ADVANCED HYBRID PARTICULATE COLLECTOR

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INTRODUCTION

This project was funded under the U.S. Department of Energy (DOE) Program Research and Development Announcement (PRDA) No. DE-RA22-94PC92291, Advanced Environmental Control Technologies for Coal-Based Power Systems Phases I and II, and addresses Topic 7: Advanced Concepts for Control of Fine Particles and Vapor-Phase Toxic Emissions. In addition to DOE, the project team includes the Energy & Environmental Research Center (EERC) as the primary contractor, Allied Environmental Technologies as a subcontractor, and W.L. Gore & Associates, Inc., as a technical and financial partner.

The primary technologies for state-of-the-art particulate control are fabric filters (baghouses) and electrostatic precipitators (ESPs). However, each of these has limitations that prevent it from achieving ultrahigh collection of fine particulate matter. A major limitation of ESPs is that the fractional penetration of 0.1- to 1.0-μm particles is typically at least an order of magnitude greater than for 10-μm particles, so a situation exists where the particles that are of greatest health concern are collected with the lowest efficiency. Fabric filters are currently considered to be the best available control technology for fine particles, but they also have weaknesses that limit their application. Emissions are dependent on ash properties and typically increase if the air-to-cloth (A/C) ratio is increased. In addition, many fabrics cannot withstand the rigors of high-SO_3 flue gases, which are typical for bituminous fuels. Fabric filters may also have problems with bag cleanability and high pressure drop, which has resulted in conservatively designed, large, costly baghouses.

A new concept in particulate control is proposed, called an advanced hybrid particulate collector (AHPC), which combines the best features of ESPs and baghouses in a manner that has not been done before. The AHPC concept consists of a combination of fabric filtration and electrostatic precipitation in the same box, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of the dust to the hopper.

OBJECTIVE

The objective of the project is to develop a highly reliable AHPC that can provide >99.99% particulate collection efficiency for all particle sizes from 0.01 to 50 μm, is applicable for use with all U.S. coals, and is cost-competitive with existing technologies. Specific anticipated benefits of this approach are as follows:

- Solves the problem of excessive fine-particle emissions with conventional ESPs, and eliminates the problem of sneakage.
- Provides ultrahigh collection efficiency, even at high A/C ratios.
- Solves the problem of reentrainment and re-collection of dust in conventional pulse-jet baghouses caused by the close bag spacing and the effect of cleaning one row of bags at a time.
- Solves the problem of chemical attack on bags, allowing application to all U.S. coals.
- Reduces the applicability problem for ESPs with high-resistivity dusts.
- Requires significantly less total collection area than conventional ESPs or baghouses.
- Is suitable for new installations or as a retrofit replacement technology.

DESCRIPTION AND THEORY OF THE AHPC

State-of-the-art ESPs can provide 99.9% total mass particulate control, but collection efficiency for 0.1- to 1.0-µm particles is significantly lower. Current fabric filters can achieve 99.9% collection efficiency on large coal-fired boilers, and when advanced fabrics are employed or when flue gas conditioning is used, fabric filters can achieve 99.99% collection efficiency with no significant deterioration in performance for sizes from 0.1 to 1.0 µm. Fabric filters cannot routinely achieve that level of control for all coals within economic constraints, and studies have shown that collection efficiency is likely to deteriorate significantly when the face velocity is increased.[1,2] An approach to make fabric filters more economical is to employ smaller baghouses that operate at much higher A/C ratios. The challenge is to increase the A/C ratio for economic benefits and to achieve ultrahigh collection efficiency at the same time. To achieve high collection efficiency, the pores in the filter media must be effectively bridged (assuming they are larger than the average particle size). With conventional fabrics at low A/C ratios, the residual dust cake serves as part of the collection media, but at high A/C ratios, only a very light residual dust cake is acceptable, so the cake cannot be relied on to help achieve high collection efficiency. The solution is to employ a sophisticated fabric that can ensure ultrahigh collection efficiency and endure frequent high-energy cleaning. In addition, the fabric should be reliable under the most severe chemical environment likely to be encountered (such as high SO_3). Such a fabric is already commercially available but is not widely applied to coal-fired boilers because of its higher cost compared to conventional fabrics. The fabric is GORE-TEX® membrane on GORE-TEX® felt and has the potential to achieve very high collection efficiencies at high A/C ratios. GORE-TEX® membrane filter bags consist of a microporous, expanded polytetrafluoroethylene (PTFE) membrane laminated to a felted or fabric backing material. Consequently, even fine, nonagglomerating particles do not penetrate the filter, resulting in significant improvements in filtration efficiency, especially for submicron particles. This fabric is also rugged enough to hold up under rigorous cleaning, and the all-PTFE construction alleviates concern over chemical attack under the most severe chemical environments. Although GORE-TEX® membrane filter media is more expensive than conventional fabrics, the much smaller surface area required for the AHPC will make the use of GORE-TEX® membrane filter media economical.

Successful operation of fabric filters at high A/C ratios is a challenge, because of the increasing difficulty in controlling pressure drop. The size of fabric filters and bag-cleaning frequency are determined by pressure drop. Assuming viscous flow, pressure drop across a fabric filter is given as:

$$\Delta P = K_f V + K_2 W_R V + K_2\, C\, V^2\, t / 7000 \qquad \text{[Eq. 1]}$$

where

ΔP = differential pressure across baghouse tube sheet (in. of water)
K_f = fabric/dust resistance coefficient (in. of water-min/ft)
V = face velocity or A/C ratio (ft/min)
K_2 = specific dust cake resistance coefficient (in. of water-ft-min/lb)
W_R = residual dust cake weight (lb/ft^2)
C = dust loading (grains/acf)
t = filtration time between bag cleaning (min)

The first term in Eq. 1 accounts for the pressure drop across the fabric. For a new fabric, pressure drop across the fabric alone is generally negligible, but in cases where the dust packs permanently into the interstitial spaces of the fabric, this may be a significant term. The second term in Eq. 1 accounts for the pressure drop contribution from the permanent residual dust cake that exists on the surface of the fabric. In many cases, after long-term operation, this is a significant term. The third term in Eq. 1 accounts for the pressure drop contribution from the dust accumulated on the bags since the last bag cleaning. K_2 is determined primarily by the fly ash particle-size distribution and the porosity of the dust cake. Typical K_2 values for pulverized coal (pc)-fired fly ash range from about 3 to 15 in. of water-ft-min/lb, but may, in extreme cases, cover a wider range. Of interest is the maximum A/C ratio at which a baghouse can be expected to operate reliably for the range of K_2 values likely to be encountered. All three terms in Eq. 1 may require increased bag-cleaning frequency with increased A/C ratio, but the third term dictates the minimum bag-cleaning interval. From Eq.1, with a face velocity of 2 ft/min, a dust loading of 3 grains/acf, and a ΔP increase of 4 in. of water, the required bag-cleaning frequency is greater than 100 minutes when K_2 is less than 23 in. of water-ft-min/lb. In a reverse-gas utility baghouse, cleaning takes place off-line and may require several minutes per compartment and more than an hour to clean all of the compartments. This is one reason why most reverse-gas baghouses are conservatively designed for a face velocity of 2 ft/min. To ensure that adequate cleaning time is available when K_2 is not known demands a conservative approach. On the other hand, if K_2 were known to be less than 6 in. of water-ft-min/lb, Eq. 1 implies that a face velocity of 4 ft/min could be employed. However, to date, reverse-gas baghouses have not been designed much above face velocities of 2 ft/min because an effective method of controlling K_2 has not existed and excessive residual dust cake weight is frequently encountered.

Pulse-jet baghouses have the potential to operate at much higher face velocities because bags can be cleaned more often and adequate pulse energy can usually prevent excessive residual dust cake buildup. Assuming that bag life is acceptable and that low particulate emissions can be maintained through the use of advanced filter materials, face velocities much greater than 4 ft/min should be possible. Assuming 10 minutes is the minimum cleaning cycle time for a pulse-jet baghouse, a face velocity of 4 ft/min is adequate to handle a dust with a K_2 greater than 30 in. of water-ft-min/lb. If K_2 is less than 15 in. of water-ft-min/lb, the face velocity can be increased to 8 ft/min. For many dusts, this might be possible with conventional systems. Doubling face velocity again to 16 ft/min implies that K_2 would have to be less than 4 in. of water-ft-min/lb. This is lower than most typical K_2 values; however, through the use of flue gas conditioning, it may be possible. Increasing the face velocity beyond 16 ft/min appears to be stretching the theoretical limit for a full dust loading of 3 grains/scf. However, if the actual dust loading that reached the fabric were reduced by a factor of 10, the allowable K_2 would increase by a factor of 10, while keeping the cleaning interval at 10 minutes. If a process could collect 90% of the dust before it reached the bags, a K_2 of up to 40 would be allowable at an A/C ratio of 16 ft/min and a 10-min bag-cleaning interval. The K_2 for almost all coal fly ash dusts is likely to be less than 40, even allowing for some size fractionating between the precollected dust and the dust that reaches the bags. Therefore, a theoretical basis exists to operate a fabric filter at a reduced dust loading and high A/C ratio with a reasonable bag-cleaning frequency.