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The collection efficiency of ESP model - Comparison of experimental results and calculations using Deutsch model

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ABSTRACT

In spite of considerable progress in the field of numerical techniques, the models based on simplified equations are still in use in practice. In particular, the Deutsch model is often used for the description of transport and separation of dust particles in EHD–field inside electrostatic precipitator (ESP). The aim of the research presented in this paper was to compare the value of collection efficiency determined experimentally and calculated using the Deutsch model. Besides, an attempt to model the phenomena of transport of dust particles in laboratory ESP using the Deutsch model was undertaken. The rigid discharge electrode in the form of spiked pipe was used in these experiments. Overall and fractional collection efficiencies were determined for two kinds of fly ashes of different particle size distributions. The overall collection efficiency was determined experimentally and compared with the results obtained from Deutsch formula. The results have shown that the collection efficiency determined using two methods: experimental and calculated by the Deutsch model were consistent.

1. Introduction

A horizontal electrostatic precipitator (ESP) is a device which is most often used to precipitate flue gas particles in the energy sector. It consists of a chamber together with grounded collecting electrodes (CE) (arranged in parallel) forming so-called paths through which the dusty gas flows. In the midplane of these paths there are placed the discharge (corona) electrodes (DE) in the form of wires, steel strips or tubes fitted with blades or spikes. Discharge electrodes are power-supplied from a DC source with negative polarity; the supply voltage ranges from 30 to 100 kV. Electrostatic forces on fly ash particles drive the particles towards collection electrodes that provide high total collection efficiency, and the dust concentration in flue gases can be as low as 2–5 mg/m^3 at the outlet of ESP A very low pressure drop of gas flowing through such an electrostatic precipitator, at a level of 50–300 Pa lets to precipitate very large volumes of gas (even up to several millions m^3/h), also at high temperatures [1]. The collection efficiency is a basic parameter taken into account when selecting an electrostatic precipitator and considering its design for specific industrial applications.

Different models are used to describe the gas flow, the electric field and the motion (transport) of the particles inside electrostatic precipitator. Due to the fact that the analysed phenomena are complex and physical variables are interrelated, currently there is no complete model of electrostatic precipitator available. In spite of considerable progress made in the field of numerical techniques it is still necessary to make some simplifications to run modelling in a reasonably short period of time [2]. It should be noted that calculations conducted by this way often provide the trajectories of particles [3–5] or streamlines of the gas flow [6]. In order to estimate theoretically a given electrostatic precipitator in terms of its performances, models of varying level of complexity are used. When a field of gas velocity is taken into consideration the models can be divided into laminar and turbulent ones. Based on a degree of dust particle mixing those models can be divided into diffusion-made or solid particle trajectory-based. Starting from the pioneering works of Deutsch [7], Matts [8] and White [9] significant progress in the modelling of precipitation process in electrostatic precipitators has been made, in particular due to the development of numerical techniques. However, designers and manufacturers of electrostatic precipitators still use the models based on simplified one-dimensional equations. The Deutsch model can be an example of that approach. Those models, despite many simplifying assumptions they adopt, allow determining the direction in changes of collection efficiency for a given electrostatic precipitator at its specific operating conditions [8].

The goal of this paper is to give an answer the question whether the results of calculations of the collection efficiency according to the Deutsch model ensure compatibility with the experimental results.

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2. Deutsch model

The Deutsch model developed at the beginning of the 20th century still allows determining the collection efficiency of electrostatic precipitators and it still is used in order to analyze their operational and design properties. A series of simplifying assumptions are applied in the Deutsch model in order to describe the transport process of solid particles in an actual electrostatic precipitator [10].

According to the Deutsch theory the collection efficiency $\eta_D(d_p)$ for a particle of size d_p can be determined using the following formula [10]:

$$\eta_D(d_p) = 1 - e^{-w(d_p)\frac{l}{b \cdot u}} = 1 - e^{-w(d_p)\frac{A}{Q}} \tag{1}$$

where:

$w(d_p)$ – migration velocity of a dust particle of diameter d_p,
l - length of the collection electrode generating electric field,
b - distance between the electrodes with different polarity,
u - velocity of gas,
A – area of two adjacent collecting electrodes, $A = 2 \cdot h \cdot l$,
Q – volume flow rate of the gas, $Q = 2 \cdot h \cdot b \cdot u$,
h – height of the collection electrodes.

The overall collection efficiency η_{TD} based on the Deutsch model is determined as the sum of fractional collection efficiencies in all size intervals for a given particle size distribution; it is described by the following equation:

$$\eta_{TD} = \sum_{d_{p\min}}^{d_{p\max}} \Delta R_{iz}(d_p) \cdot \eta(d_p) \tag{2}$$

where:

$\Delta R_{iz}(d_p)$ - is the percentage of dust particles in the i-th interval comprising particle of diameter d_p.

Furthermore, there were also attempts to model some phenomena which occur during the transport of fly ash in the laboratory electrostatic precipitator using the Deutsch model.

In the following the calculations obtained from the Deutsch model will be compared with experimental results obtained from the measurements of collection efficiency at a laboratory scale physical model of electrostatic precipitator.

Furthermore, modelling of some other phenomena occurring during the transport of fly ash particles in the laboratory electrostatic precipitator using the Deutsch model was also attempted.

3. Experimental

3.1. Laboratory scale ESP

The tests were conducted in laboratory conditions on a model of electrostatic precipitator (Fig. 1) which consisted of a chamber of length of l_{ch} = 2280 mm, height of h_{ch} = 580 mm, and a pitch between electrodes of $2b$ = 400 mm. The electrodes of ESP model were supplied with smoothed constant voltage of negative polarity by a high-voltage power supply (0–100 kV). The velocity of gas flow was u = 0.8 m/s. A rigid discharge electrode: a tube with nails was applied. Tests on the total and fractional collection efficiency were conducted for two different fly ashes characterised by significantly different particle size distribution.

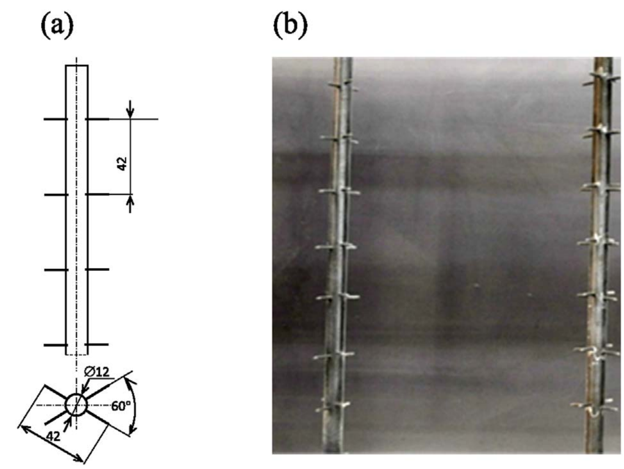

Fig. 2. Discharge electrode: (a) geometrical dimensions, (b) photograph.

The scheme of discharge electrode used in these tests is shown in Fig. 2a and its photograph in Fig. 2b.

3.2. Measurements of collection efficiency of ESP model

Measurements of collection efficiency were conducted for the air flow velocity of 0.8 m/s, at a temperature of approx. 293 K and relative humidity of φ = 45%.

The concentration of fly ash particles at the electrostatic precipitator outlet was measured by means of gravimetric dust meter sampling the gas conveying the particles with isokinetic probe. The sampled fly ash was collected on a highly-efficient absorbent paper at a measuring filter. Fly ash was injected to the channel by a feeder with mass concentration of 0.6 g/m^3.

The overall collection efficiency $\eta_{T\ exp}$ was estimated by measuring fly ash mass sampled at the inlet and outlet of electrostatic precipitator, and calculated according to the following formula:

$$\eta_{T\ \exp} = 1 - \frac{\dot{m}_{out}}{\dot{m}_{in}} \tag{3}$$

where:

$\dot{m}_{in}$ – mass flow rate at the electrostatic precipitator inlet,

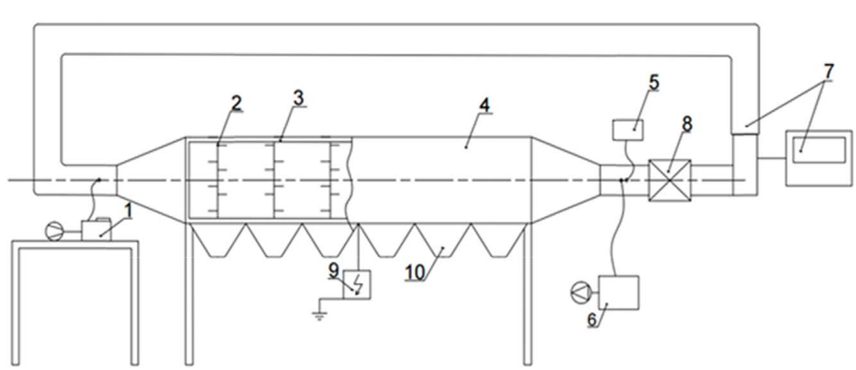

Fig. 1. Diagram of the testing stand: 1 - dust feeder, 2 - emission electrode, 3 - collecting electrode, 4 - model chamber, 5 - flow-rate measurement unit, 6 - dust sampling system, 7 - exhaust fan with RPM adjustment, 8 - final filter, 9 - high-voltage power supply, 10 – dust hopper.