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Novel wet electrostatic precipitator for collection of fine aerosol

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ABSTRACT

A novel wet electrostatic precipitator (WESP) is designed for effective control of fine aerosol from humid gases. It operates on the principle of unipolar particle charging in the corona discharge and particle precipitation under the field of their own space charge. The new precipitator is characterized by high gas velocity in the ionizing stage. Tests were carried out for gas with $(NH_4)_2SO_4$, HCl and $(NH_4)Cl$ aerosol at particle number concentration up to $5 \cdot 10^7$#/cm^3 and mass concentration 10–1000 mg/Nm^3. For test conditions one-field WESP ensures mass collection efficiency 90–97% and two-field electrostatic precipitator up to 99%.

1. Introduction

The submicrometer size range constitute a small fraction by weight of the total suspended particulate matter in typical particle emissions. But in spite of this, fine particles are considered potentially hazardous to health because of their probability of deposition in deeper parts of the respiratory tract [1].

In many industrial processes the removing of submicron particles from the effluent gases is quite a costly business [2–4]. In the case of humid gases or sticky particles, wet electrostatic precipitators (WESP) are effective used to control fine aerosol emissions [2,5]. But wet electrostatic precipitators suffer from clogging problems due to build up of sticky particles on the high voltage and collection electrodes leading to decrease of electrode gap, sparkover and loss of efficiency. WESPs also suffer with decreasing of collection efficiency when dealing with corona discharge suppression at high particle concentrations in the effluent gas.

A conventional electrostatic precipitator usually consists of a series of high voltage and corresponding collector electrodes. There are plate/wire, flat plate and tubular type electrostatic precipitators. The high voltage electrodes are normally wires. Particles are charged and subsequently separated from the gas stream under the influence of the electric field generated between the electrodes. In a single-stage electrostatic precipitator, the electric field, used to generate the corona discharge is also used to attract and hence remove the charged particles. In a two-stage precipitator, charging and removal of particles occurs in separate electric fields [2]. In the so called space charge precipitators unipolar charged particles are precipitated due to the field of their own space charge [6,7]. The efficiency of electrostatic precipitators is usually at a minimum in the range of 0.1–0.5 micrometers [2]. The reason is the combined effect of two particle electrical charging mechanism, neither of which is highly effective in this particle size range [5,6]. The collection efficiency can be improved by enhancing the particle charging in the corona discharge field or by use of a high intensity high velocity ionisation stage [8]. Such an ionizing stage provides operating field strengths of 10–17 kV/cm compared to levels of 3–6 kV/cm in a conventional electrostatic precipitator and operates at the gas velocities of 7–10 times higher than conventional electrostatic electrode configurations.

In the current paper, the results of the design and tests of the novel wet electrostatic precipitator are presented. The scope of investigations was the development of a cost-effective flue gas cleaning technology for fine particles.

2. Design of a novel wet electrostatic precipitator

A novel wet electrostatic precipitator (**C**orona **Aero**so**l** **A**bscheider – **CAROLA**®) is developed in the Forschungszentrum Karlsruhe [9,10]. The high velocity ionizing section of the

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precipitator consists of a grounded plate with orifices in which short tube-electrodes are installed. Star-shaped high voltage electrodes are installed in the tube-electrodes. The grounded field-free collection section consists of a tower packing elements installed downstream the ionizing section without any plenum section. The ionizing and collection sections are separated by a grounded mesh at the exit of the tube-electrodes.

A particle laden gas flows through the multiple of the tube-electrodes. The gas velocity in the electrode gap is ~20 m/s. Particles are charged in a DC negative corona discharge. In the input part of the tower packing collector, the collection of charged particles takes place under the influence of gas turbulence and due to space charge effects. Inside the tower packing column, where the velocity of the gas flow is mainly 2 m/s, the collection of charged aerosol takes place under the influence of electrostatic forces of aerosol space charge and due to image forces of electrostatic interaction of charged particles with grounded surface of the collector elements. The clean gas is discharged into the atmosphere or it is further used in the technological process [11].

Collected particles are removed from the collector by the liquid which condenses on the tower packing elements and flows downwards flooding them. The tower packing can be also periodically cleaned by flashing with water from the spraying system installed downstream the collector.

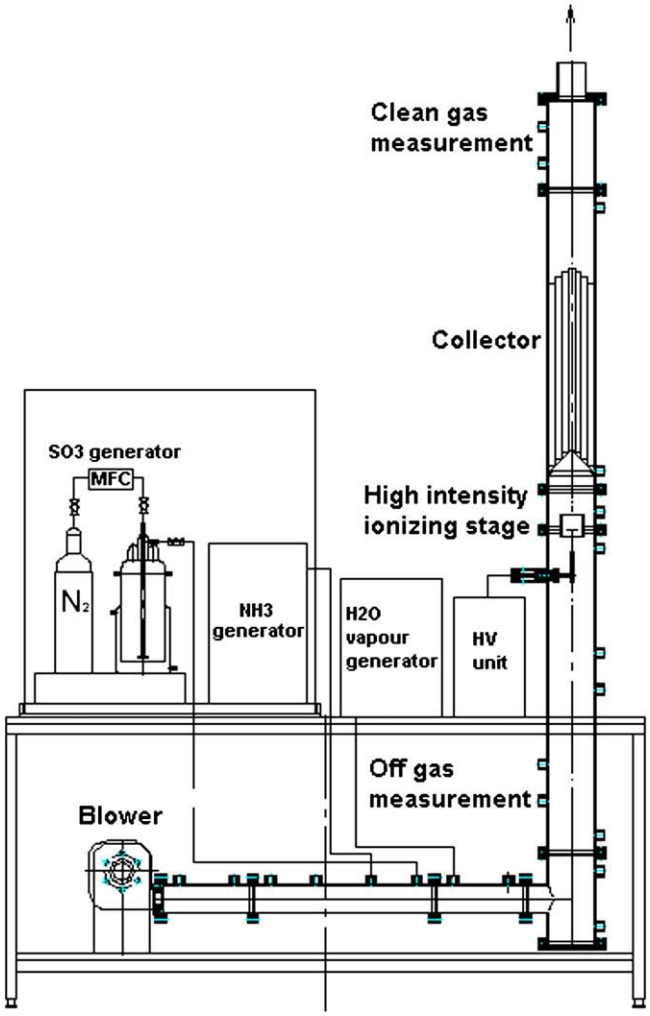

Fig. 1. Laboratory set-up.

Table 1
Results of experiments with one-field laboratory wet electrostatic precipitator, $(NH_4)_2SO_4$ aerosol.

Parameter	Test									
	1	2	3	4	5	6	7	8	9	10
Voltage, kV	11.5	14	11.7	14.2	11.8	14.5	14.5	14.5	11.7	14.4
Corona current, mA	0.3	0.9	0.3	0.9	0.3	1.1	0.93	1.07	0.3	0.9
Particle mass concentration (off gas), mg/Nm^3	56	78	55	127	906	36	80	192	939	126
Particle mass concentration (clean gas), mg/Nm^3	19	17	17	11	18	0.4	4.5	1.2	17	9.6
Mass collection efficiency, %	67.2	77.7	69	91.1	98	99	94.4	99.4	98.2	92.4

3. Tests and results. Laboratory set-up

The laboratory set-up (Fig. 1) was used for investigations of the influence of the operation parameters on the efficiency of electrostatic precipitator. The laboratory one-stage WESP consists of a one to three grounded tube-electrodes with star-shaped high voltage (HV) electrodes. The number of the needles on the HV electrode was 3, 5, 7 and 18. The outer diameter of HV electrode was 18, 24 and 30 mm. The tube-electrode inner diameter was 48 mm and the width of the electric gap was 9, 12 and 15 mm for different HV electrode diameters. The flow rate through the precipitator varied from 60 m^3/h to 110 m^3/h. At the flow rate 80 m^3/h, the gas velocity in the electrode gap was ~18 m/s (electrode gap 9 mm). A collector with tower packing elements (Hiflow rings® with diameter 15 mm and 50 mm, Fa. RVT Process Equipment GmbH) was used for particle collection. The height of the collector was 400 mm and 800 mm. The gas velocity in the collection section was 1.5–2.2 m/s. Gas temperature was 34–40 °C depending of the operation conditions. Up to 5 kg/h of water vapour was introduced into the air flow to ensure water vapour saturation conditions [17,18]. The DC negative voltage U = 12–14 kV was applied and corona current I varied from 0.3 mA to 1.1 mA.

The results of the tests with of $(NH_4)_2SO_4$ aerosol (droplets with size < 1 μm) are presented in Table 1. Tests 1–4 were with and tests 5–10 were without plenum chamber between the ionizing and collection stages. In the tests 3–10 the particle charging zone was shielded by a metal mesh. Measurements 1–8 were with 800 mm height and tests 9 and 10 with 400 mm height tower packing column. The analysis of the results shows that the space charge in the plenum chamber decreases the mass collection efficiency of the WESP due to corona discharge suppression (tests 1 and 3). At high corona currents (tests 2 and 4), spark-over discharges also decrease the collection efficiency. At constant applied voltage, the increase of gas velocity in the ionizing section from 6 to 18 m/s increases the operation current by decrease of corona suppression in the charging zone from 70% to 20%.

The increase of gas velocity in the charging zone improves the stability of operation of the precipitator due to increase of the spark-over voltage from $U_{sp} \cong 13.5$ kV to $U_{sp} \cong 15$ kV.

At low level of corona suppression, with increase of particle mass concentration (results 6 and 8) the mass collection efficiency of the precipitator increases. The shielding of the charging zone by metal mesh, installed directly at the exit from the tube-electrode improves the mass collection efficiency of a one-field precipitator from 73–75% to 93–97%. For the same conditions, the mass collection efficiency of a two-field precipitator increases up to 99%. At strong space charge (tests 5 and 9, corona current 0.3 mA and tests 7 and 10, corona current 0.9 mA), there is only a minor difference between the mass collection efficiency for the precipitator with tower packing column 400 mm and 800 mm height. The minor influence had also the size of the tower packing elements.