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SIEVING ELECTROSTATIC PRECIPITATOR

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ABSTRACT

The paper describes so-called Sieving Electrostatic Precipitator (SEP) suitable for efficient and cost-effective cleaning of polluted gases of both large and ultra fine particulates in a very broad temperature range. Some of the laboratory-pilot-test results are discussed. The paper also describes the ongoing research project jointly funded by the Ohio Coal Development Office (OCDO), American Electric Power (AEP), Electric Power Research Institute (EPRI), Ohio University (OU) and PECO Inc. related to design, building and testing of a large-size pilot SEP to be built as a part of slipstream at the AEP's Conesville, Ohio power plant.

In the SEP the particulate-laden gas is passed through a set of closely packed and charged fine wire screens. Depending on the application, the screens can have the same or alternating polarity-- the former configuration being a more compact and cost-effective solution.

In the last three years, a large number of fly ash collection-efficiency experiments have been conducted, first on a bench-size SEP with about 100 6-by-6-inche screens, at room temperature, high temperature (300-350 ^{0}F), and a few tests at 1500 ^{0}F.

Most recently, the SEP has been demonstrated in a laboratory pilot-scale setting with 6-by-2-foot screens, at room temperature. All the results confirm that this technology deserves further studies. Its high efficiency is primarily attributed to good charging of particles, to particulate agglomeration, and to the beneficial combination of different charging and particulate-capturing mechanisms, all in the laminar flow conditions.

Utilization of this technology could result in drastic reduction of the precipitator size and cost.

CURRENT ESP TECHNOLOGY

Present ESPs are inefficient in capturing sub-micron particles in the range of 0.1-2.0 microns. The most frequently utilized means to solve this problem is to replace or combine the existing under-performing precipitators with baghouse filters [1], [2]. However, these technologies are characterized by large pressure drops, large, complex and expensive baghouse/ESP structure, and frequent cleaning, replacements and maintenance of bags.

A number of various agglomerators could also be used to capture submicron particulate [3]-[6]. Some of these devices are installed after conventional ESPs. Typically, they agglomerate small particles that escaped the precipitator into bigger particles that can be captured more easily by another, downstream precipitator. However, although large in size and costly, agglomerators suffer from low efficiency [6].

The SEP technology could offer an inexpensive and efficient alternative to all of the above devices.

DESCRIPTION OF SEP

Fig. 1 shows the SEP in which all screens **1** are charged with the same polarity. 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 particulates **9** that need to be captured. Screen openings are typically smaller than one millimeter, with wire diameters of few hundred microns. The screen opening area is typically 35-40% or less of the total screen area.

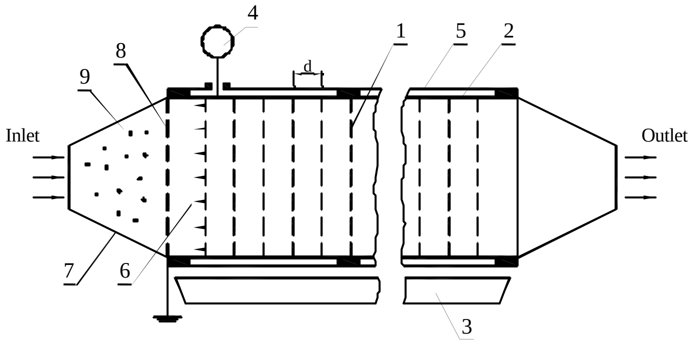
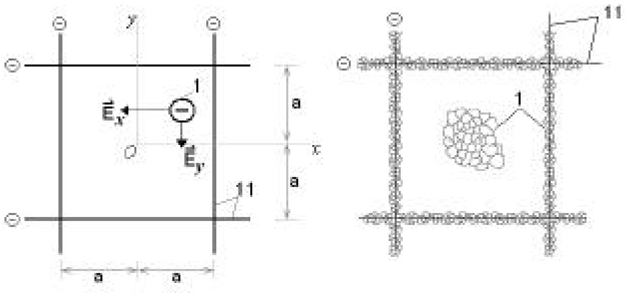


Fig. 1 Schematics of SEP

A lot of incoming neutral particles **9** are captured at the grounded screen **8** or especially between that screen and the front charged screen **6. While As** particles approach the corona 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. 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 corona-producing 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 that screen's openings 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 [6]. 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.



a) b)

Fig. 2 Agglomeration mechanism

Also, 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 also contributes to agglomeration of particulates in the screen opening, Fig. 2b.

Furthermore, 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.

EXPERIMENTS

Bench SEP Tests

These experiments were first performed in a 6-by-6.5 in. Lexan duct, at room temperature, using low-carbon fly ash originating from AEP's General James M. Gavin Power Plant, Cheshire, Ohio. Fly ash 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 fly ash delivered. The number of screens was gradually increased from 40 to 90, usually using 20x20 screens with openings about 1mm at 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 1 to 1.5 m/s, and measured by Omega Engineering Inc.'s hotwire anemometer, Model FNMA906V. Similar to conventional ESPs, fly ash concentration was tested at concentrations ranging from 4 to 8 g/m^3. The voltage applied was 50 to 60 kV and the current 0.1 to 0.2 mA.

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 40 cm, via a fan whose capacity is up to 12,000 cftm and which provided an additional draft. The pressure drop across the screens, measured with the Dwyer Instruments Inc. gage with the range 0-1 inches H_2O, was low-- up to 0.4 inches H_2O. The collection efficiency was measured by EPA Method5, based on comparisons of the fly ash collected on the Method5 filter at the inlet and outlet.

Before each new test, fly ash remaining on screens and the duct from the previous test were thoroughly cleaned with the blower. The collection lasted 10 minutes, without interruption and rapping of screens. The amount of fly ash delivered was about 48 grams for concentration of 4 g/m^3 and 96 grams for concentration of 8 g/m^3, within the error of 0.1 g.
In all experiments, after 10 minutes, the amount of fly ash remaining on screens was hardly noticeable and was estimated to be about 5 % of total fly ash delivered to the SEP on all screens together. Most of that remaining fly ash was on the first dozen of screens.

Next, a limited number of high-temperature collection-efficiency tests were conducted as well, Fig. 3. The unit is made from refractory bricks. It is schematically shown in Fig. 4. Being made from 304Stainless steel, the screens could endure 1500^0F temperatures. The burner, fired with natural gas, combined with the blower, supplies the gas flow. Gas flow velocity can vary between 0 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 fly ash collection efficiency was virtually the same as at room temperature. This indicates that the SEP is a good candidate for 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.

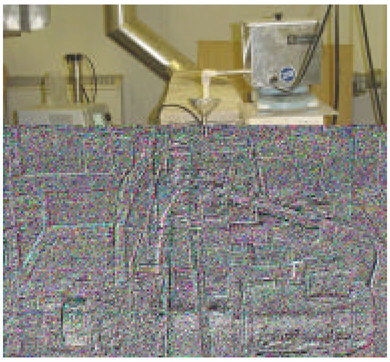


Fig. 3 High-temperature SEP

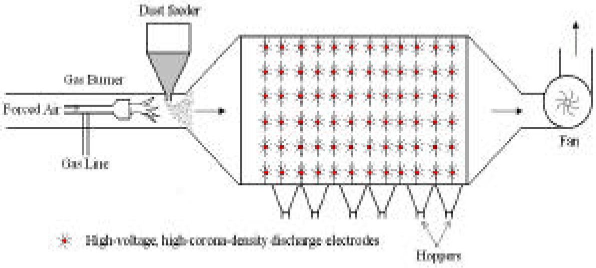


Fig. 4 Schematics of high-temperature bench SEP

As expected, in all bench-scale experiments described above, the results show that the fly ash collection efficiency is increased by increasing the number of screens and operating voltage, and by decreasing fly ash concentration, as well as percentage of screens' opening area and their opening size. But the most critical parameter is the gas velocity. 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 so 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 m/s, with fly ash concentration 4 g/m^3, at room temperature, fly ash collection efficiency varied between 99.2 and 99.7%. The pressure drop was about 0.4 inches-H_2O.

Laboratory-Pilot-SEP Tests

Fly ash collection-efficiency tests have been repeated, at room temperature, in the lab-pilot SEP, Figs. 5 to 8, using 6-by-2-foot screens. In these initial tests 90 20x20 screens with 0.762 mm opening and the wire diameter 0.491 mm have been used. The distance between screens was 5 mm. Fly ash was cleaned by using pneumatic VIBCO, Model VS250 turbine vibrators. They operate at 120 Hz using compressed air at 80 psi.

The collection efficiency, measured by EPA Method5, at flow speed of 1 m/s and fly ash concentration 4 g/m^3, was found to be 99%. Fig. 9 shows fly ash collected on Method5 filters at inlet and outlet at 15 locations in the half of the vertical cross sections.

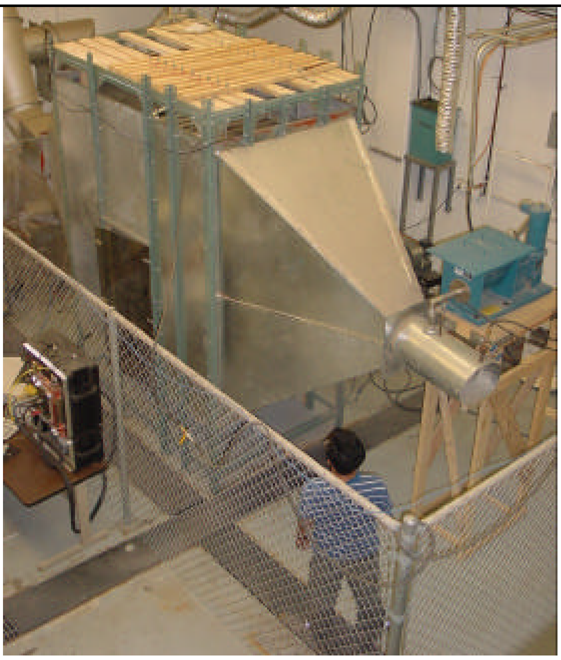


Fig. 5 SEP main box with inlet and VibraSrew Inc. dust feeder

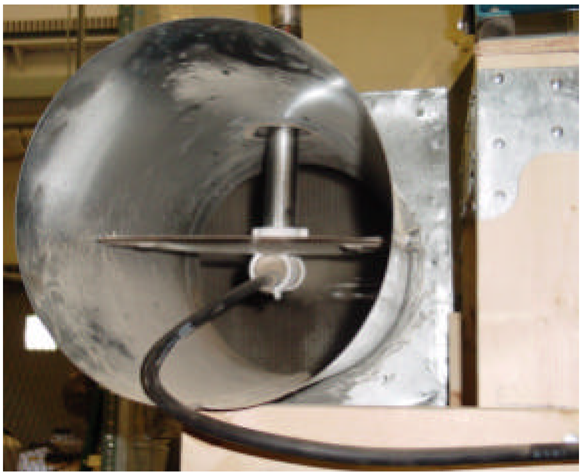


Fig. 6 Fly ash is delivered by feeder through vertical pipe and spread by compressed air and nozzle

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

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

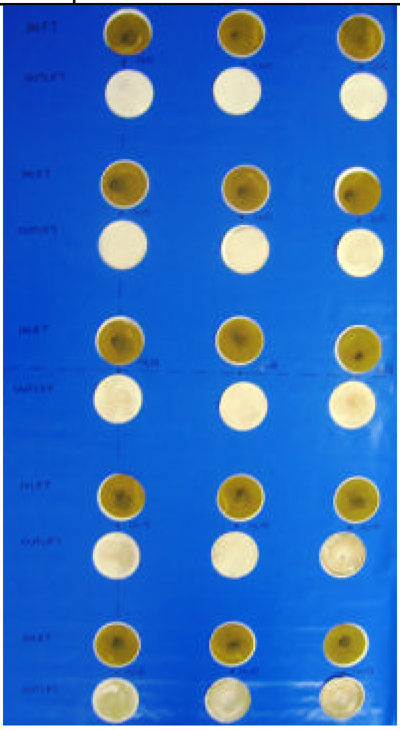


Fig. 9 Method5 filters at different positions at inlet (dark) and outlet (white)

The TSI Scanning Mobility Particle Sizer (SMPS) Model 3936L22 was used to measure submicron particulate concentration numbers. Fig. 10 shows that submicron particulate was removed almost completely.

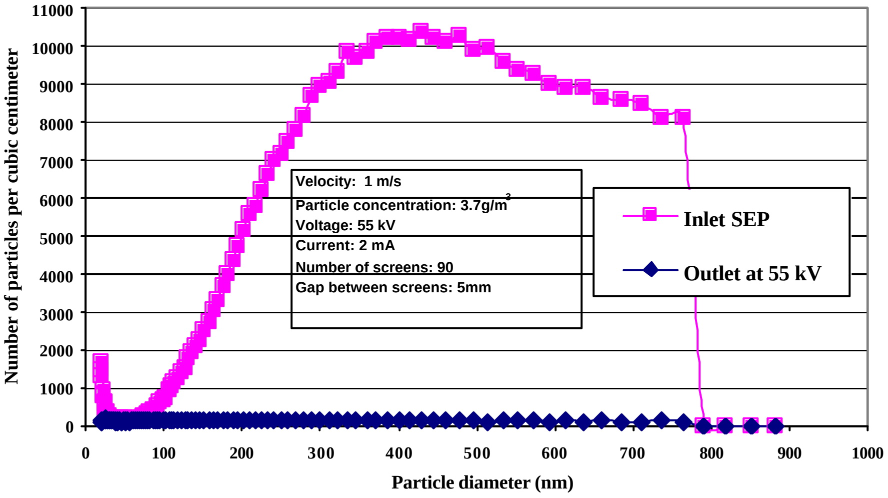


Fig. 10 Submicron particle concentration reduction

The pressure drop across one screen for Reynolds number $2 \le \mathrm{Re} \le 400$ can be found from [7]:

$$\Delta p = \frac{1}{2} r k v^2, \; N/m^2$$

where r is gas density (kg/m^3) and v is the gas approach velocity *(m/s)*. The coefficient k is found from:

$$k = 4.6\,\mathrm{Re}^{-1/3} \frac{1-b}{b^2}$$

where $0 < b < 1$ is the screen open area, while the Reynolds number, based on the screen's wire diameter *d* is:

$$\mathrm{Re} = \frac{v\,d}{n},$$

where n is kinematic viscosity, m^2/s. For example, at $v = 1\,m/s$, with air at room temperature $r = 1.2, n = 1.5\,10^{-5}$, with 100 20x20 screens with d=0.491 and $b = 0.36$, we find Re=44.4 and $\Delta p = 385\,N/m^2$ or 1.5 inches H_2O. At 300^0F $r = 0.836, n = 2.95\,10^{-5}$, Re=41.4, $\Delta p = 274\,N/m^2$ or 1.1 inches H_2O.

Slip Stream Demonstration Tests

The Slip Stream Demonstration project will be a joint venture between the AEP, OCDO, EPRI, OU and Peco Inc. and will be placed at AEP's Conesville Plant (OH) on Unit 4. This unit has a CE tangentially fired pulverized coal steam generator. The inlet grain loading to the ESP from the steam generator is 2.61 gr/acf. The Slip Stream Demonstration SEP will be sized to pass 1500 acfm of flue gas at 4.5 fps which is equivalent to a 5 MW unit. The SEP is being designed to operate under multiple ash loading and flow scenarios. The inlet to the SEP will have the capability of supplying untreated flue gas from the inlet nozzle of the ESP, treated flue gas from the outlet nozzles or a combination of both streams. The outlet of the SEP will discharge back into the inlet nozzle as an emission ‘safety net” in case of the SEP or other equipment malfunctions.

The first testing series of this SEP will be to operate only extracting flue gas from the inlet duct of the Unit 4 ESP. The gas will pass through a pre-charger and then through ten banks of screen bundles with each bundle having ten screens. The size mesh of the bundles will be varied to achieve a 99.2% or higher collection efficiency while minimizing the pressure drop across the device. The project will be considered a success if laboratory results can be maintained under actual flue gas conditions for extended periods of time.

The second series of testing will be more aggressive. The Slip Stream Demonstration SEP is being designed such that the inlet and outlet flue gas can be combined to reduce the inlet grain loading while increasing the flue gas volume to bring the velocity through the SEP to 7.5 fps. These conditions would emulate the parameters seen at the leading edge of an outlet field of a marginal three-field ESP. Again the mesh would be varied as well as screen polarities to determine what efficiency could be achieved in a polishing application. It is the opinion of many in the utility industry that the SEP if used as a polishing device would significantly improve the performance of a marginal ESP.

Once the Slip Stream Demonstration is successful, we believe the next step would be a full-scale test of the SEP in the rear bus section of a marginally sized existing ESP. The rear field retrofit would be targeted for 2008.

CONCLUSIONS

The SEP technology possesses numerous advantages, including:

- -Precipitator’s size, weight and cost could be drastically reduced; one hundred screens can be installed in about 0.5 m space,
- -Fly ash collection efficiencies are very high,
- -Pressure drop across screens is relatively low,
- -The SEP is suitable for retrofitting of existing conventional ESPs and for combining it with filterbags, if desired,
- -SEP could be an inexpensive and efficient means for stack opacity reduction,
- -SEP with its stainless steel screens is suitable for high-temperature applications, as high as 1500^0F.
- -The T/R power consumption is very low,
- -The likelihood of sparking and back corona is minimal since they can occur at one place only-- between the first grounded screen and the corona-producing screen.

REFERENCES

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