Carbon Nanocomposite Electrode for Electrostatic Precipitators

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ABSTRACT

The electrostatic precipitator[1] (ESP) is a key pollution control component in air pollution control devices for small oil and coal-fired industrial boilers. ESPs can operate with an efficiency of 98 to 99% for the removal of mercury and fly ash from the flue gas stream. Within the electrostatic precipitator, fly ash particles are charged electrically due to a corona current from discharge electrodes (Figures 1 and 2) as the flue gas passes through the precipitator, allowing the charged particles to be collected on oppositely charged plates typically made of metal.

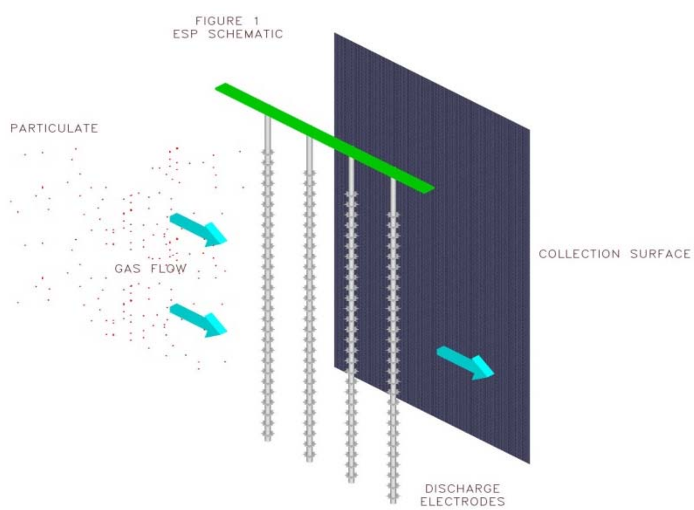

Figure 1. Conceptual view of ESP showing the discharge electrode in the gas flow

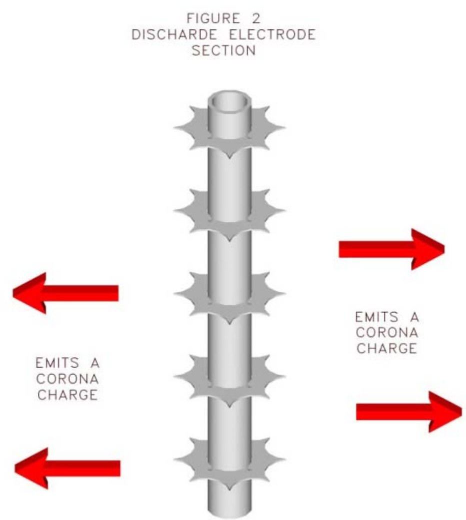

Figure 2. Detailed schematic of discharge electrode and corona field

Recent advances in the ESP technology include the development of the wet ESP[2], in which water flow on the collection electrode improves the performance of the ESP. Wet ESPs use a metal or fabric for the collection surface. They typically have higher capture of sub-micron particulates due to the better adhesion of the particles to the liquid flowing on the collection surfaces, and virtually no re-entrainment. Wet ESPs are very effective when fine particles need to be removed from the exhaust air stream, typically with aerodynamic diameters less than 2.5 µm. Wet ESPs that use metal discharge electrodes must use alloys such as stainless steels or different grades of hastelloy to protect against the highly corrosive environment. Therefore, these electrodes are very expensive. Polymer nanocomposite electrodes are a less expensive alternative for wet ESPs, particularly because of their corrosion resistance. The lower

NSTI-Nanotech 2010, www.nsti.org, ISBN 978-1-4398-3401-5 Vol. 1, 2010

weight of the polymer nanocomposite electrode also provides an advantage because the supporting structure can be designed for lower loads.

This paper discusses the development of a novel carbon composite electrode for ESPs by using an electrically conductive polymer matrix composite with carbon fiber. Graphitic carbon microfibers that have been used in composites for aero-space and sports equipment can be sufficiently conductive for the discharge electrode application. To make a conductive polymer, carbon nanofibers can also be used as an additive in small volume fractions. When the volume fraction of the nanofiber is small, the nanofiber may not provide much enhancement of the mechanical strength; but the electrically conductivity can be improved significantly.

One option for making conductive electrodes is to incorporate continuous carbon microfiber in a polymer matrix using a pultrusion process. Further improvement of electrical conductivity can be achieved by adding carbon nanofibers to the polymer resin so that there is greater continuity of electrical contact between the microfibers and nanofibers within the polymer matrix. Good results are obtained if the nanofibers are well dispersed and aligned. Analysis and simulation of the nanofiber incorporation (both dispersion and alignment) into a polymer has been carried out at Ohio University[3].

However, producing a composite with nanofibers requires careful processing steps because the stiff nanofibers must be dispersed without significant breakage. If the fibers are broken due to the mixing action, the reduction in fiber length can significantly reduce the conductivity because the shorter fibers may not provide a continuous path for the flow of current. This may degrade the electrical conductivity and make it difficult for the composite product to match the performance requirements of the metal discharge electrodes.

For the nanocomposite electrode to be a potential replacement for the traditional metal electrode, a typical test is to verify that it will produce comparable or superior voltage-current (V-I) characteristic as the current state-of-the-art ESP components. In this study, nanocomposites were produced in the form of pultruded tapes containing carbon microfibers and carbon nanofibers in a polypropylene matrix. The nanofibers (Pyrograf III, PR-19, produced by Applied Sciences, Inc., Cedarville, OH) were embedded into the tape by a thermoplastic pultrusion process with tows of carbon microfiber (Besfight G30-700). The tapes were typically 10 mm wide and 1 mm thick.

The nanocomposite tapes were then supported on a polymer tube (Figure 3) to form the electrode. The metal electrode shown in the middle was fabricated on the basis of guidelines provided by a designer and manufacturer of electrodes[4]. All the electrodes were then tested in three different small and large scale ESP chambers (Figures 4 to 7) to determine the corona discharge current. Figure 4 shows the metal electrode in a 6 inch high test chamber. Figure 5 shows a similar metal electrode in a 3 feet high test chamber. And Figures 6 and 7 show a large scale test chamber that can test electrodes that are 12 feet long. In Figure 7, the composite electrode is shown in the test configuration within the large scale test chamber.

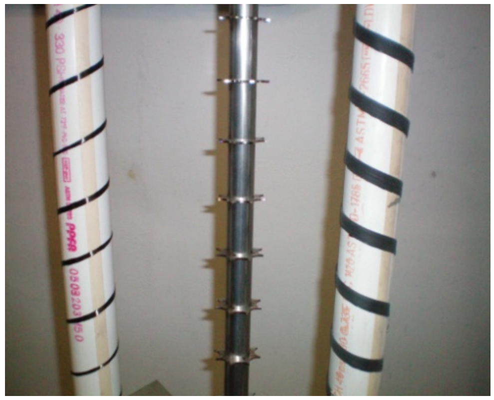

Figure 3. Electrode configurations of nanocomposite tapes wrapped on a polymer tube. The steel electrode in the center is designed on the basis of a commercial discharge electrode.

Figure 4. ESP test chamber 1

Figure 5. ESP test chamber 2

Figure 6. ESP test chamber 3

Figure 7. ESP test chamber 3 (inside view)

NSTI-Nanotech 2010, www.nsti.org, ISBN 978-1-4398-3401-5 Vol. 1, 2010

The composite tape electrodes and the commercial type metal electrodes were tested in the ESP chambers to evaluate and compare the voltage-current (V-I) behavior. A more efficient electrode will generate higher current at a specific voltage. Comparison of the V-I performance (Figure 8) of the electrodes reveals that the highest performing electrode contained carbon fiber and carbon nanofiber. The best performing composite electrode was the tape produced with carbon fiber and polypropylene that was preloaded with 20 weight percent carbon nanofiber. This demonstrates that polymer composite electrodes with carbon fiber have the potential of replacing metal electrodes in ESPs.

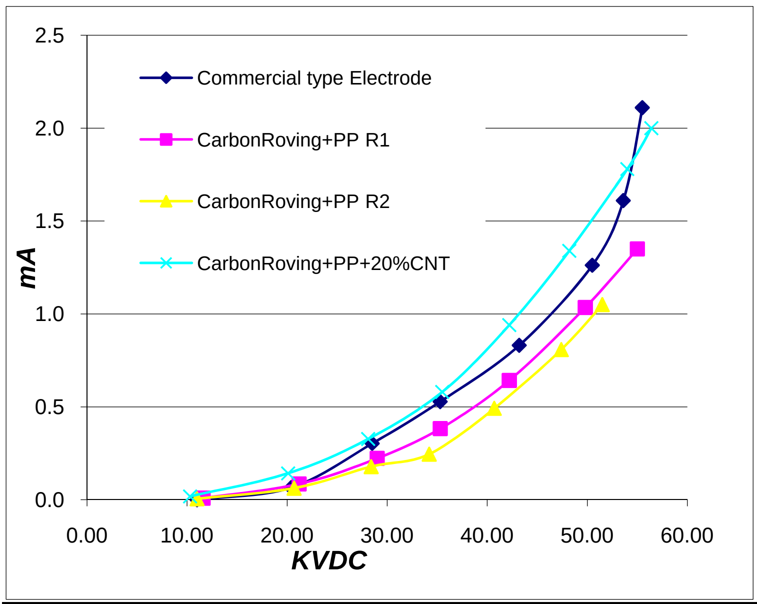

Figure 8. Comparison of the corona discharge current produced by 4 different electrodes: one commercial metal electrode, two composite electrodes (R1 & R2) with carbon microfiber, and one nanocomposite electrode.

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