FINE PARTICULATE COLLECTION USING DRY ELECTROSTATIC PRECIPITATORS

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INTRODUCTION

Potential legislation concerning fine particulate or PM-2.5 (particulate matter less than 2.5 microns) has been under discussion for several years. Atmospheric air quality is the issue that legislation is trying to address. However stack emissions from stationary sources are only one contributor to atmospheric PM-2.5. Since PM-2.5 can come from a wide variety of sources (road dust, automobile exhausts, farm fields, acid condensation, etc.), PM-2.5 from stationary sources is only one source contributing to total atmospheric PM-2.5. Also the PM-2.5 generated by stationary sources can come from two distinctly different sources; 1) solid particulate emissions, and 2) gaseous emissions which condense in the atmosphere. USA-EPA studies have shown that PM-2.5 in the Eastern USA atmosphere, consists nearly 50 % of condensable sulfates, nitrates, and ammonium. Unfortunately, the ESP is a device which only collects solid particulate, and does not collect these condensable materials (note that a fabric filter is also just a dust collector). Therefore gaseous species will pass through the ESP to atmosphere with no control by the ESP. If control of gaseous species is required, a wet flue gas scrubber, or dry/semi-dry injection of sorbents ahead of the dust collector (ESP or FF) must be used.

DISCUSSION

When designing ESPs to collect PM-2.5 or even PM in general, the test method becomes extremely critical. The most common particulate test methods in use today in the USA are listed below, with comments on the amount of condensable material that is included as particulate;

Test Method	Comments
EPA 17	Measures particulate (rocks) only
EPA 5F	Measures particulate (rocks) only
EPA 5 (320F Probe Temperature)	Particulate plus small level of sulfuric acid
EPA 5 (248F Probe Temperature)	Particulate plus high levels of sulfuric acid
EPA 5 (180F Probe Temperature)	Particulate plus most sulfuric acid
PM 201	Particulate plus all sulfuric acid
PM 202	Particulate plus all sulfuric acid

Depending on the test method required for permitting, the solid particulate (rocks) can make up all or only a part of the measured "particulate". Often-times people refer to the front half catch as the "filterable" particulate. There is no more ambiguous term in the air pollution industry than "filterable" particulate. To the EPA when discussing the atmospheric particulate, filterable particulate means solid particulate plus all condensable particulate. EPA test methods 201 and 202 clearly state their intent to include condensibles as particulate. To an ESP vendor, filterable particulate means solid particulate (rocks) only (as measured by EPA Test Methods 17 or 5F). After all, solid particulate is all that an ESP collects and is therefore all the ESP vendor can guarantee. Sometimes ESP systems have to be designed for extreme low solid particulate emissions, so that the sum of solid particulate plus condensibles (i.e. the so-called filterable particulate) meets the environmental compliance method/limit. Note that this same discussion applies equally to fabric filters, which also only collect solid particulate.

1. ESPs for Electric Utilities

With regard to the impact of ESPs on the solid particulate, studies have been performed on the particle sizes of particulate entering and leaving our ESP's on pulverized-coal fired boilers (i.e. electric utilities). We have found first that the measurement of particle size is an imprecise science and that depending on test method, different results are possible. For example, typical mass mean particle size distributions for pulverized-coal fired boilers (at the ESP inlet) with various test methods would be as follows;

Test Method	Typical Mass Mean
Insitu Plate Type Impactor (Anderson)	5 Microns
Centrifugal Laboratory Sizing (Bahco)	12 Microns
Insitu Cyclonic Impactor (Brinks)	16 Microns

Thus, even when discussing solid particulate only, there is confusion as to just what portion of the particulate is what particle size. However for the purposes of this paper we have based the following discussion on Bahco test data. We chose Bahco because there tends to be more historical data available on outlet particle size using a laboratory device.

A high efficiency ESP will emit particles both larger and smaller than 2.5 microns. And the particle size distribution will get finer and finer as the ESP efficiency increases. This is because the ESP is more efficient on large particles than small.

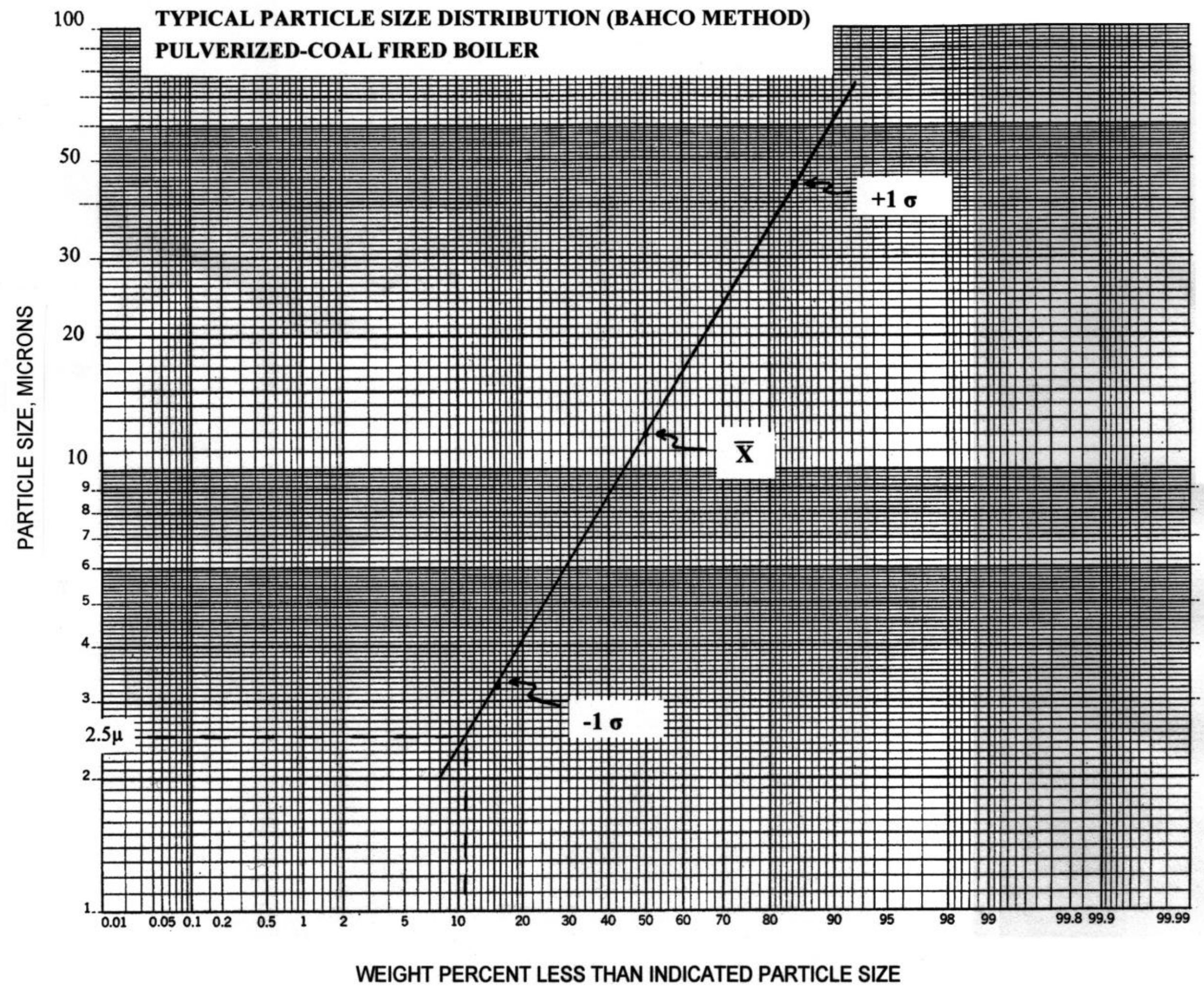
If we consider a typical coal analysis (i.e. HHV=12,000 BTU/LB and 12 % ash), the total solid particulate ESP inlet concentration would be;

$$1{,}000{,}000 \text{ BTU} / 12{,}000 \text{ BTU/LB} * 0.12 \text{ Ash} * 0.85 \text{ Carryover} = 8.5 \text{ LB/MMBTU}$$

From historical data, a typical particle size for a utility pulverized-coal fired boiler would be a mass mean of 12 microns and a standard deviation of 3.8. The particle size distribution would be as shown on Figure 1.

FIGURE 1

TYPICAL PARTICLE SIZE DISTRIBUTION (BAHCO METHOD)
PULVERIZED-COAL FIRED BOILER



From Figure 1, we can see that about 11 % of the incoming solid particulate will be PM-2.5. Thus the inlet loading of PM-2.5 would be;

8.5 LB/MMBTU * 0.11 = 0.935 LB/MMBTU of inlet PM-2.5

Particle size measurements have been made on the outlet particle size distribution from high efficiency ESP's. These studies have shown that as the collection efficiency of the ESP gets higher, the outlet particle size distribution gets smaller. Typically, the percentage PM-2.5 in the outlet particle size distribution for an ESP achieving USA New Source Performance Standards of 0.03 LB/MMBTU (approx. 30 MG/NM3), was in the range of 50 % of the outlet particulate. Therefore in this case, we would calculate that the mass emissions of PM-2.5 micron particulate with a total emission of 0.03 LB/MMBTU would be;

0.03 LB/MMBTU * 0.50 = 0.015 LB/MMBTU of PM-2.5

Thus the overall calculated efficiency of this ESP on PM-2.5 would be;

(0.935 - 0.015) / 0.935 = 98.4 % on PM-2.5

Note that the overall efficiency on total particulate would be;

(8.5 - 0.03) / 8.5 = 99.65 % on all particulate

So as mentioned above, the ESP is less efficient on fine particles than large, but ESPs do collect fine particles at high efficiency.

Of course the above calculations assume that the ESP makes exactly 0.03 LB/MMBTU on the outlet particulate emission. However, most recent ESP start-ups on P-C boilers have achieved well better than 0.03LB/MMBTU. Particulate emissions as low as 0.01 LB/MMBTU (approximately10 MG/NM3) are common on recent start-ups. If the customer has included some conservatism in the specified operating conditions and/or redundant fields, and the ESP vendor has additional conservatism for guarantee, the ESPs will do exceptionally well.

In the case of very low emissions, 0.01 LB/MMBTU (approx. 10 MG/NM3), the mass emission of PM-2.5 would be calculated as follows;

0.01 LB/MMBTU * 0.70 = 0.007 LB/MMBTU of PM-2.5

Note that for this case, the percentage of PM-2.5 has been increased from about 50 % to 70 % in this outlet penetration, because the ESP will collect the coarser fractions in high efficiencies.

This serves to make the particle size smaller as the emissions get lower. Thus the overall calculated efficiency of this ESP on PM-2.5 would be;

(0.935 - 0.007) / 0.935 = 99.25 % on PM-2.5

Note that the overall efficiency would be;

(8.5 - 0.01) / 8.5 = 99.88 % on all particulate

Thus these new utility ESPs are demonstrating higher than 99% collection efficiency on PM-2.5 solid particulate.

2. ESPs for Biomass Firing

Before discussing PM-2.5 on biomass boilers, it might be useful to discuss PM-10. Legislation has already been implemented in some parts of the USA for biomass fired boilers, which has required PM-10 emissions to be achieved. However, most biomass has one important chemical characteristic, which is that biomass has almost no sulfur content. Thus studies have shown that the contribution of condensibles to particulate mass measurements is very low (using ESP 5 type testing at 248 F probe temperature). Thus for this specific application solid particulate very closely approximates atmospheric particulate.

On the above basis, the ESP vendors in the USA have been able to make guarantees of particulate emissions in a specific particle size range. However, guarantees involving PM-10 were easy to manage. This is because data on high efficiency ESPs has shown that nearly 100 % of the outlet particulate is less than 10 microns in size. Thus if a guarantee were required for total particulate less than 0.03 LB/MMBTU (approximately 30 MG/NM3) and PM-10 less than 0.02 LB/MMBTU (approximately 20 MG/NM3), we simply sized the ESP to achieve 0.02 LB/MMBTU of total particulate. We could accept either EPA-5 or EPA-17 testing, because there was little or no sulfuric acid in the flue gas.

The guarantee of PM-2.5 on biomass firing is a simple extension of the PM-10 case. There will be little condensibles to worry about, and one simply has to address the fact that some portion of the dust will be less than 2.5 microns and some greater than 2.5 microns. Assumptions would be similar to the pulverized coal case, in that as required outlet emission gets lower assumed fraction less than 2.5 microns would be greater.

One major disclaimer on biomass type firing, is that we are discussing bark, sawdust, grape vines, etc. which are natural plant material. These types of boilers can sometimes get involved with construction debris, creosoted timber, and tire firing. These materials, especially tires which use sulfur as a vulcanizing agent, do have higher levels of condensibles. The PM-10 assumptions cannot be extended to that higher sulfur fuels situation.

3. ESPs for Refinery Fluid Catalytic Cracking Units

Perhaps the most complicated application for achieving PM-2.5 emissions would be FCCU. Oddly enough, the problem is not actually in the collection of the solid particulate (silica/alumina catalyst fines). Particulate emissions on this application with dry ESPs have been demonstrated down to 0.001 GR/ACF (approximately 5 MG/NM3). Similar to other applications, as the solid particulate emission gets lower, the percent of the penetrating particulate less than 2.5 microns gets greater.

The complication on this application is that there can be a considerable condensibles contribution to particulate measurements. The amount of condensibles depends on test method (EPA 5, 5F, or 17) and probe temperature (180 F, 248 F, 320 F, or process operating F), oil sulfur content, and presence or lack of hydro-treating. So we can have condensibles contributions ranging from near 0 GR/ACF, to as high as 5 or 10 times the amount of solid particulate in the flue gas. So the selection of test method is critical to the ESP design, to the point of forcing the technology to wet scrubbers. If the condensibles present are high and the test method is going to include all or most of the condensibles as particulate, then the use of an ESP is not recommended.

This can make the achieving of total PM or PM-2.5 a very complicated situation. What happens in some cases is that the condensibles contribution is measured/predicted in advance. Then the ESP has to be sized for solid particulate, so that;

Solid Particulate + Condensibles Contribution = Total Measured Particulate

Thus the ESP might be sized for solid particulate emissions well lower than the performance requirement. In this process the particulate is being pre-cut by a series of two or three cyclones. This removes most of the large particles ahead of the ESP. Then the ESP selectively reduces particle size as well. Therefore a high collection efficiency ESP on FCCU will have an outlet particle size distribution consisting of very high, >90%, PM-2.5. Therefore the conservative approach in this case would be to assume total solid particulate to be equal to solid PM-2.5.

4. ESPs for Cement, Nickel, Lime Mud <u>Kilns</u>

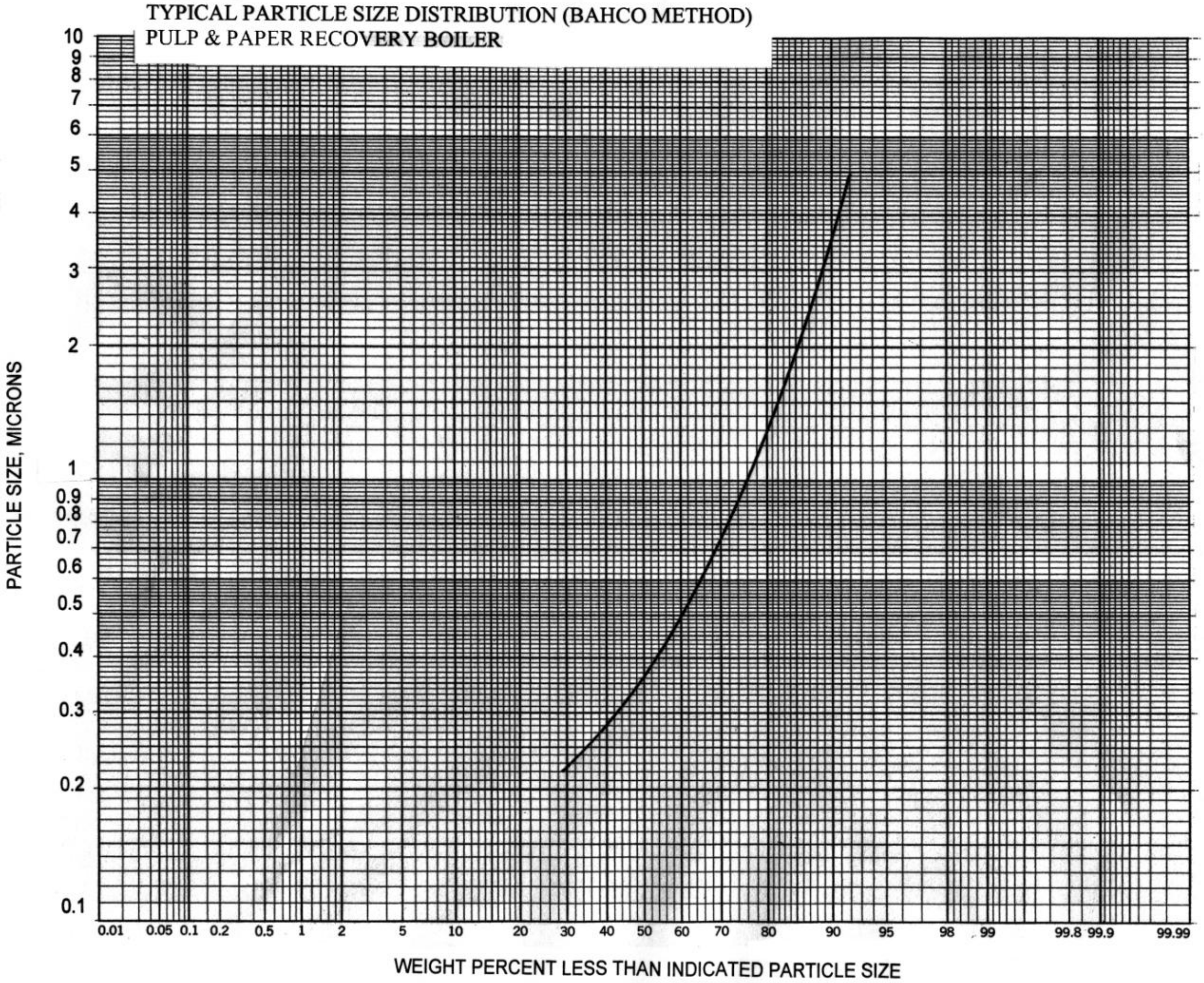
On kiln applications, there is typically a very coarse/large particle size distribution. At face value, one might assume that these ESPs do not have to collect very many fines. This since the percent of the particle distribution less than 2.5 microns, is much lower than other applications. However in fact, there are quite high levels of fine particulate from kiln applications if the fines are measured in mass concentration, not percent. This is because the ESP inlet dust concentrations from kilns are extremely high. Thus a smaller percentage of a much larger mass concentration can result in fines concentrations levels which are as high or higher than some other applications.

Condensibles levels on kilns will be somewhat of a “mixed bag”. This is because the fuel for the kiln can range from natural gas, to coal, to oil. There is even disposal of PCB contaminated oils in some kilns. Therefore care should be taken to evaluate the amount of condensibles, as a significant contribution is possible under some conditions.

5. ESPs for Pulp & Paper Recovery Boilers

Of all the ESP applications, this is probably the easiest one to deal with in terms of PM-2.5 performance. That is because the ESP inlet particle size on this application is extremely fine (See Figure 2). The typical mass mean particle size on a recovery boiler ESP is 50% less than 0.35 microns.

FIGURE 2
TYPICAL PARTICLE SIZE DISTRIBUTION (BAHCO METHOD)
PULP & PAPER RECOVERY BOILER



As an aside, the fact that ESPs routinely collect these very fine particles on recovery boilers, lays to rest any notion that ESPs cannot collect fine particles. As can be seen on Figure 2, this recovery boiler particulate is about 90% less than 2.5 microns. ESPs are routinely installed on this application, which achieve 99.9% collection efficiency (total PM) on this very fine particulate. As can also be seen on Figure 2, about 25% of the particulate is in the size range less than 0.2 microns. Some researchers in the early or middle parts of the 20th century speculated that ESPs could not collect particles very well in the 0.2 micron range due to particle charging difficulty. Commercial ESPs have not demonstrated this problem that was speculated from theoretical studies. Commercial ESPs are collecting 0.2 micron particles as a matter of course in achieving the very high collection efficiencies required on modern installations.

Returning to the recovery boiler case, the penetration of a high efficiency ESP on recovery boilers should be assumed to be near 100% less than 2.5 microns. Thus guarantees of total PM and PM-2.5 would be identical, if the test method does not include condensibles. This application does however contain some levels of sulfates, which could contribute somewhat to a condensable particulate. So care must be taken in designing for PM-2.5 emissions on recovery boiler ESPs, with regard to what test method is required. Test methods which include condensibles will have some condensibles contribution on this application, so both total PM or PM-2.5 would be somewhat higher than “rocks” only.

6. Oil Fired Boilers

Fuel oils contain very low levels of ash, typically 0.1 to 0.3 %. When the oil droplets burn out, the remaining residue is much finer in particle size than say coal combustion. Typical inlet particle size distributions to the ESP will be in the range of 70% less than 2.5 microns. Then after the ESP removes the larger particles, this application will also drive down toward near 100% less than 2.5 microns on the ESP exit particulate. Therefore the conservative approach in this case would be to assume total solid particulate to be equal to solid PM-2.5.

Many fuel oils contain high levels of sulfur. Some like PetCoke can even range up to 3-6% sulfur in the fuel. These high levels of sulfur translate to high condensibles levels in the flue gas. Test method should be carefully analyzed as total particulate may have a large contribution from the condensibles fraction.

Some very approximate inferences on solid PM-2.5 collection efficiencies in dry ESPs can be calculated based upon the above discussions. Of course every site and ESP collection efficiency will vary widely. This variation will depend on process conditions, ESP age/size, and ESP condition. So the results should be considered trends and not exact predictions. The inferences are summarized in the following table;

Figure 3 - APPLICATION vs. PM 2.5 COLLECTION

APPLICATION, OUTLET EMISSION	TYPICAL ESP INLET % LESS THAN 2.5 MICRONS	TYPICAL PM-2.5 COLLECTION EFFICIENCY	TYPICAL ESP INLET MASS LOADING	TYPICAL PM-2.5 MASS LOADING COLLECTED
Utility - Eastern Bituminous Coal, 0.03 LB/MMBTU	11 %	98+ %	8.5LB/MMBTU	0.92 LB/MMBTU
Utility – PRB Coal 0.03 LB/MMBTU	50 %	99+%	6.0LB/MMBTU	2.53 LB/MMBTU
Biomass, 0.01 GR/SDCF	50 %	99+%	3 GR/SDCF	1.49 GR/SDCF
FCCU - Two stages of cyclones, 1 LB/KLB	60 %	85+%	20 pounds per 1000 pounds of coke burn-off	11.1 pounds per 1000 pounds of coke burn-off
FCCU – With third stage separator, 1 LB/KLB	90 %	50+%	2 pounds per 1000 pounds of coke burn-off	0.8 pound per 1000 pounds of coke burn-off
Rock Processing Kilns, 0.02 GR/SDCF	5 %	99.6+%	100 GR/SDCF	4.98 GR/SDCF
Recovery Boilers, 0.01 GR/SDCF	90 %	99.8+%	10 GR/SDCF	9.99 GR/SDCF
Oil-Fired Boilers, 0.03 LB/MMBTU	70 %	85+%	0.3LB/MMBTU	0.18 LB/MMBTU

Figure 3 shows that the percentage of solid PM-2.5 in ESP inlet flue gases can vary widely. Depending on process type and upstream pre-collection, the amount of solid PM-2.5 in flue gases can vary from the range of near 0% to near 100%. However it is miss-leading to consider that flue gases with low percentages of PM-2.5 do not emit much PM-2.5. Some of the rock processing type kilns have a lot of very large particles, but they also have a considerable level of PM-2.5. This is because of the very large particulate concentrations in these flue gases. Some other applications such as FCCU with third stage separator, have almost all PM-2.5. But due to the pre-collection, the total particulate concentrations are very low. So collecting PM-2.5 can be critical on both types of applications.

Dry ESPs are able to collect these materials at very high efficiencies, with 99+% collection of PM-2.5 being very typical. Other applications with lower collection efficiency on PM-2.5 result because the inlet loadings are very low in general. These low collection efficiencies on PM-2.5 are not the result of a lesser capability to collect fine material on these applications. Instead the low efficiencies result from not having much PM-2.5 mass loading to collect from.

SUMMARY

Dry ESPs have been proven to be highly efficient in reducing fine solid particulate matter (i.e. PM-2.5), but at a somewhat lower fractional efficiency than the total particulate efficiency. However, care must be taken in clearly understanding the regulated PM-2.5 requirement. If gaseous components (condensibles) are included as PM-2.5, alternate technology may be required. Once these factors are clearly understood, specific PM-2.5 emissions requirements can be designed for and achieved with a dry ESP.

REFERENCES

1. Impacts of ESP Performance on PM-2.5, Robert Mastropietro, European Particulate Control Users Group Meeting, Pisa, Italy, November 7, 2000.
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