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UNIVERSAL RELATIONSHIP BETWEEN COLLECTION EFFICIENCY AND THE CORONA POWER OF THE ELECTROSTATIC PRECIPITATOR

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ABSTRACT

The basic principles of aerosol and particle collection using the electrostatic precipitation process are well understood as the result of extensive laboratory and field testing carried out over almost a century. Thanks to these tests the phenomena of ionization by corona discharge, particle charging and collection, the influence of gas velocity distribution and gas flow turbulence, and so on, are now reasonably clear. The numerical prediction of the main design parameters of the ESP is less advanced due to the very complex flow phenomena which are the result of the interaction between a high-strength electric field, a turbulent gas flow field, and the motion of particulates. Therefore, to date the widely used ESP design approach is based on the systematic accumulation of performance data from existing devices. On the basis of these performance data one can evaluate the collection efficiency, electrical power and main design parameters of new ESP installations. Designs based on existing devices require experience, talent and engineering intuition. The importance of these qualities cannot be denied, nevertheless the design of an effective and optimal industrial ESP has to be based on basic principles and fundamental universal relationships that are still missing.

In this paper we will discuss one of such theoretically derived approaches which describes the relationship between collection efficiency and the corona power of the Electrostatic Precipitator.

INTRODUCTION

The use of electrostatic forces to remove dust from air by special devices, so-called electrostatic precipitators (ESP) has been known for many years as one of the most efficient technologies. The advantage of electrostatic precipitation is that energy is applied directly the particles to be charged and collected, rather than to the gas stream, such as happens in cyclones and scrubbers. The energy to accelerate the gas and particles through a cyclone or scrubber is considerably higher than is required for electrostatic separation.

Removal efficiency of the particulates in an electrostatic precipitator is directly proportional to the electric power which is supplied to the corona electrodes to create effective ionization in the precipitation zone.

The electrical power consumption determines mainly the operational cost of the gas cleaning. Because the initial and desired particle loading in the industrial air are known, the collection efficiency of the ESP to be designed is therefore known at the first stage of designing. Hence, the relationship between collection efficiency and corona power of the ESP allows an estimation to be made of the operational cost of the ESP at the first stage of the design.
In the sixties of the last century Harry J. White [1] obtained an analytical relationship between precipitator particle loss *p* (penetration) and corona power:

$$p = \exp\left(-K\frac{P_c}{Q}\right) \qquad (1)$$

where

P_c is the corona power in watts

Q is the gas flow rate in cubic feet per second

and $K = 6.5$ is a parameter

H.J. White proves this relationship on the basis of performance data for a group of nine representative fly ash collectors installed in different plants of the United States, ranging from the Midwest to the Eastern and New England areas.

It should be noted that the parameter K in Equation (1) is dimensional, because the ratio P_c/Q is dimensional. The numerical value of the parameter K is obtained on the basis of performance data of very old ESP's and has to be proved useful for modern ESP designs developed more than half a century later.

In order to develop a new relationship between ESP collection efficiency and the corona power we will discuss in this paper a new concept based on the theory of dimensional analysis and on a large number of laboratory tests [2, 3]. This concept has allowed us to obtain a universal relationship between collection efficiency and a new ESP nondimensional number, based on corona power, which satisfies the conditions of similarity.

APPLICATION OF THE THEORY OF SIMILARITY TO THE ESP PERFORMANCE

According to the theory of dimensional analysis and similarity we will describe the ESP performance using the following most important dimensional variables:

1. Electrical power supplied to the corona electrodes of length unit $P_c\left(\frac{\text{kg}\cdot\text{m}^2}{s^3}\right)$ $\left[L^2MT^{-3}\right]$
2. Gas velocity $U\left(\frac{m}{s}\right)$ $\left[LT^{-1}\right]$
3. Gas viscosity $m\left(\frac{kg}{m\cdot s}\right)$ $\left[ML^{-1}T^{-1}\right]$
4. Cross-sectional dimension of the collector tube $a\ (m)$ $[L]$
5. Distance from the collecting wall to the sharp edge of the corona electrode $d(m)$ $[L]$

where

L is the length scale
T is the time scale
M is the mass scale

which can be called the primary or fundamental dimensions.
From these five dimensional variables we selected the following three variables with independent dimensions: power, gas velocity and side size.

According to the Pi Theorem using five dimensional variables and three primary dimensions, we obtain two nondimensional parameters, so called similarity numbers that can be used to describe the ESP performance:

$$N_p = \frac{P_c}{mU^2a} \quad (2)$$

$$\bar{a} = \frac{a}{d} \quad (3)$$

On the basis of the law of similarity we can affirm that the collection efficiency for two ESP's with constant length and with different corona power, gas velocity, cross-sectional dimension of the collection tube, etc., is equal to:

$$h_1 = h_2 \quad (4)$$

when

$$\left(\frac{P_c}{maU^2}\right)_1 = \left(\frac{P_c}{maU^2}\right)_2 \quad (5)$$

and

$$\left(\frac{a}{d}\right)_1 = \left(\frac{a}{d}\right)_2 \quad (6)$$

To verify the importance of these similarity numbers for ESP performance we use the experimental data obtained in Beltran's ESP test laboratory, varying, among others, the corona power, gas velocity, shape of tube cross section (round, square and hexagonal), cross-sectional dimension of the tube, the distance from the collecting wall to the sharp edge of the corona electrodes and the number of energization edges. The tube length was l = 122 cm (4 feet).

As a result we obtained the universal relationship between collection efficiency h and corona power similarity number N_p at constant numbers of $\overline{a} = a/d$ in the range from $\overline{a}$ = 2.3 to $\overline{a}$ =2.7.

A further useful correlation is derived by plotting ESP collection efficiency data versus combined similarity number $N_p \left(\frac{a}{d}\right)^{10}$.

In Figure 1 the experimental data of penetration values p% = 100-h% in percentages have been plotted against $\frac{P_c}{maU^2}\left(\frac{a}{d}\right)^{10}$ at constant length of the tube l = 122 cm.

It can be seen that all the experimental data are in very good correlation with the similarity number obtained on the basis of the theory of dimensional analysis and similarity.

The obtained unique relationship can be described by the following mathematical expressions:

$$5 < p\% \le 100 : \log p\% = 2 - \exp\left(0.94 \log\left[\frac{P_c}{maU^2}\left(\frac{a}{d}\right)^{10}\right] - 9.86\right) \quad (7)$$

$$p \le 5\% : \log p\% = 19 - 1.7 \log\left[\frac{P_c}{maU^2}\left(\frac{a}{d}\right)^{10}\right] \quad (8)$$

CONCLUSION

Numerous tests with laboratory ESP were performed, varying the corona power, gas velocity, shape of tube cross section (round, square and hexagonal), cross-sectional dimension, the distance from the collecting wall to the sharp edge of the corona electrodes and the number of energization edges.

On the basis of these experimental data and the theory of dimensional analysis and similarity, a universal relationship between collection efficiency and the corona power of the ESP was obtained. This analytical formula allows an estimation to be made of the operational cost of the ESP by given cleaning efficiency at the first stage of the design.

REFERENCES

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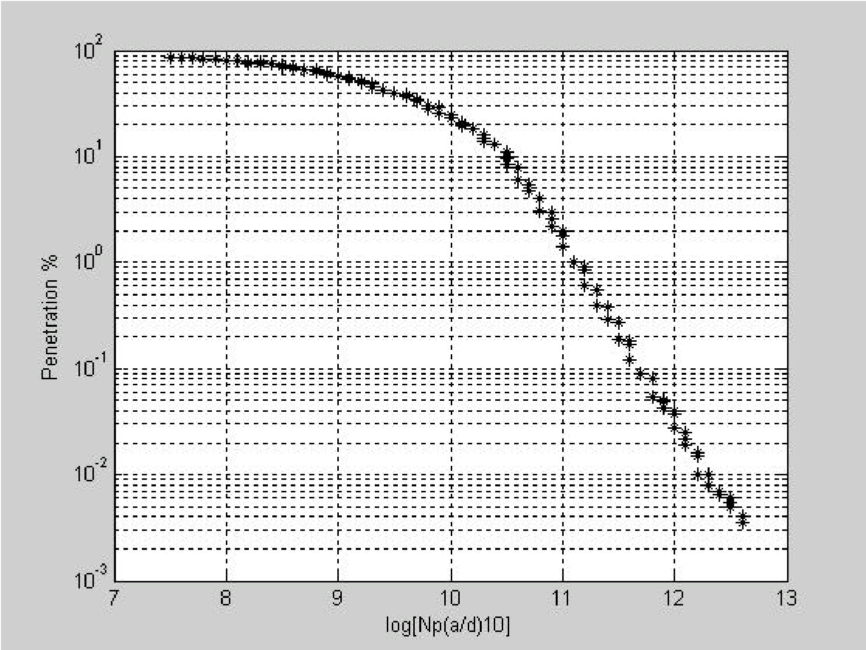

Figure 1. Particle penetration *p*% versus the ESP similarity number $\frac{Pc}{maU^2}\left(\frac{a}{d}\right)^{10}$.