Proceedings of the
International Conference on Mechanical Engineering 2005
(ICME2005) 28- 30 December 2005, Dhaka, Bangladesh

ICME05-AM-50

SIEVING ELECTROSTATIC PRECIPITATOR: AN INNOVATIVE DEVICE FOR POLLUTION CONTROL

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ABSTRACT

This paper describes the Sieving Electrostatic Precipitator (SEP) recently developed at Ohio University, USA. SEP qualifies for effective and economical cleansing of both large and ultra fine particulates of polluted gases. The SEP is a closely packed device with fine wire screens. The screens are set perpendicular to the direction of gas flow and charged with high voltage. This combined conventional sifting and electrostatic precipitation makes it possible to capture particulates efficiently with minimal pressure drop. Most recently, a number of experiments have been conducted both a bench-scale setup and in a laboratory pilot scale setting. All the results support the fact that SEP is capable of collecting flyash most effectively. The process also allows greater efficiency for removing ultra fine, submicron particulates. This high efficiency is primarily attributed to good charging of particles, to their agglomeration, and to the beneficial combination of different charging and particulate–capturing mechanisms.

Keywords: Electrostatic Precipitator, Sieving, Screen, Flyash, Fine Particulates

1. INTRODUCTION

Current Electrostatic Precipitators (ESP) cannot be used for efficient capture of small particles and cannot therefore meet the newest EPA PM2.5 and other regulations of the Clean Air Act Amendments. Capturing small particles however is of great importance. Small particles can float and accumulate in the atmosphere for long periods of time and be transported to long distances. Nanometer sized particles easily penetrate and deposit into people’s and animals’ lungs. Toxic vapors and heavy metals, as well as aerosols formed by such particulate and various gases (due to NOx and SOx gas-to-particle conversion) condense uniformly on the surface area of all particles in proportion to the surface area. Small particles have a much larger surface area per unit weight [1]. This problem can be solved by replacing or combining the existing under-performing precipitators with baghouse filters [2], [3]. However, these technologies are characterized by large pressure drops, complex and expensive baghouse/ESP structure, frequent cleaning, replacement and maintenance of bags, and so on.

Different kinds of agglomerators can also help in capturing fine particulates [4]-[7]. In such cases, the agglomerators are installed after conventional ESPs. These devices agglomerate small particles that escaped the conventional ESPs into bigger particles that can be captured more easily by another downstream precipitator. The literature suggests, however, that these agglomerators suffer from low efficiency, capturing only small portion of sub-micron particles, and also from high capital costs [7].

The SEP offers an inexpensive and efficient alternative to capture fine particulates as well as big particles from polluted gas.

2. DESCRIPTION OF SEP

Fig. 1 shows the SEP of its first embodiment, i.e. with all screens **1** charged at the same polarity, suitable for efficient and cost-effective collection of both large and super fine particulates. The screens are set apart at distance *d* as small as several millimeters and mounted in the electro conductive housing **2.** This housing is closed everywhere except at the bottom above the hopper **3**. The housing **2** is connected to the high voltage source **4** and mounted in the grounded ductwork **5**, from which it is insulated. The first charged screen can have sharp spikes **6,** which under high voltage produce corona in the electrical field established between this screen and the inlet **7** or grounded screen **8.** This field has a direction opposite of the gas flow carrying particulate **9** that needs to be captured. Screen openings typically range from 0.5 to 1.5 mm, with wire diameters of few hundred microns. The screen opening area is typically 35-40% or less of the total screen area.

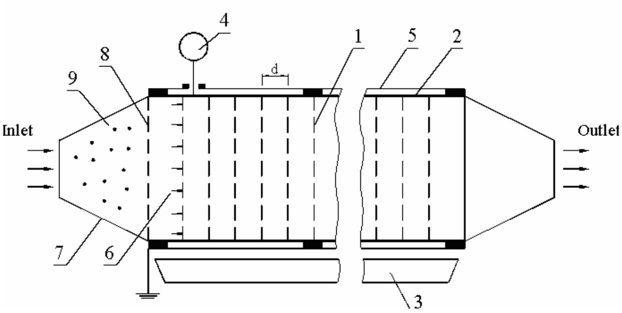

Fig 1. SEP with all screens having same polarity

Most of the incoming neutral particles **9** are captured at the grounded screen **8** or especially between that screen and the front charged screen **6.** As the particles approach the front charged screen **6** they are charged and a large amount of dust is repelled back towards the grounded screen **8** since the direction of electrical field there has a direction opposite to that of the gas/particulate flow. In addition, the corona wind generated by screen **6** helps to push the oncoming particulates back towards the grounded screen **8** and the inlet. (It is well known from the literature that corona wind can be very strong and can have speed as high as 2.5 m/s one centimeter away from a weighted wire discharge electrode exposed to 50 kV [8]) Hence, the combined effects of the electrical field and the corona wind in front of the very first charged screen, both decelerating the particulate, have a decisive role in the overall increase of dust removal efficiency. This is especially true for ultra small particles since they have low inertia.

While passing through the charged screen **6** the following mechanism that enhances particulate agglomeration takes place: since all of the charged particles have the same polarity as the screens, due to a strong electric field **E,** Fig. 2a, particles passing through the screen opening are repelled by the screen wires towards the middle of the opening and, due to inertia, towards the wire on the opposite side. However, the wire on the other side pushes it back. Hence, although operating under DC the particles would have a vibratory motion in the middle of the front screen opening while passing through it—just like in the AC-operated agglomerators [8]. It is speculated that this high concentration of the particulate and its intense vibratory motion in a relatively small area results in its agglomeration in the middle of the front screen openings, Fig. 2b.

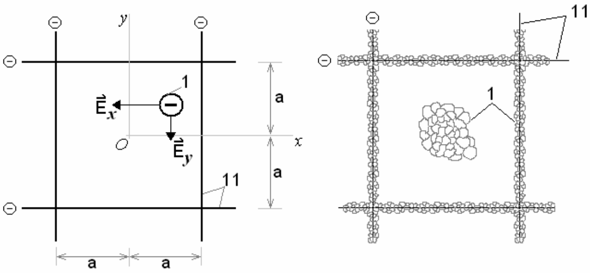

Fig 2. Agglomeration mechanism

The particles are repelled by the wires towards the centers of the openings not only by the electric field **E,** Fig. 2a, but also by a corona wind generated by wires in all directions, including the one in the plane of the screen, which too contributes to agglomeration of particulates in the screen opening, Fig. 2b.

Typical open area of the screens is about 35-40 %, or less. This should enhance particulate agglomeration within all of the openings described above, in all screens.

Finally, a large amount of dust passing through screens is captured by the interception mechanism. This mechanism is known to work well for both large particles, which poses large inertia, as well as for ultra small particles that are captured by hitting the obstacles thanks to their random Brownian motion.

An interesting test result, which needs further examination, is that charging the screens with a positive polarity seems to enhance the efficiency of particulate collection. If true, this would result in reduced production of ozone.

3. EXPERIMENTS AND RESULTS

So far, a number of flyash collection efficiency has been conducted in bench scale and laboratory pilot scale.

3.1 Bench Scale SEP

The experiments were performed in the fourth version of the bench scale SEP, shown in Fig. 3, in a 18 cm by 16.5 cm lexan duct, at room temperature, using low-carbon flyash originating from AEP's General James M. Gavin Power Plant, Cheshire, Ohio. Flyash was supplied at the inlet by a low capacity volumetric screw feeder produced by the Schenk Process GMBH, Model MOD102M, mounted on a 0.1-gram-sensitive scale, which measured the weight of the flyash delivered. The number of screens was gradually increased from 40 to 90, usually using screens with large openings (about 1mm) near inlet, followed by a smaller number of screens with small openings (up to 30 screens with 300- to 500-micron opening). The distance between the screens was 3 to 5 mm. The gas speed was varied from 2 to 4 m/s, as measured by Omega Engineering Inc.'s hotwire anemometer, Model FNMA906V. Similar to conventional ESPs, flyash concentration was tested at concentrations ranging from 4 to 8 g/m^3. The voltage applied was typically 50 to 60 kV and the current 0.1 to 0.2 mA.

Fig 3. SEP at room temperature

In addition to the air blower mounted in front of the inlet, the precipitator outlet was connected to a 15-meter tall chimney whose diameter is about 40 cm, via a fan whose capacity is up to 340 m^3/minute and which provided an additional draft. The pressure drop across the screens, measured with the Dwyer Instruments Inc. gage with the range 0-25 mm of H_2O, was low-- typically 5 mm to 7.5 mm-H_2O. The collection efficiency was measured by EPA Method5, based on comparisons of the flyash collected on the Method 5 filter at the inlet and outlet.

Before each new experiment, flyash remaining from the previous experiment on screens and the duct were thoroughly cleaned with the vacuum cleaner and blower. The collection lasted for 10 minutes and the amount of flyash delivered was about 14 g/min for concentration of 4 g/m^3 and 28 g/min for concentration of 8 g/m^3 at 2 m/s gas speed, within the error of 0.1 g.

In all experiments, after 10 minutes, the amount of flyash remaining on screens was hardly noticeable and was estimated to be about 5 % of total flyash delivered to the SEP on all screens together. Most of that remaining flyash was on the first, say ten, screens.

Next, a limited number of high-temperature collection-efficiency tests were conducted as well, Fig. 4. The unit is made from refractory bricks. Being made from stainless steel, the screens could endure 1050 Kelvin temperatures. The burner, fired with natural gas and combined with the blower, supplies the gas flow. Gas flow velocity can vary between 2 and 8 m/s, and is regulated with a variable speed blower. The exhaust from the unit is routed through the fan mounted on the outside wall of the OU ESP Lab. The flyash collection efficiency was virtually the same as at room temperature. This indicates that the SEP could probably be used in various high-temperature applications. Those could include coal gasification, for example, where SEP could hopefully replace expensive “candle filters” (ceramic version of bag filter), and possibly in some other applications.

Fig 4. High temperature SEP

As expected, in all bench-scale experiments described above, the results show that the flyash collection efficiency is increased by increasing the number of screens and operating voltage, and by decreasing flyash concentration, as well as percentage of screens’ opening area and their opening size. But the most critical parameter is the gas velocity: as the velocity is increased from 2 to 4 m/s the efficiency drops about 3 to 4%. All the above conclusions apply to the pilot-SEP tests to be described next and will therefore not be repeated.

In conclusion, out of many bench-scale test results obtained thus far, one of them will be given for illustration. With 60 screens whose opening is 1-by-1 mm, followed by 30 screens whose opening is 0.5-by-0.5 mm, at 60 kV, with gas speed 1.2 m/s, with flyash concentration 4 g/m^3, and at room temperature, flyash collection efficiency varied between 99.2 and 99.7%. The pressure drop was about 7.5mm-H_2O.

3.2 Pilot SEP

Flyash collection-efficiency tests have been repeated, at room temperature, in the lab-pilot SEP, Figs. 5 to 8, using 1.83 m-by-0.61m screens. In these initial tests 90 screens with 1 mm opening (config.-1), have been used, and the distance between screens was 5 mm. Flyash was cleaned by using pneumatic VIBCO, Model VS250 turbine vibrators. They operate at 120 Hz and uses compressed air at 550 kPa. The collection efficiency, measured by EPA Method5, shown in Fig. 9, at flow speed of 1.1 m/s and flyash concentration 3.7 g/m^3, was found to be 99%. Experiments was also conducted by adding 10 more screens at the end with 0.2 mm opening (config.-2) and at the same condition, collection efficiency was found to be 99.5%. Figs. 10 to 12 show flyash collected on Method5 filter at inlet and outlet of 9 different positions. Sample was taken from half portion of the duct due to symmetric.

Fig 5. SEP main box with inlet and VibraScrew Inc. feeder

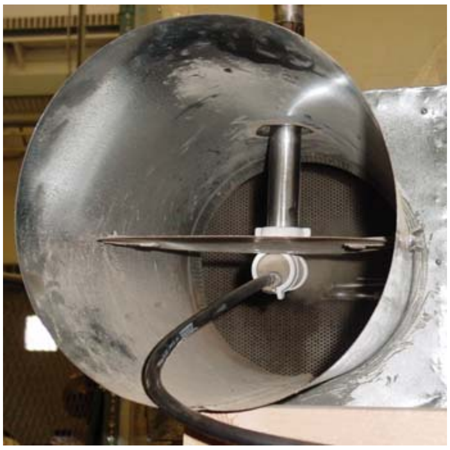

Fig 6. Flyash is delivered by feeder through vertical pipe and spread by compressed air and nozzle

Fig 7. Bottom view of the first grounded screen (left) and charging (right) screen with spike

Fig 8. Sets of screens suspended by bars on SEP sealing with pneumatic turbine shakers on top

Fig 9. EPA Method5 at the inlet of SEP

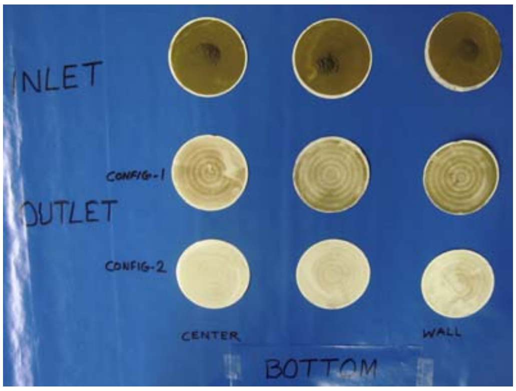

Fig 10. Photo of EPA Method5 filters after 10-minutes tests at the bottom of the duct

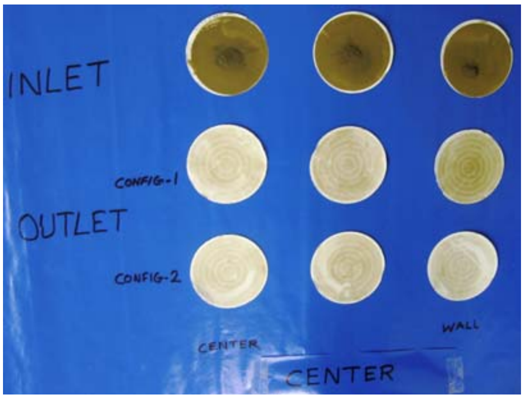

Fig 11. Photo of EPA Method5 filters after 10-minutes tests at the center of the duct

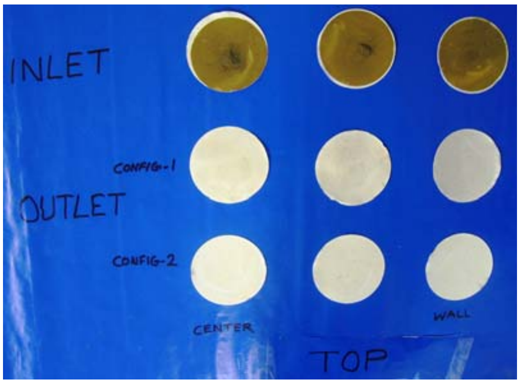

Fig 12. Photo of EPA Method5 filters after 10-minutes tests at the top of the duct

The TSI Scanning Mobility Particle Sizer (SMPS) Model 3936L22 was used to measure submicron particulate concentration. Fig. 13 shows that submicron particle concentration was reduced by 90% with config.-1. Fig. 14 shows comparison between config.-1 and config.-2.

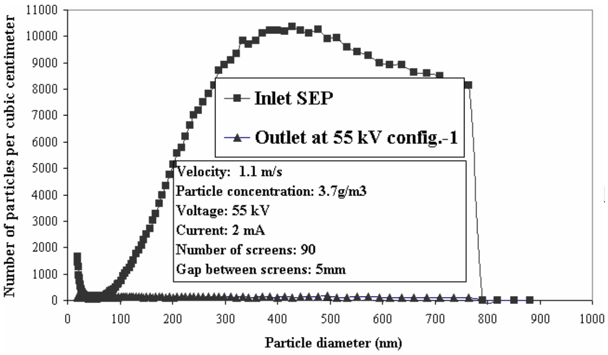

Fig 13. Submicron particle concentration reduction with config.-1

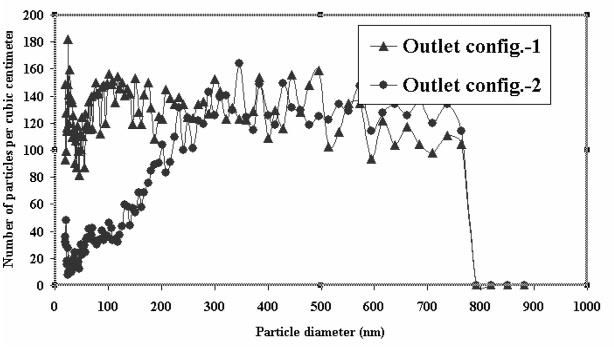

Fig 14. Outlet particle concentration comparison between config.-1 and config.-2

4. CONCLUSIONS

Based on the above results the following points can be advanced:

1. The precipitator's size, weight and cost can be drastically reduced. Distance between screens can be kept at minimum, several millimeters only, hence with a 5mm gap one hundred screens can be installed in about 0.5 m space.
2. The precipitator's cross section area can be considerably reduced, i.e. the screens could be much shorter than collecting electrodes in conventional ESPs.
3. Pressure drop across screens is low: with 90 screens it is about 7.5 mm-10 mm of H_2O only.
4. SEP is inexpensive and efficient means for stack opacity reduction.
5. SEP with its stainless screens is suitable for high-temperature applications, as high as 1090 Kelvin
6. The Transformer /Rectifier (T/R) power consumption is very low: with 90 screens, at 60 kV, the current is about 2 mA only. The T/R unit needs no sophisticated control system to avoid sparking and back corona, since they are nonexistent.

Next step would be to optimize pilot scale SEP to ensure zero emission. SEP is a potential technology for pollution controls that when researched further can contribute to automobile emission control, room air cleaning, and brick field emission control in countries like Bangladesh.

6. REFERENCES

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