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Enhancement of collection efficiency for fly ash particles (PM2.5) by unipolar agglomerator in two-stage electrostatic precipitator

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ABSTRACT

Semi industrial-scale, two-stage electrostatic precipitation system comprised of unipolar electrostatic agglomerator and electrostatic precipitator was investigated in this paper. In this type of agglomerator, the process of particle charging and their agglomeration is accomplished in the same device. The particles are charged by ion current in alternating electric field, and agglomerated due to their oscillatory motion in this field, perpendicular to the gas flow. The charged and agglomerated particles are collected in the next stage, which is a conventional electrostatic precipitator with spiked wire discharge electrodes and collection electrodes of the sigma type. Collection efficiency of this system was measured for different gas temperatures, different fly ash concentrations and for various magnitudes of AC voltage applied to the agglomerator.

Two-stage electrostatic precipitator allows obtaining higher fractional collection efficiency for PM1 and PM2.5 particles than a one-stage electrostatic precipitator. In this type of two-stage electrostatic precipitator with an agglomerator, the number collection efficiency for fly ash particles in PM10, PM2.5 and PM1 size ranges was about 96%, 96% and 94%, respectively, and mass collection efficiency in same size ranges was 98%, 97% and 95%, respectively.

1. Introduction

Efficient removal of PM2.5 particles from flue gases produced by power plants is still the major technological challenge in environment protection. The concentration of heavy metals in PM2.5 particles emitted by coal-fired power boilers or municipal incinerators is much greater than in large particles (>2.5 μm) Sandelin and Backman [30], Pavageau et al. [29], Giere et al. [8], Hower and Robertson [10], Meawad et al. [25], Jaworek et al. [11], Binnemans et al. [4]. Due to low collection efficiency of conventional gas cleaning devices for PM2.5 particles, a large fraction of compounds of those elements is exhausted to the atmosphere. Most of those elements are dangerous to human health and environment and their removal from exhaust gases became a real concern in recent years.

Currently, there are few technical solutions which enable efficient cleaning of flue gases form solid particles. Electrostatic precipitators have high collection efficiency for large particles (>2.5 μm) and nanoparticles (<100 nm), but in the size range from 100 nm to 1 μm the collection efficiency decreases, reaching the minimum at about 200–500 nm, at which it is significantly lower than for particles outside this range. Bag filters are more effective than electrostatic precipitators in this size range, but due to small size of pores in bag filter, they have a high pressure drop, and large filtration area is required for keeping the pressure drop as low as possible that is associated with high investment costs. Submicron fly ash particles can also cause clogging the pores in bag, leading to their premature wear. High collection efficiency in PM2.5 size range can be obtained in electrostatic scrubbers, but because of water used as the cleaning agent, scrubbers require additional equipment for the treatment of slurry resulting from that process.

One of the solutions that can address the problem with the removal of PM2.5 particle is the process of their electrostatic agglomeration Jaworek et al. [14]. Agglomeration is a process of permanent connection of two or more particles into larger agglomerate, which can be removed from the gas by conventional methods. Using agglomerator, larger particles can easier be precipitated by a conventional electrostatic precipitator, and the

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collection efficiency of the whole system can be significantly increased. Various variants of agglomerators have been investigated in the literature, but they can be categorized into two classes:

1. *Bipolar agglomerators* in which particles charged to both polarities participate in the agglomeration process. Usually, the stream of particles is divided into two equal streams, which are electrically charged to opposite polarities, in two separate prechargers. In the next stage, those particles are mixed and agglomerated in DC or AC electric field due to Coulomb attraction between them Mitchner and Self [26], Kanazawa et al. [18], Kildeso et al. [19], Laitinen et al. [22,23], Kim et al. [20], Ji et al. [16,17], Chang et al. [7]. In another version, particles are charged to opposite polarities in AC corona discharge Won and Castle [32], Zukeran et al. [35]. Clouds of oppositely charged particles flowing one after another attract and the particles can collide and agglomerate.
2. *Unipolar agglomerators* in which particles charged to only one polarity are agglomerated. In such devices, all particles are electrically charged by ions of the same sign, and next the particles are subjected to oscillatory motion by AC electric field, in which the particles collide due to difference in their mobility, that can lead to their agglomeration Kildeso et al. [19], Kim et al. [20], Mizuno [27], Jaworek et al. [13,15]. In another version of unipolar agglomerators, the particles of unipolar charge are forced to collision by focusing their trajectories by a quadrupole electrode arrangement supplied with AC voltage Hautanen et al. [9], Chang et al. [6,5], Nakajima and Sato [28].

In this paper, the collection efficiency of semi-industrial scale two-stage electrostatic precipitator comprised of unipolar electrostatic agglomerator and spiked wire-plate electrostatic precipitator has been determined for PM2.5 particles. Unlike previous studies presented in the literature, the agglomerator used in these investigations simultaneously charges electrically the particles by ion current in alternating electric field, and agglomerates those particles due to their oscillatory motion in this field Jaworek and Krupa [12], Adamiak et al. [1]. For this reason, in the following, the device will also be called electrostatic precharger/agglomerator. The agglomeration of particles occurs due to differences in mobility between larger and smaller particles that means, larger particles of higher oscillation amplitude collide with smaller ones that lead to their agglomeration. The device utilizing those processes was installed prior to electrostatic precipitator allowing increasing the collection efficiency of the whole system. All experiments have been carried out at Gdynia Maritime University (Poland), at Faculty of Mechanics.

2. Experimental

Scheme of experimental set-up is shown in Fig. 1 and a photograph of experimental stand in Fig. 2. The stand comprised of rectangular channel of cross section of 112 cm (width) × 62 cm (height) and total length of 6.4 m made of construction steel, housing the precharger/agglomerator (AGGL) and electrostatic precipitator (ESP). HEPA filter and two gas heaters of 22 kW each were placed at the inlet of the channel. Fly ash feeder providing fly ash particles was mounted at the upper wall of the channel, behind the heaters. The fly ash feeder provided the particles to the gas flow with mass flow rate of 0.86 or 1.72 kg/h. The precharger/agglomerator section and electrostatic precipitator section were about 2 m long each. The channel was ended with a confusor reducing its cross section dimensions to an outlet pipeline of 5″ in diameter. The gas flow rate was measured with Prowirl F 200 (Endress & Hauser), mounted at the 5″ pipeline, and behind this flow-meter an exhaust fan was placed. The temperature at the inlet and the outlet of the system was measured with PT100 thermometer (Endress & Hauser). The pressure in the channel was measured with pressure transducer Cerabar T PMC131 (Endress & Hauser).

The particle concentration and their fractional size distribution were measured by laser aerosol particle sizer LAP 322 (TOPAS) in 64 size classes, in the range from 0.24 to 10 μm. The particles were sampled with isokinetic probe located in the centre 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 particle concentration was measured at the outlet of two-stage electrostatic precipitator for the following conditions:

1. ESP OFF and agglomerator OFF (ALL OFF),
2. ESP ON and agglomerator ON,
3. ESP ON and agglomerator OFF,
4. ESP OFF and agglomerator ON,
5. ESP OFF and agglomerator OFF (ALL OFF).

The inlet gas temperature in the channel was set to 60 °C or 100 °C, and gas velocity to 0.5 m/s or 0.8 m/s. The measurements have been conducted for two fly-ash particles mass concentrations, 748 mg/Nm^3 and 1496 mg/Nm^3 for 60 °C, and 878 mg/Nm^3 and 1755 mg/Nm^3 for temperature 100 °C at the inlet. Before measurements, fly ash was dried in an oven at a temperature of about 150 °C for 1.5 h. The supply voltage of agglomerator was changed from 14 kV to 26 kV, by 2 kV. The frequency of voltage applied to agglomerator was 50 Hz. The voltage applied to the discharge

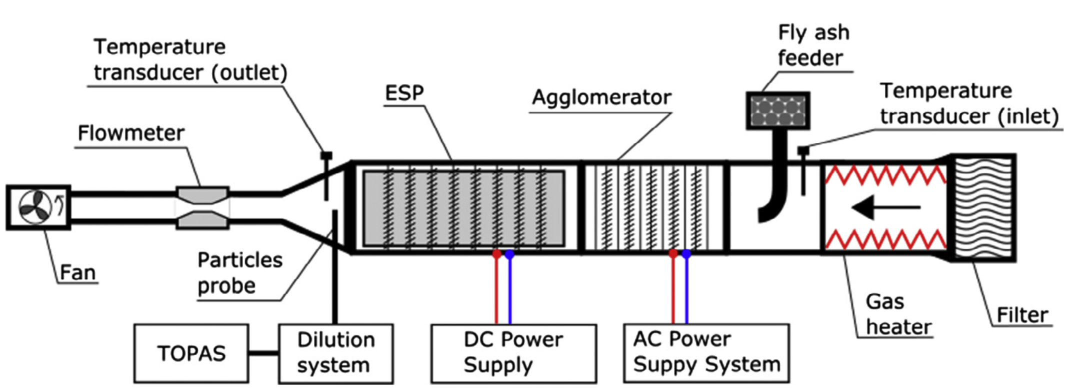

Fig. 1. Scheme of experimental setup.