EXPERIMENTAL STUDY OF A PLATE-TYPE ELECTROSTATIC PRECIPITATOR

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ABSTRACT

The electrostatic precipitator is an equipment of great academic and industrial interest, mainly because of its high collection efficiency and low pressure drop. Based on this fact, the objective of this work was to project and evaluate the performance of a plate-type electrostatic precipitator based on equations from different sources found in the literature. Calculated and experimental values of total collection efficiency and I-V curves (current – voltage) were compared to verify the applicability of the equations used in the project and also the versatility of the equipment.

PROJECT: ANALYSIS AND RESULTS

A hypothetical particle with similar properties of those found in real processes was used in the equipment project. Operational conditions, which determined the air properties used in the project, were previously chosen in order to make possible the reproducibility of tests in the laboratory. The versatility of the equipment was evaluated through tests in conditions different from those used in the project, i.e., different air velocities and active electrode diameters and also with dust material with different properties. Equations used to evaluate the overall collection efficiency were based on the classic model presented by Deutsch for the prediction of fractionary collection efficiency of electrostatic precipitators. Such a model has been well accepted in the literature for its good results and easy application.

Electrostatic Precipitator Project

Air and dust properties used to project the equipment are presented in Table 1.

Table 1 - Air and dust properties used in the equipment project.

Dust			Air		
C_o (g/m^3)	ρ_P (g/cm^3)	ε (-)	T_g (°C)	Q (m^3/min.)	φ (m^2/V.s)
4.0	2.5	3.0	30.0	2.0	$2.1\text{x}10^{-4}$

The tolerance range (LT) adopted for the particle concentration at the exit of the equipment was ± 0.1% (4.0 mg/m^3) and was fixed to establish the minimal collection efficiency for the equipment operating at project conditions.

Equations used for the evaluation of the total (η_T), fractionary (η_i) and minimal collection efficiencies can be expressed as (see Strauss[1]):

$$\eta_T = \frac{C_0 - C_S}{C_0} = \frac{\sum_{i=1}^{n} (\%m_i)\eta_i}{\sum_{i=1}^{n} (\%m_i)} \tag{1}$$

and

$$\eta_i = \left(1 - \exp\left(-\frac{0.368 i Cu dp_i}{\varphi \mu v}\left(1 + \frac{\varepsilon A s}{\varepsilon + 2}\right)^2\right)\right) \tag{2}$$

where:
C_o is the inlet particle concentration (g/m^3);
C_s is the outlet particle concentration (g/m^3);
$\%m_i$ is the particle mass percentage for each particle diameter range (-);
Cu is the Cunningham factor (assumed for calculations in this project as equal to 1) (-);
dp_i is the particle diameter (m);
φ is the ionic mobility (m^2/Vs);
μ is the dynamic air viscosity (kg/ms);
v is the mean fluid velocity per collect unity (m/s);
A is the total particle surface area (assuming particles as spheres) per fluid volume unity (m^2/m^3);
s is the distance between the active electrode and the collection electrode (m);
i is the electric current per active electrode length unity (A/m);
ε is the particle dielectric constant, (-).

Since both the tolerance range (LT) and the outlet particle concentration (C_S) were fixed in the project, a minimal collection efficiency of 99.9% was predicted by equation (1).
Based on the experimental parameters presented by Strauss[1], the values adopted in this work for the ratio 2s/2c (where 2c is the distance between two consecutive active electrodes, in meter) and for the ionic current were 1 and 9.33×10^{-3} A/m, respectively.

Considering the smallest particle in the size distribution as the critical project parameter ($dp_{i,c} = 0.5$ μm in this work) and assuming that the equipment is constituted of Ψ collection units, each one with dimensions of 2s = 0,10 m, 2c = 0,10 m and H = 0,30 m, the mean air velocity (v) for each collection unit was calculated. Since the transversal section area of each unit is given by 2sH, where H is the unit height, the volumetric flow rate per collection unit (q) was calculated by $q = v(2sH)$, in m^3/s. The operational volumetric flow rate (Q) chosen in this work as 2.0 m^3/min (0.0333 m^3/s) was used to calculate de number of collection units ($\psi = Q/q$) necessary in the equipment. According to the dimensions and operational conditions adopted, Ψ was found to be approximately 14. In order to optimize the spatial arrangement of the units and to make uniform the fluid flow through the equipment, a precipitator of 15 units was built, which were distributed in 3 channels of 5 units each, given a total collection area of 0.90 m^2.
It can be easily demonstrated that, at the studied concentration (C_o = 4.0 g/m^3), the overall collection efficiency is independent of the spatial arrangement of the collection units (in series or parallel), once guaranteed that the minimal number of units is respected.

Equations used for results analysis

Recent equations found in the literature where used to represent and evaluate the experimental parameters in this work. The behavior of the current-voltage curve (I-V) was evaluated through the equation proposed by Cooperman[2]:

$$i_{GC} = \frac{\varepsilon_0 \varphi}{16 s^3} \left(9 \left(V - Vo + \frac{s \pi Vo}{2c \ln \frac{d}{r}} \right)^2 - 12 \left(\frac{s \pi Vo}{2c \ln \frac{d}{r}} \right)^2 + \sqrt{\alpha^2 + 192 \left(\frac{s \pi Vo}{2c \ln \frac{d}{r}} \right)^3 (V - Vo)} \right) \quad (3)$$

where:
i_{GC} is the current per collection area unit (A/m^2);
ε_0 is the permittivity of free space (8.86×10^{-12} As/Vm);
r is the active electrode radius (m);
d is an equation parameter, d = 0.36exp(2.96(s/2c), (m);
V is the applied voltage (Volts);
Vo is the voltage at the beginning of the corona discharge (Volts)

The equation proposed by Zhao and Pfeffer[3] was used to predict the total efficiency (η_T) of the equipment:

$$\eta_T = 1 - \exp\left(- \frac{k \varepsilon \varepsilon_0 A_C E^2 d_{m50}}{(\varepsilon + 2) \mu Q} \right) \quad (4)$$

where:
k is a constant which depends on the ratio between the effective migration velocity and its theoretical value (k may vary from 1/10 and 1/2; Zhao and Pfeffer[3] suggest k = 1/7) (-);
Ac is the total collection area (m^2);
d_{m50} is the mass median diameter of particles (m).

Experimental tests and typical results

A high-voltage source with continuous discharge (SPELLMAN, MOD. SL 1200), with voltage and current levels variable between 0-50 kV e 0-20 mA, respectively, and operating with positive corona was used in the experimental tests. Collection efficiency (η) was evaluated through isokinetic sampling probes at the entrance and exit of the precipitator.

The dust material used in the tests was a phosphatic rock. The material was dispersed in ambient air flow which was fed to the precipitator. The main dust and air properties used in the tests are presented in Table 2. Steel wires with three different diameters (D): 0.23×10^{-3} m, 0.5×10^{-3} m and 0.8×10^{-3} m were used as discharge electrodes.

Table 2 - Dust and air properties used in the experimental tests.

Dust			Air		
C_o (g/m^3)	ρ_P (g/cm^3)	ε (-)	T_g (°C)	v (m/s)	φ (m^2/V.s)
1.4-1.8	3.0	6.5	30.0	0.40 e 0.68	2.1×10^{-4}

Typical results obtained according to the proposed methodology are presented in Figures 1 – 4.

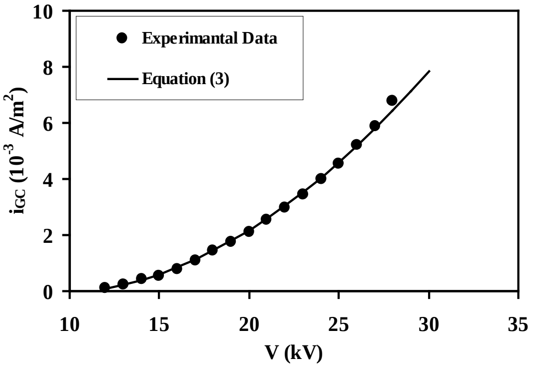

Figure 1 – Fitting of Equation (3) to the experimental I-V curve (v = 0.40 m/s and D = 0.5x10^{-3} m).

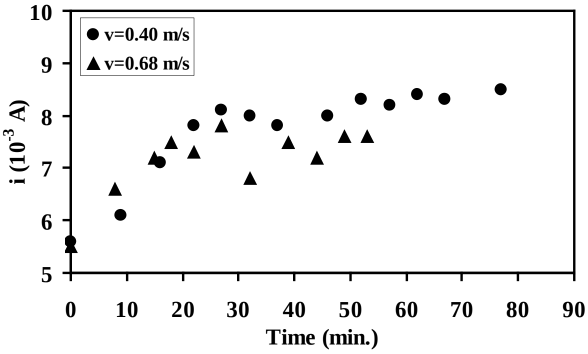

Figure 2 – Current behavior as a function of the operation time (v = 0.4 m/s and v = 0.68 m/s, D = 0.5x10^{-3} m and voltage of 27 kV).

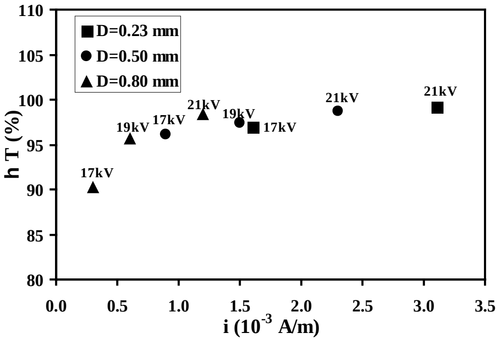

Figure 3 – Experimental current and overall efficiency results for active electrodes with different diameters (D). Voltages of 17, 19 and 21 kV; v = 0.40 m/s.

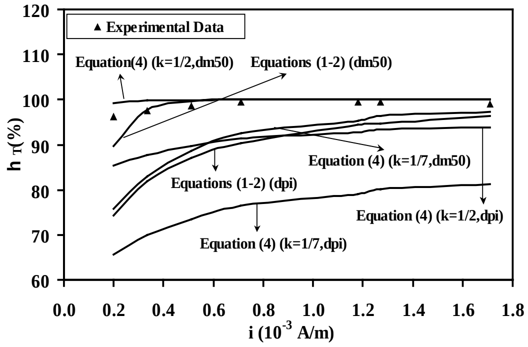

Figure 4 – Comparison of Equations (1-2) and (4) for different experimental situations and same velocity (v = 0.4 m/s).

Figure 1 shows that Equation (3), proposed by Cooperman[2], suitably describes the experimental current-voltage (I-V) curve. The equipment displayed a typical electric behavior, which was essential to guarantee the project reliability.

An electric current unstability as a function of time was observed when high voltages (25-27 kV) were applied to the system, as shown in Figure 2. Such a behavior and also the presence of sparkles are, according to White[4], typical of reverse corona that can take place on the electrode surface when this is coated with particles of high resistivity.

It can be seen in Figure 3 that geometrical parameters, such as the electrode diameter, had a decisive influence on the collection efficiency. For a same applied voltage, a tendency of decrease in the collection efficiency was observed for the largest electrode diameter (0.8x10^{-3} m).

Experiments at different air velocities (0.40 and 0.68 m/s) showed that a little increase in this parameter was responsible for a decrease in the collection efficiency, as predicted by Equations (1-2) and (4), which state an inversely proportional dependence of air velocity on the fractionary or global efficiency.

A comparison of Equations (1-2) and (4) to predict the experimental data of global efficiency is shown in Figure 4. Evaluation of global efficiency by Equations (1-2) is based on the sum of all fractionary efficiencies, which are individually calculated. Equation (4), on the other hand, predicts the global efficiency only based on the mean particle diameter (dm_{50}). In this work, it was observed that the predictability of Equations (1-2) and (4) was improved when the mean particle diameter (dm_{50}) was applied to both models. The parameter k, in Equation (4), was experimentally found to be 1/2, which is significantly different from the value 1/7 suggested by Zhao and Pfeffer[3]). Despite the good results observed in this work, Equations (1-2) and (4) may lead to wrong conclusions if they are applied as originally proposed in the literature. This can be explained considering that these are semi-empirical equations, which markedly depend on the equipment, dust and air features.

CONCLUSIONS

Based on the experimental results discussed in this work, the following conclusions were obtained:

- The projected equipment presented a suitable electric behavior, which was confirmed through the good fit of Cooperman´s equation to the experimental data. Unstability effects, such as the reverse corona, were only observed at high voltages (25 – 27 kV).
- The increase in the fluid velocity and in the active electrode diameter caused a decrease in the particle collection efficiency.
- Equations found in the literature were not reliable as originally proposed. Predictability was only improved when the mean particle diameter (dm_{50}) was applied and the value of the empirical constant k was experimentally determined.
- The applied current has a decisive influence on the project of a plate-type electrostatic precipitators. The efficiency improves with the increase in the current, but the suitable current value must be found taking into account the dust material properties, operational conditions and geometrical factors in order to optimize the equipment performance.

ACKNOWLEDGEMENTS

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