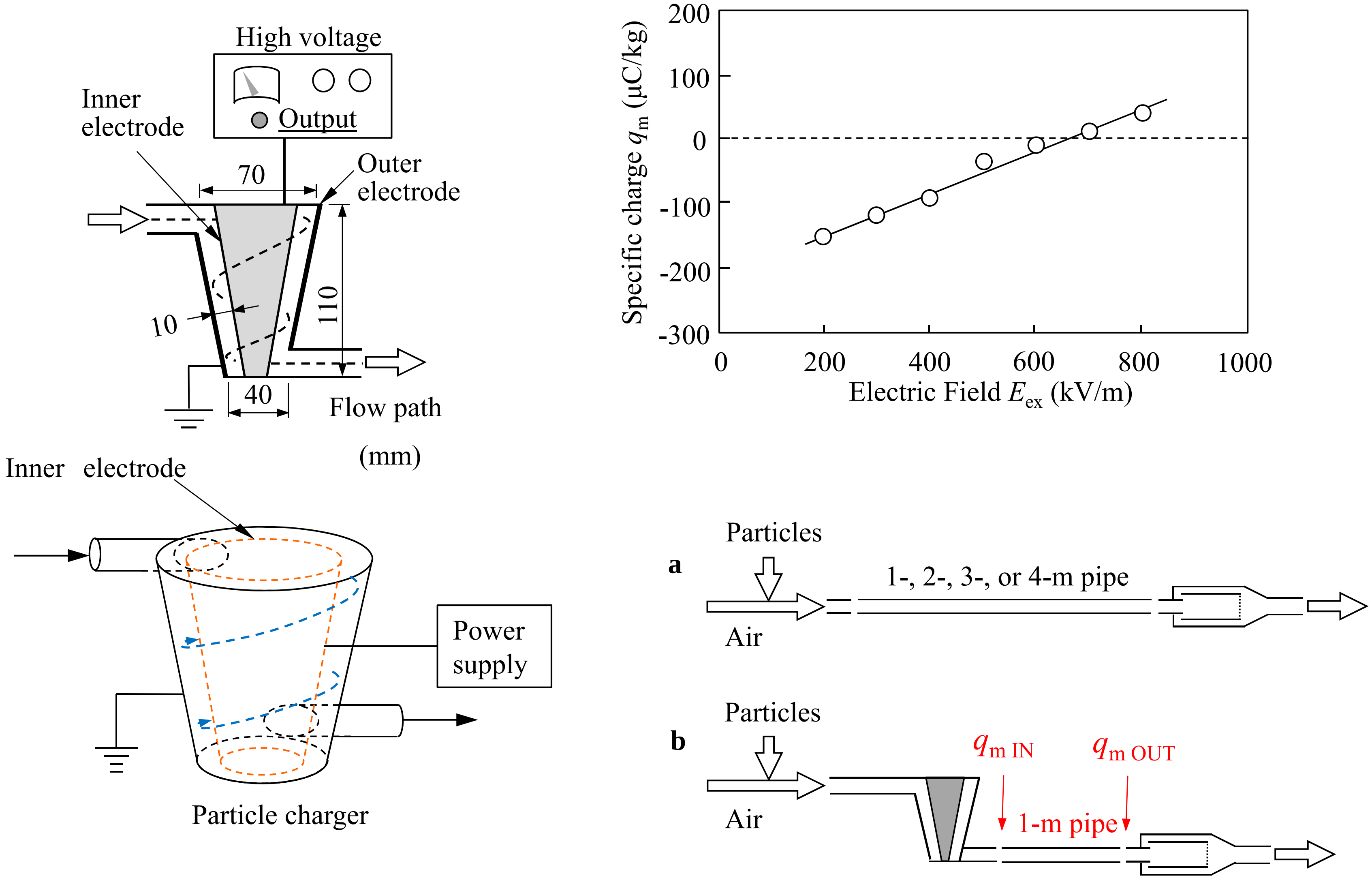
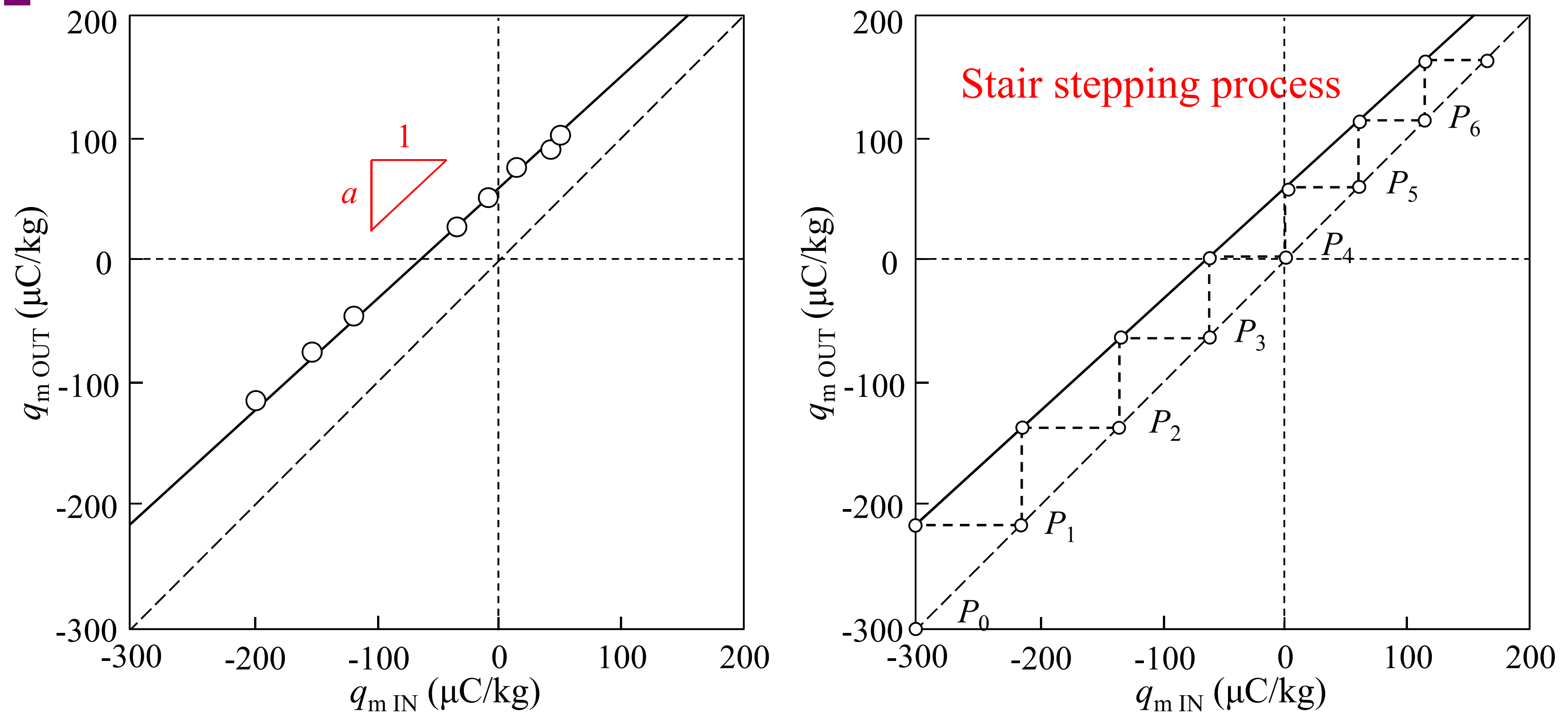


Fig. 2-2. A new experimental setup to characterize particle tribocharging in gas-solids pipe flow.

Bunchatheeravate, Matsusaka et al.; Prediction of Particle Charging in a Dilute Pneumatic Conveying System, AIChE Journal, 59, 2308-2316 (2013)



$$\begin{cases} q_{mOUT}(L) = q_{mIN}\exp\left(-\frac{L}{L_0}\right) + q_{m\infty}\left\{1-\exp\left(-\frac{L}{L_0}\right)\right\} \\ q_{mOUT} = a\,q_{mIN} + b \end{cases}$$

$$L_0 = -\frac{L}{\ln a}$$

$$a = \exp\left(-\frac{L}{L_0}\right) \qquad b = q_{m\infty}\left\{1-\exp\left(-\frac{L}{L_0}\right)\right\}$$

$$q_{m\infty} = \frac{b}{1-\exp(\ln a)}$$

Fig. 2-3. $q_{m\,IN}$ vs. $q_{m\,OUT}$ for borosilicate particles in 1-m natural glass pipe.

$$q_{\mathrm{m}}(L) = q_{\mathrm{mIN}} \exp(-\frac{L}{L_0}) + q_{\mathrm{m}\infty} \left\{1 - \exp(-\frac{L}{L_0})\right\}$$

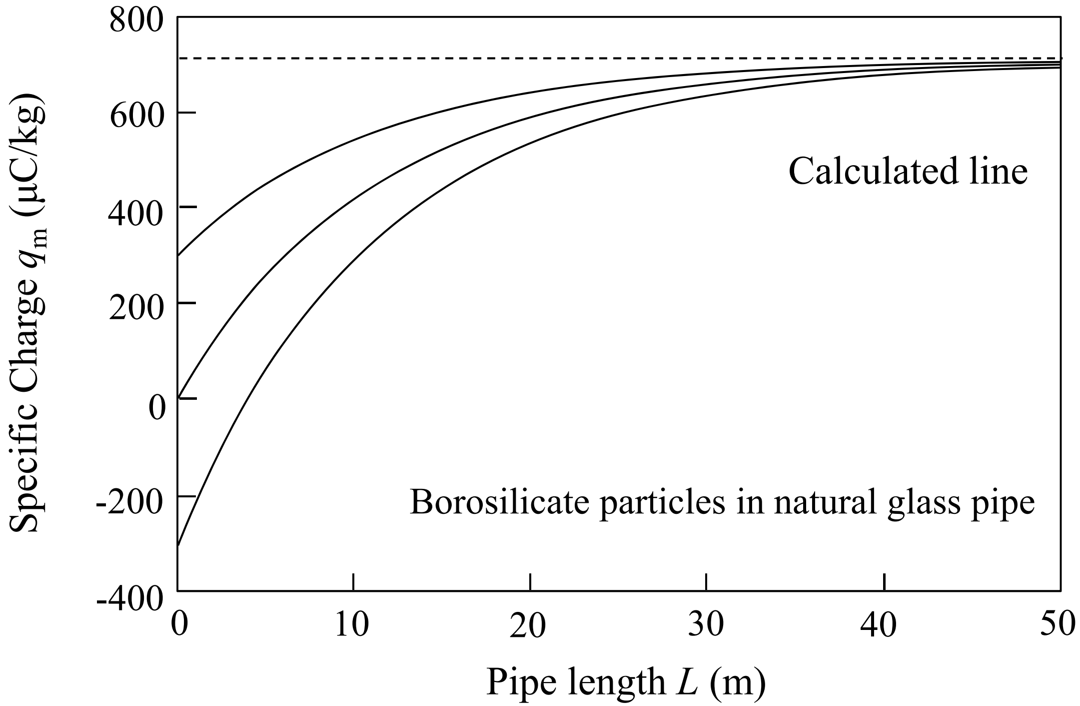
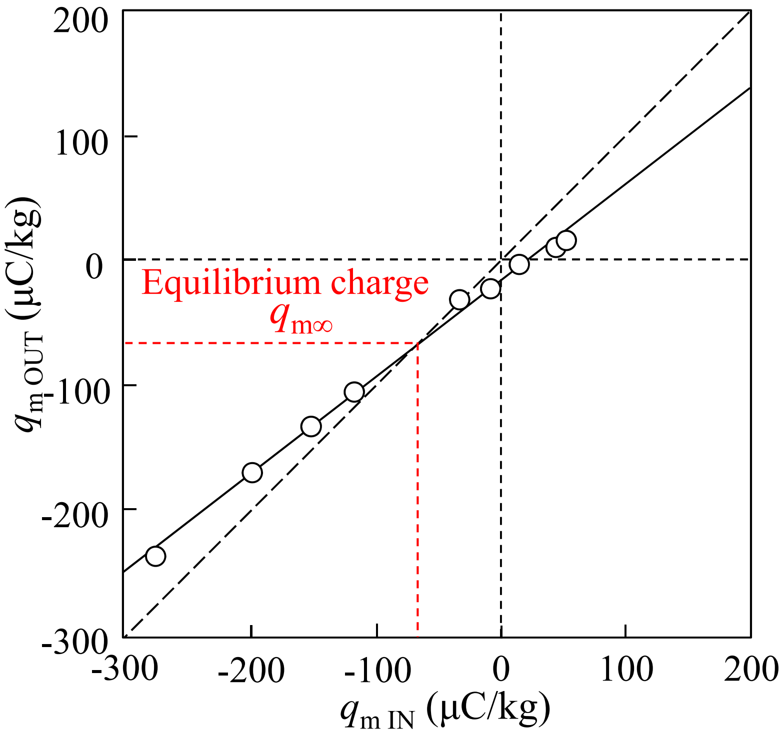


Fig. 2-4. Predicting charging profile for borosilicate particles a) in natural glass pipe b) in copper pipe.



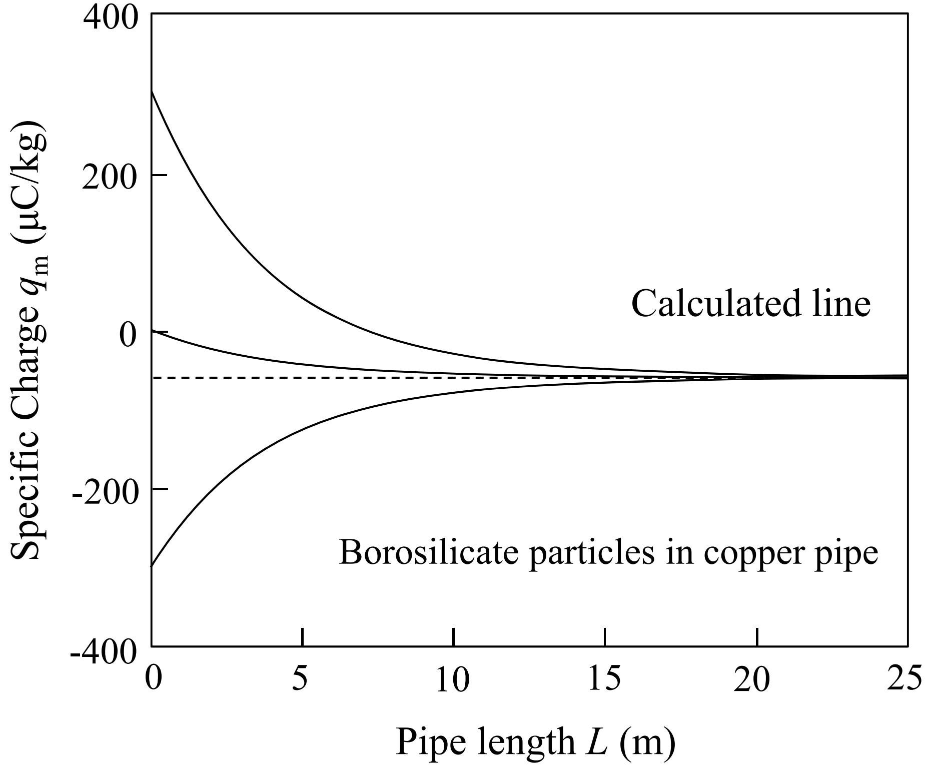
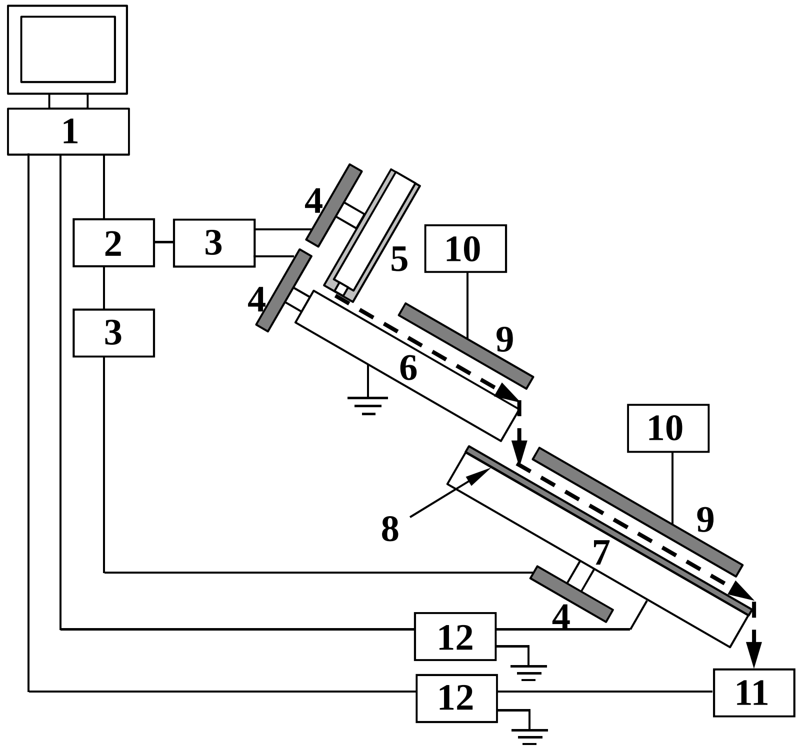


Fig. 2-5. $q_{m\,IN}$ vs. $q_{m\,OUT}$ for borosilicate particles in 1-m copper pipe.

Bunchatheeravate, Matsusaka et al.; Prediction of Particle Charging in a Dilute Pneumatic Conveying System, AIChE Journal, 59, 2308-2316 (2013)

2.2 Two-stage system with vibrations and external electric fields



1. computer;
2. Controller
3. Amplifier
4. piezoelectric vibrator
5. short pipe filled with particles
6. first vibrating plate
   (lower electrode)
7. second vibrating plate
   (lower electrode)
8. removable material
9. upper electrode
10. power supply
11. faraday cup
12. electrometer

Fig. 2-6. Schematic diagram of the setup.

Mizutani, M., M. Yasuda, and S. Matsusaka; Advanced characterization of particles triboelectrically charged by a two-stage system with vibrations and external electric fields, Advanced Powder Technology (in press)

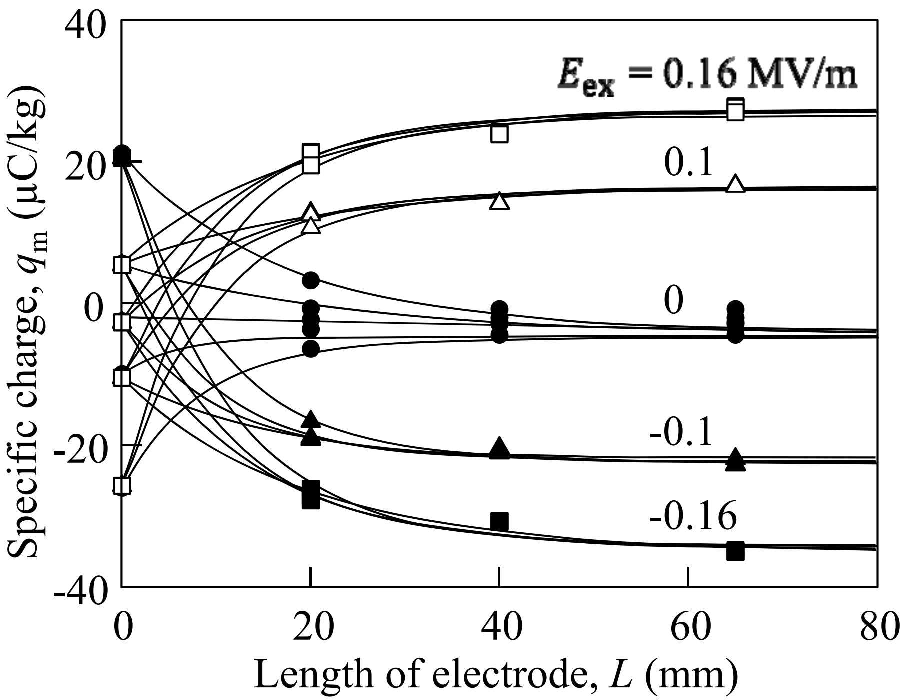


Fig. 2-7. Particle charge profiles (Manganese ferrite particles, stainless steel plate).

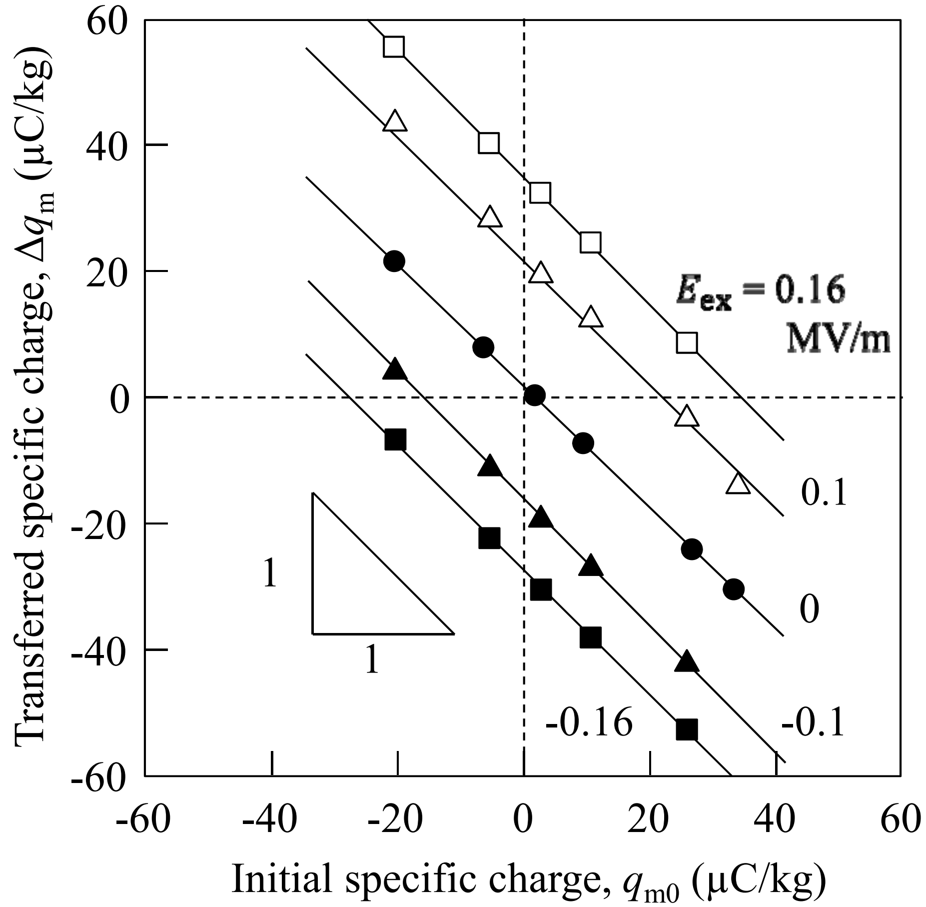
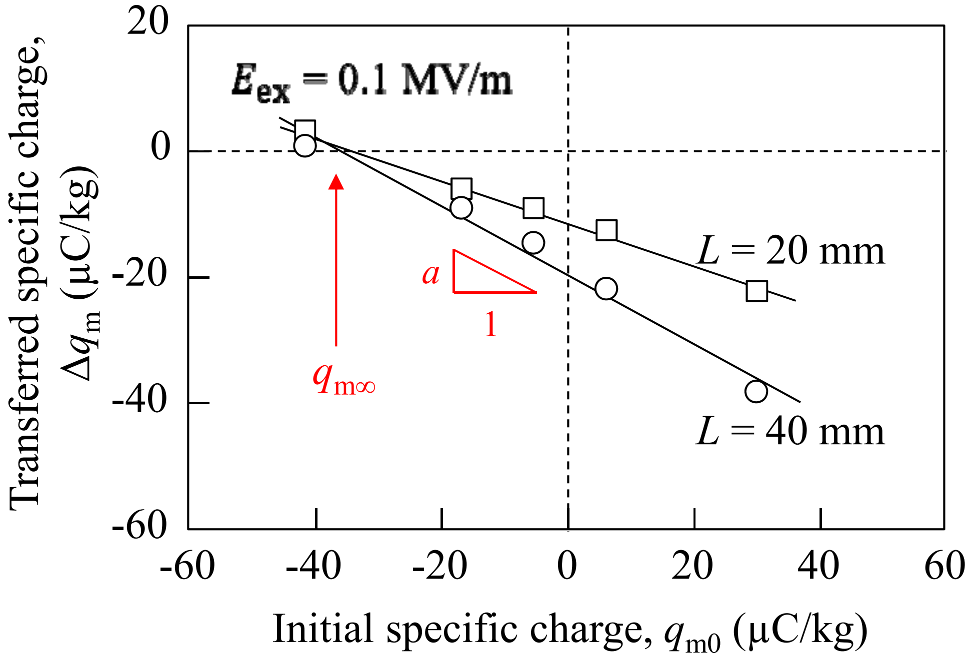


Fig. 2-8. Relationship between transferred specific charge and initial specific charge as a function of external electric field (Manganese ferrite particles, stainless steel plate, L = 65 mm).



$$\Delta q_m = q_m - q_{m0}$$

$$= q_{m\infty}\left\{1 - \exp\left(-\frac{L}{L_0}\right)\right\} - q_{m0}\left\{1 - \exp\left(-\frac{L}{L_0}\right)\right\}$$

$$= a\, q_{m0} + b$$

$$a = \exp\left(-\frac{L}{L_0}\right) - 1 \qquad b = -a\, q_{m\infty}$$

$$q_{m\infty} = -\frac{b}{a} \qquad L_0 = -\frac{L}{\ln(1+a)}$$

Fig. 2-9. Relationship between transferred specific charge and initial specific charge as a function of travel distance of particles (Glass beads, stainless steel plate).

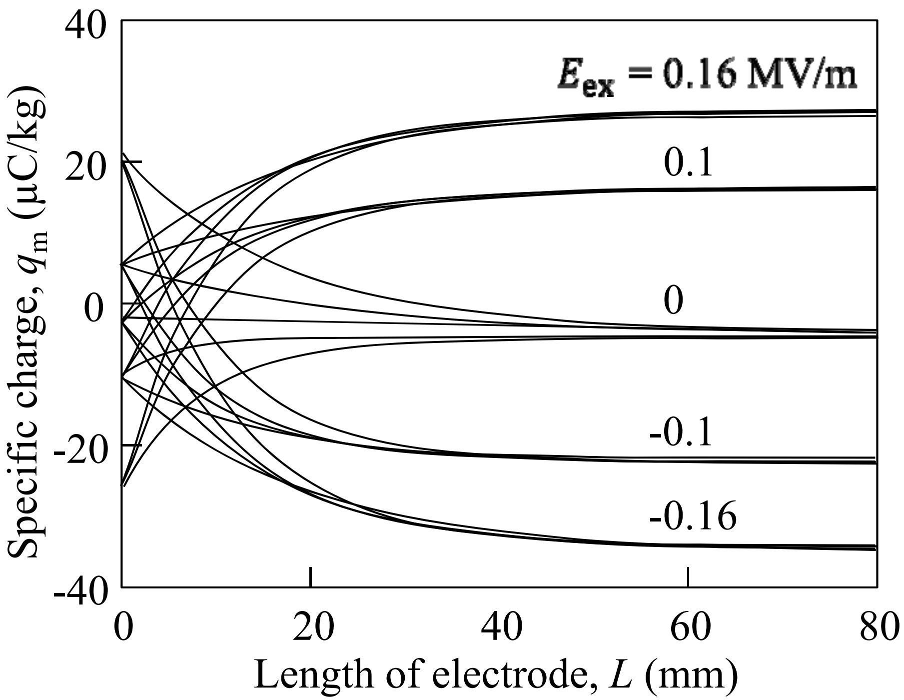


Fig. 2-10. Particle charge profiles (Manganese ferrite particles, stainless steel plate).

Mizutani, M., M. Yasuda, and S. Matsusaka; Advanced characterization of particles triboelectrically charged by a two-stage system with vibrations and external electric fields, Advanced Powder Technology (in press)

3. Adhesive strength distribution of charged particles on metal substrate in external electric field

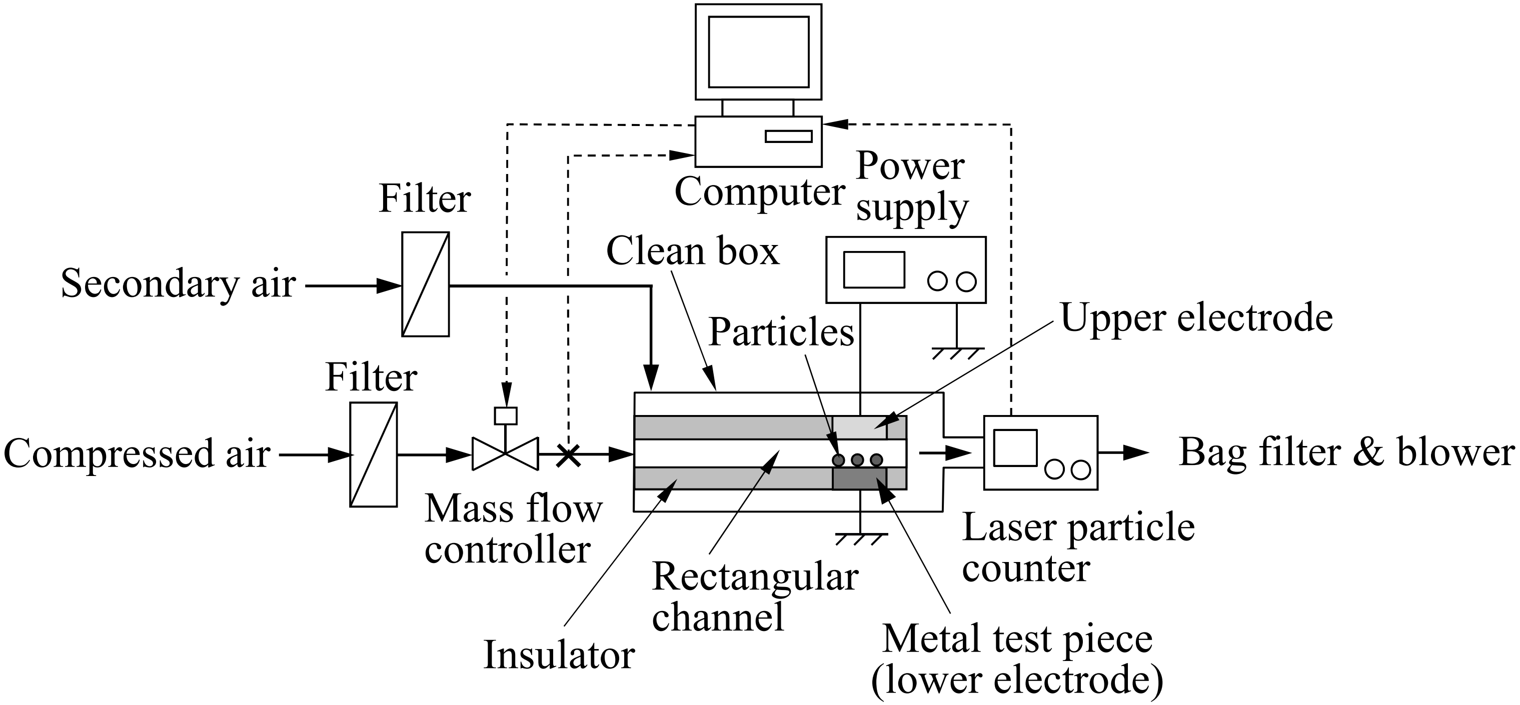


Fig. 3-1. Experimental setup for measuring particle–substrate adhesion.

Matsusaka, S., D. Wei, M. Yasuda and S. Sasabe; Adhesive strength distribution of charged particles on metal substrate in external electric field, Advanced Powder Technology (in press)

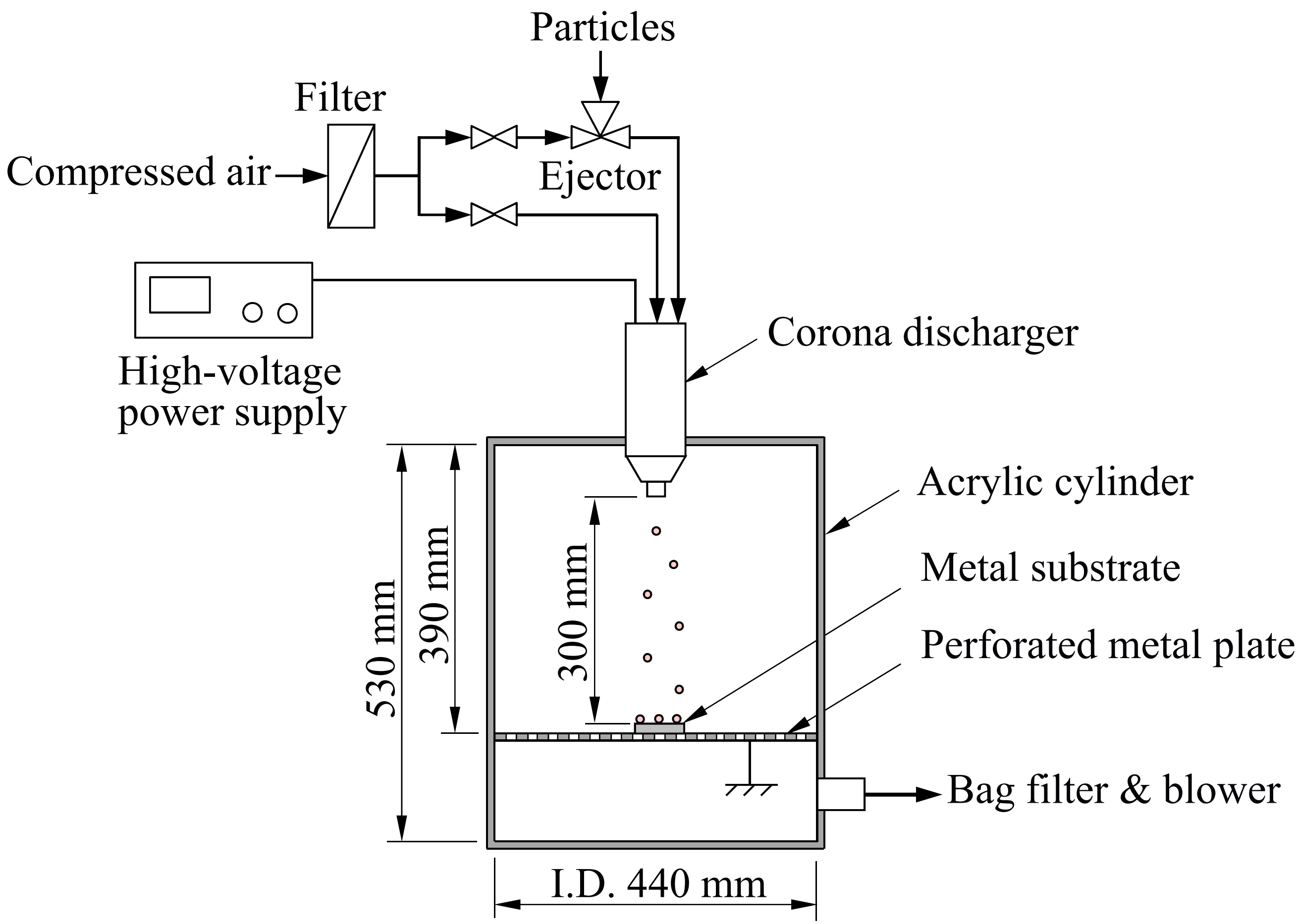


Fig. 3-2. Experimental setup for controlling the initial charge of particles and depositing the charged particles on a metal substrate.

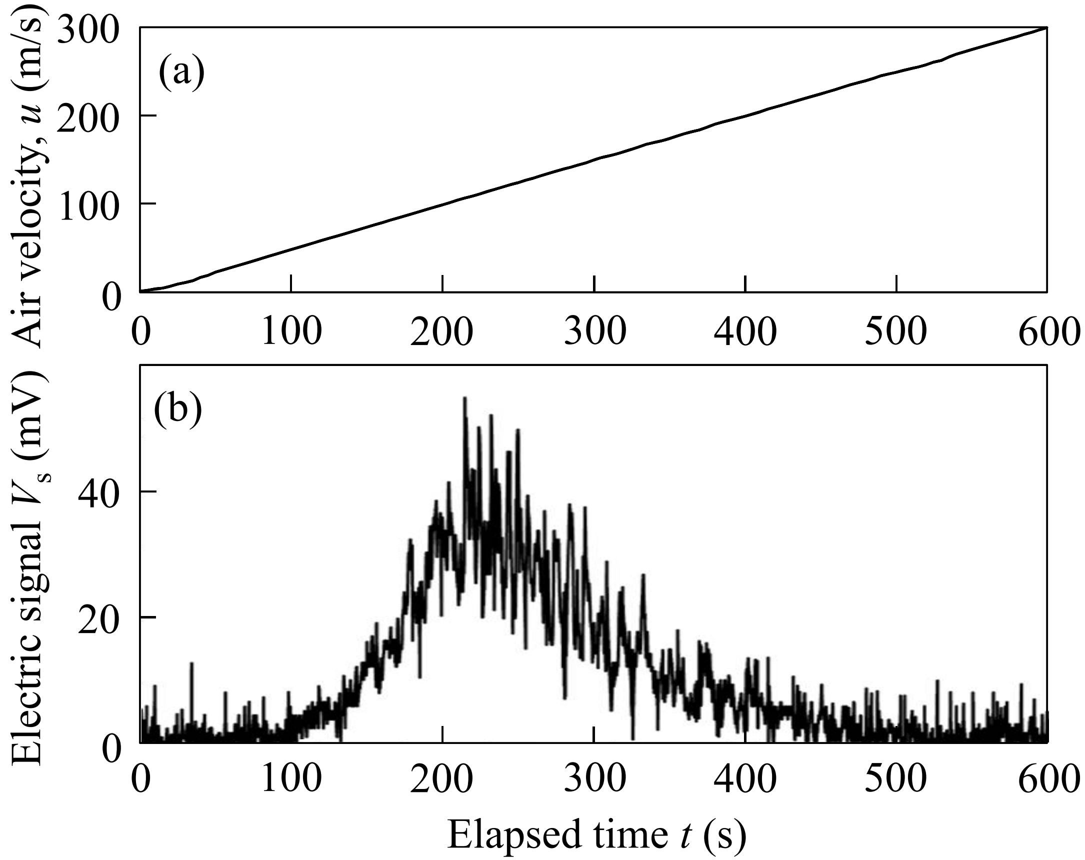
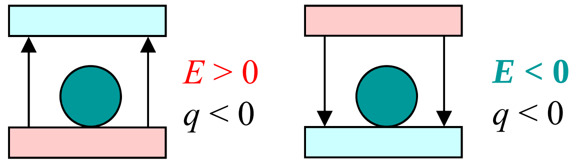


Fig. 3-3. Experimental result for toner A: (a) variation of air velocity in the channel; (b) particle entrainment profile (deposition density on the substrate: 1.8 g/m^2, initial charge: –37 mC/kg, external electric field: +300 V/m).



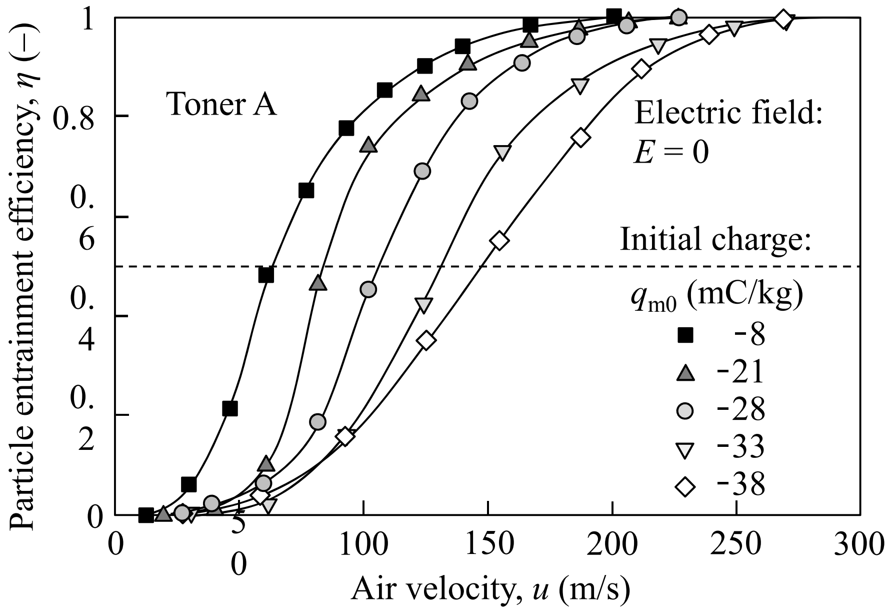


Fig. 3-4. Relationships between particle entrainment efficiency and air velocity as a function of the initial charge of particles.

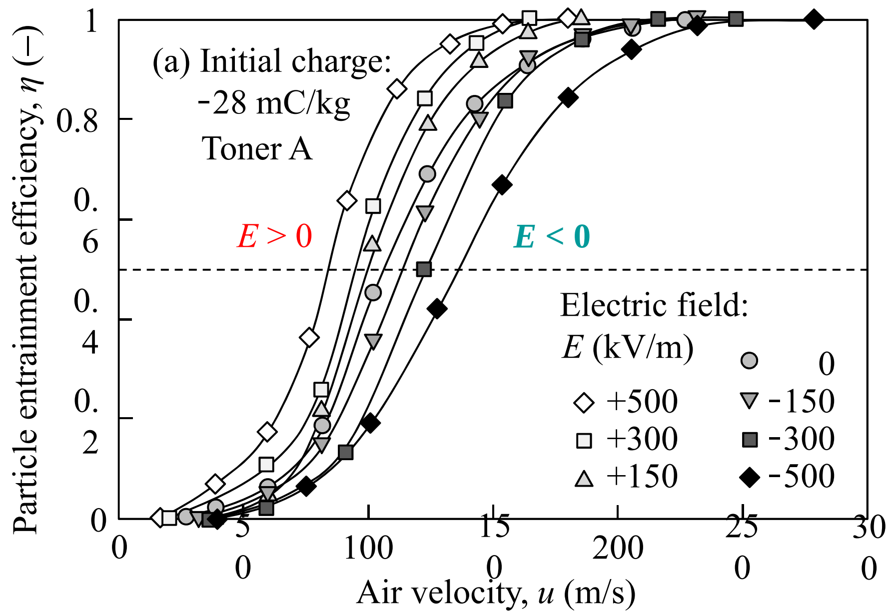


Fig. 3-5 Relationships between particle entrainment efficiency and air velocity as a function of the external electric field (Toner A).

Matsusaka, S., D. Wei, M. Yasuda and S. Sasabe; Adhesive strength distribution of charged particles on metal substrate in external electric field, Advanced Powder Technology (in press)

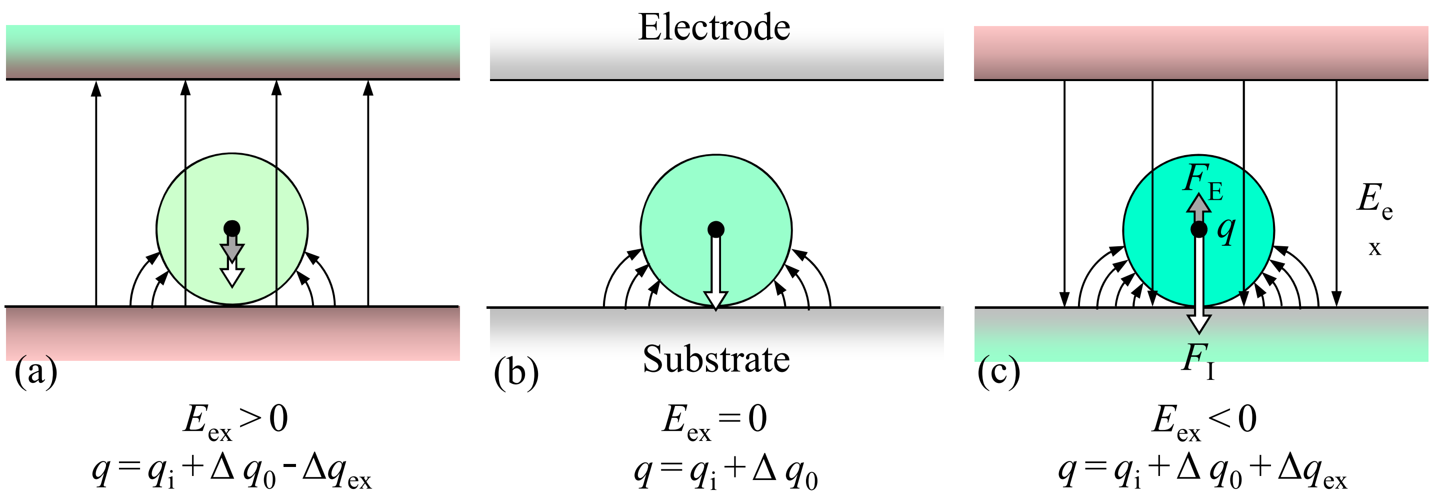


Fig. 3-6. Image force F_I and Coulomb force F_E in an external electric field E_{ex} (q: particle charge, q_i: initial charge, Δq_0: charge transferred without external electric field, Δq_{ex}: charge transferred caused by external electric field, $q_i < 0$, $\Delta q_0 < 0$, $\Delta q_{ex} < 0$).

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