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Two-stage vs. two-field electrostatic precipitator

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ABSTRACT

The paper presents comparison of the collection efficiency of semi-industrial, two-field electrostatic precipitator and two-stage electrostatic precipitator comprising an electrostatic agglomerator. The two-stage electrostatic precipitator was converted from two-field electrostatic precipitator, in which the first field was replaced by unipolar electrostatic agglomerator. The investigated electrostatic precipitator was of parallel-plate type, with spiked-wire discharge electrode between sigma type collection electrodes. In the unipolar agglomerator used in this system, the particles were charged by ion current and forced to oscillate by alternating electric field. The oscillatory motion of particles perpendicular to the gas flow causes the collision between particles and deposition of small particles onto the larger ones. The agglomerated particles were next collected by one-field electrostatic precipitator.

The collection efficiency of two-stage electrostatic precipitator for PM2.5 and PM1 particles was 99.1% and 98.8%, compared to 99% and 98.1% of two-field electrostatic precipitator, respectively. The most important result of this research is that the replacement of the first field of electrostatic precipitator by an electrostatic agglomerator does not change the overall collection efficiency of the system but the power consumption of electrostatic agglomerator can be 10–50 times lower than by the replaced field of electrostatic precipitator.

1. Introduction

The collection efficiency of electrostatic precipitators for PM2.5 particles from flue gases produced by power plants steeply decreases with decreasing particle size, in some cases below 50%, at 200–500 nm. The interest in removal of PM2.5 and PM1 particles is caused by harmful effects of those particles due to high heavy metals percentage in PM2.5 particles, higher than in large particles (> 2.5 μm) [2,4,6,7,24,27,28]. Due to low collection efficiency of electrostatic precipitators for PM2.5 particles, most of those particles are exhausted to the atmosphere.

In order to solve the problem of low collection efficiency of electrostatic precipitators with the removal of PM2.5 particles various types of electrostatic agglomerators have been designed and tested in many laboratories. Agglomerator is a device which forces fly ash particles to a collision in order to form a permanent connection between them. The size of resultant particle, called agglomerate, is larger than the individual particles entering agglomerator, and can be removed from flue gas with higher collection efficiency. With respect to physical principle, two main types of electrostatic agglomerators can be distinguished:

1. *Bipolar agglomerator*. In this type of device, the gas flow is split into two equal streams, which flow through two parallel prechargers charging the particles to opposite polarities. Next, those flows are mixed to allow agglomeration of particles with the assistance of DC or AC electric fields [3,10,13–17,20,21,25]. In another version, flowing particles can be charged in AC corona discharge, forming a train of clouds of oppositely charged particles, in which particles are agglomerated due to Coulomb attraction [11,31,32].
2. *Unipolar agglomerator*. This type of device charges the particles to only one polarity, but in order to promote the agglomeration process, the particles are subjected to oscillatory motion and to their collision by AC electric field. Due to differences in mobility of large and small particles, the larger, highly charged particles oscillate with higher amplitude than the smaller ones, whose charge is lower. The difference in particles' velocity causes the scavenging of small particles by the large ones. This process is called the kinematic agglomeration [9–12,16,17,26,29].

It was shown in many papers that small particles of similar size can form a dendrite or chain-like structures, which can collapse to a globule. This type of agglomerate is characteristic of bipolar agglomerator

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and the process is called particle-particle agglomeration. When the size distribution of particles is wide or bimodal, comprising also large particles (5–20 μm), the smaller particles (< 1 μm) are preferentially deposited onto those larger particles. The larger particles are called collectors, and the process is called particle-collector agglomeration. The particle-collector agglomeration is effective in unipolar agglomerators [5,11,18,19,22,23,29,30]. In the following only a unipolar agglomerator will be tested in order to investigate the effect of agglomeration on the collection efficiency of two-stage electrostatic precipitator.

In this paper, the collection efficiency of two-field spiked wire-plate electrostatic precipitator has been compared with the collection efficiency of two-stage electrostatic precipitator, in which the first field was replaced by unipolar electrostatic agglomerator while the second field remained the same. The agglomerator used in these investigations charges fly ash particles by ion current in alternating electric field, and simultaneously agglomerates those particles in this field due to oscillatory motion of particles [1,8,11,29]. All experiments have been carried out on experimental stand at Gdynia Maritime University (Poland), at the Faculty of Mechanics. To the best of our knowledge such comparative studies have hitherto not been presented in the literature.

2. Experimental

Scheme of experimental set-up is shown in Fig. 1. Fig. 1a presents the two-field electrostatic precipitator (ESP1 and ESP2), and Fig. 1b the one-field electrostatic precipitator (ESP) and electrostatic agglomerator (AGGL), which together form the two-stage electrostatic precipitator. The precipitators and agglomerator were mounted in a rectangular channel of cross section of 112 cm (width) × 62 cm (height), and of total length of 6.4 m, made of construction steel. A gas heater of a power of 44 kW was mounted at the inlet of the channel.

Fly ash particles collected from a hopper of third field of electrostatic precipitator from a coal-fired boiler in a power plant Opole in Poland have been used as test particles in the experiments.

On the upper wall of the channel, next the gas heater, a fly ash feeder, dispersing fly ash particles with mass flow rate of 1.72 kg/h, was installed. The length of each field of electrostatic precipitator and the stage of agglomerator was about 2 m. A confusor at the outlet of the channel ended with the pipeline of 5″ in diameter has connected the channel to a gas flow meter and a suction fan. The gas flow rate was measured with Prowirl F 200 (Endress & Hauser), mounted at the 5″ pipeline. The temperature at the inlet and the outlet of the system was measured with PT100 thermometers (Endress & Hauser). The pressure in the channel was measured with pressure transducer Cerabar T PMC131 (Endress & Hauser). The gas temperature at the channel inlet was 100 ± 2° C, and gas velocity 0.5 m/s.

The measurements have been carried out for inlet fly-ash particles mass concentration of 1755 mg/Nm^3. Before measurements, the fly ash was dried in an oven at a temperature of about 150 °C for 1.5 h.

The particles concentration and their size distribution were measured with laser aerosol particle sizer LAP 322 (TOPAS) in 64 size classes, in the range from 0.25 to 10 μm. The particles were sampled with isokinetic probe located at the channel outlet, in the centre of the cross section of the channel, behind electrostatic precipitator. Two dilution systems VKL 10 (PALAS) connected in series, of total dilution ratio of 1:100 were used in order to reduce the particle concentration to the measurement range of aerosol particle sizer LAP 322. The gas with fly ash was sampled at a flow rate of 3 l/min. The time of measurement for each ON/OFF combination of all stages was 5 min, and each measurement series was repeated 3 times. The results presented in the following figures are the average values from those series. After each series the electrodes were washed up with water, dried and the channel was heated again to 100 °C before measurements. The residence time of particles within the agglomerator was about 2.5 s (by gas velocity of 0.5 m/s) that allowed charging the particles leaving the agglomerator close to the Pauthenier limit.

Scheme of electrode arrangement of two-field electrostatic precipitator and electrostatic agglomerator + precipitator are presented in

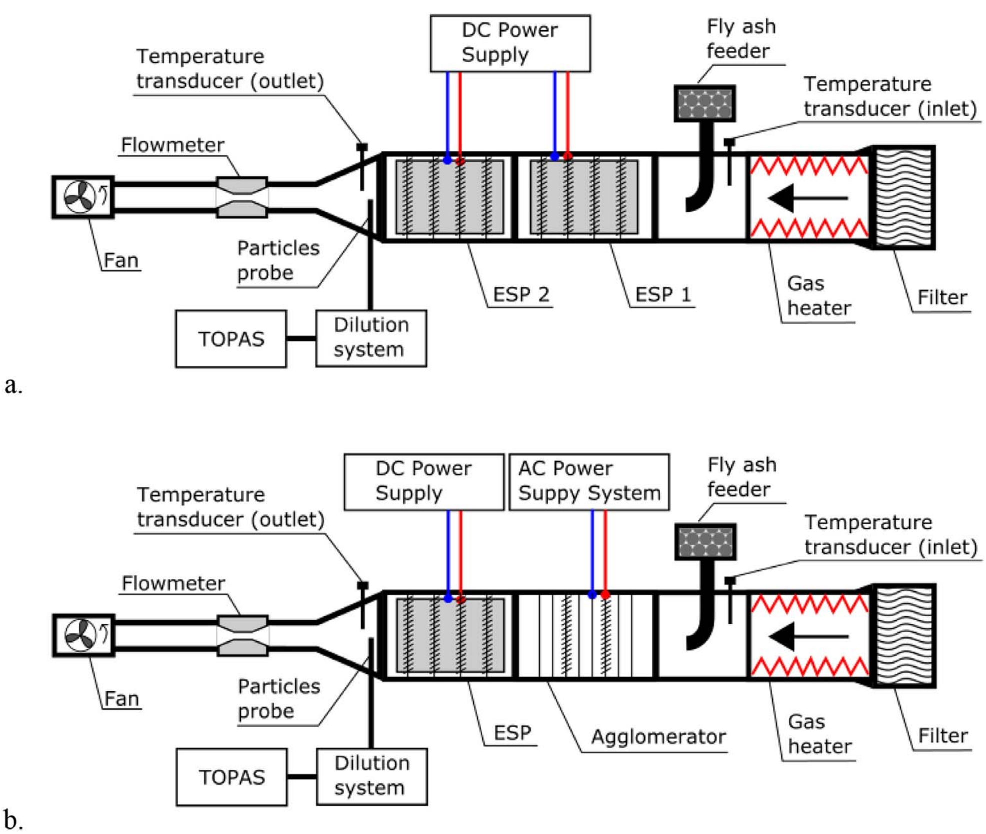

Fig. 1. Scheme of experimental setup. (a) two-field electrostatic precipitator; (b) two-stage electrostatic precipitator comprising electrostatic agglomerator and one-field electrostatic precipitator.