Factors affecting particulate removal efficiency of kraft recovery boiler electrostatic precipitators: a technical review

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ABSTRACT: Electrostatic precipitators (ESPs) are used in most pulp mills to remove particulate from recovery boilers, power boilers, and lime kilns. As environmental regulations have become increasingly stringent in recent years, maintaining high ESP performance is of vital importance in mill operation. This paper discusses results of a literature review of the ESP technology used in industrial combustion units, including recovery boilers, as well as results of a parametric study using the well-known Deutsch-Anderson equation to correlate recovery boiler operating conditions with ESP collection efficiency. The results show that for particles up to about 0.3 µm, the ESP collection efficiency decreases drastically with increased particle size and with decreased temperature. For particles larger than 0.5 µm, however, the trend reverses; the collection efficiency increases with increased particle size and decreased temperature. The results also suggest that the particle concentration (or loading) in the flue gas has no effect on collection efficiency and that sodium chloride particles are more readily captured than sodium sulfate particles. The latter prediction, however, appears to be in contradiction with mill experience that sodium chloride particles are more difficult to capture.

Application: Mills can maximize their boiler throughputs by better understanding key operating factors that affect electrostatic precipitator performance.

While air quality standards have become increasingly stringent over the past few decades, the removal of particulate matter (PM) entrained in flue gases from various industrial combustion processes have been the concern of engineers and scientists for much longer. Devices used to remove PM from boiler flue gases can be either mechanical or electrical. Cyclones and filters are the main devices that rely on mechanical principles to remove particles, while the electrostatic precipitator (ESP) is the most common device that relies on electrical principles. Electrostatic precipitators are preferred over their mechanical counterparts because of their ability to treat larger volumes of gas at higher removal efficiency (up to 99.9%) and with lower pressure drop.

This paper discusses the development history of ESP technology, the operating principles, and results of a sensitivity analysis to examine the effects of temperature, ash composition, and concentration on the collection efficiency of ESP.

HISTORY OF ESP TECHNOLOGY

The Greeks were believed to be the first to make use of electrostatic phenomena to attract and remove fine particles [1], but it was not until the eighteenth century that the science behind this concept was explained as a result of advances in the fields of electricity and magnetism. The first application of electrostatic precipitation was the equipment commercialized in 1907 for collecting condensed sulfuric acid fumes [1]. The technology was then adopted by the mining industry in 1910 and the cement industry in 1911. It was not until 1916 that an electrostatic precipitator (ESP) was first used by the pulp and paper industry to collect alkali salts from evaporators and later, in the 1930s, on recovery boilers. The motive behind using an ESP in the pulp and paper industry at the time was mainly economical; the intent was to recover valuable alkali salts rather than to reduce particulate emissions [2]. The rapid increase in coal-fired boilers for power production in the early 1920s spurred the use of ESPs as a means of capturing fly ash particulates from coal combustion and established ESP as the most common particle capturing technology to clean flue gases.

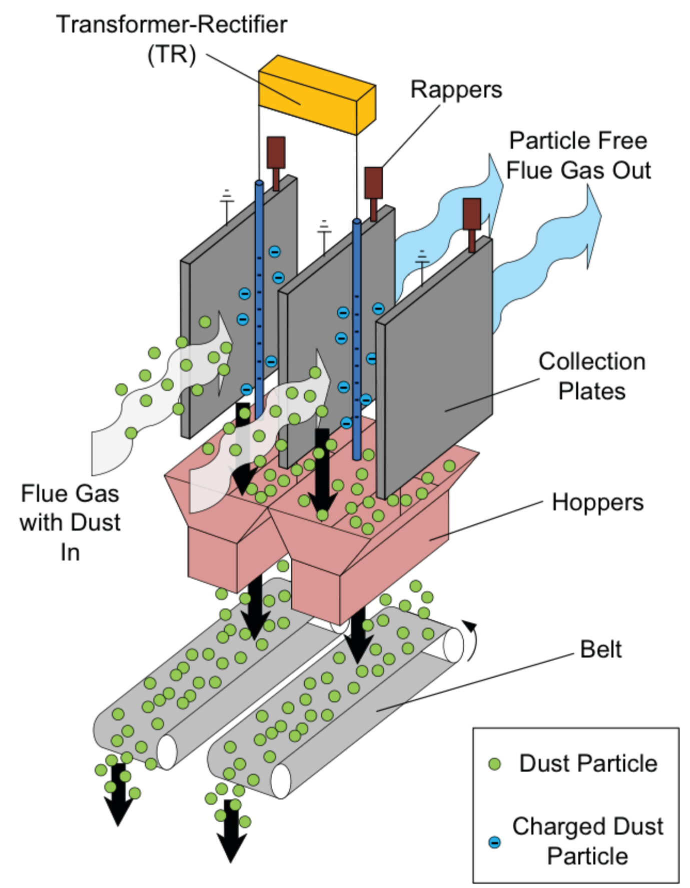
As ESPs became increasingly accepted as an effective method for removing particulates from flue gases, advances in ESP technology initially aimed at increasing the collection efficiency. As the removal efficiency approaches 100%, the focus of improvements shifted toward making the ESP more compact and able to handle changes in boiler operation, which lead to wide variation in dust load, as well as increasing the equipment life. These improvements were possible thanks to various research programs on ESP technology. Some research focused on improving the mechanical components of the ESP, mainly the high voltage electric circuit, and the mechanics of deposit removal from the collection surface.

Advances in computational power have also helped researchers to develop models to simulate flows in the ESP and predict its performance under different conditions. Numerical models have been used in various ways; some simulated particle charging [3,4] and others attempted to understand the overall particle removal process and how it is affected by different ESP parameters [5,6]. Other models have been used to simulate full-scale ESPs, either to simulate the gas flow through the ESP and determine how that could affect particle collection [7] or to simulate the particle collection mechanisms inside an ESP to determine its collection efficiency [8]. Tests have also been performed to examine the impact of ash composition and flue gas conditions on the performance of either full-scale ESPs [9-11] or laboratory-scale ESPs [12-14].

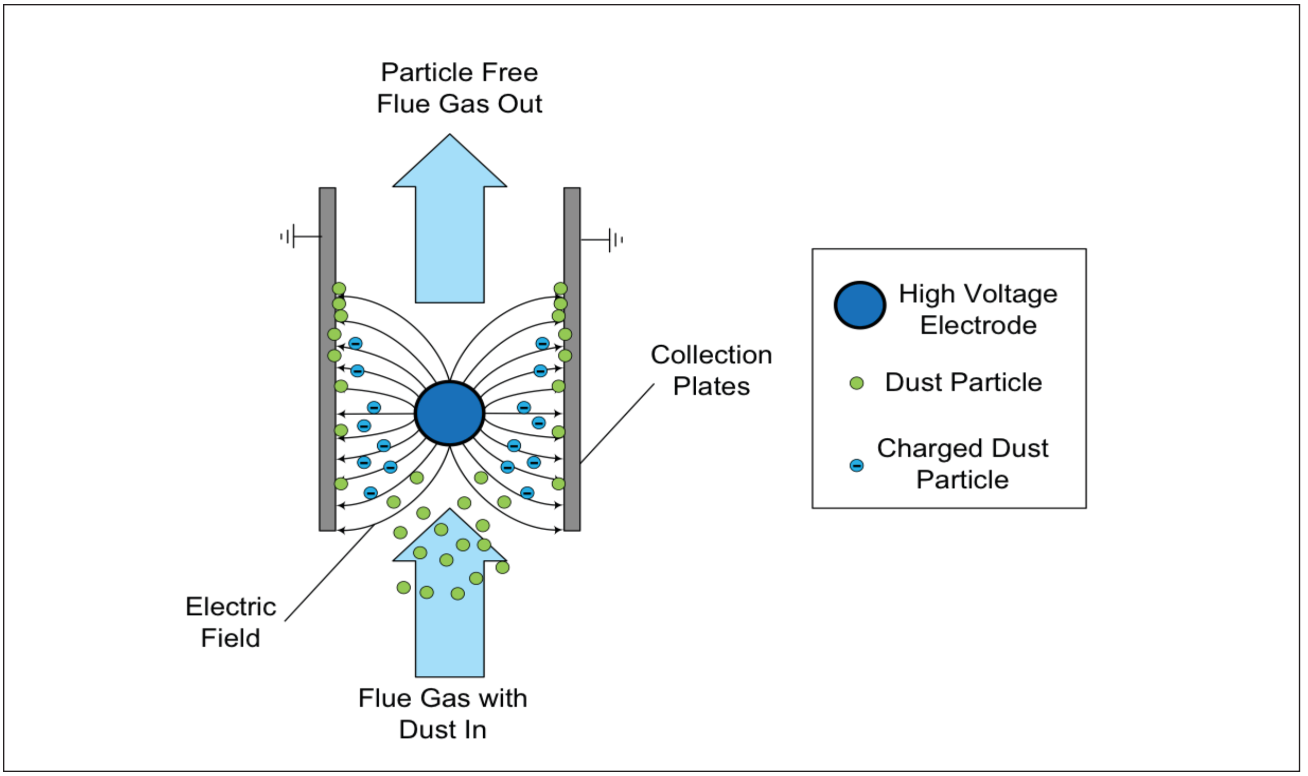
An important factor affecting the ESP performance is the electrical resistivity of the fly ash. The fly ash resistivity has an optimal range where it is easiest to capture and discharge from the ESP. Any increase or decrease from that optimal value results in a decrease in collection efficiency. A common belief is that high-resistivity ash particles are more difficult to charge and therefore cannot be collected well [15,16]. Once charged, high-resistivity ash particles are less likely to lose their charge. This means that once the particles have deposited on a collection plate, they cannot lose their charge readily and so would tend to be more tenacious and keep buildup on the collection plate due to the electrostatic attraction between the charged deposited dust and the plate. This, in turn, would reduce the voltage difference between the collection plate and discharge electrode, lower the electric field strength, and negatively affect the collection efficiency. Low-resistivity ash particles, on the other hand, can be collected more efficiently but also can be discharged more readily. As a result, they may fall off the plate and become re-entrained in the flue gas [17].

While there has been extensive research done on the performance of ESP in coal-fired boilers, little attention has been given to date to ESP in recovery boilers. Research to understand the behavior of ash in the recovery boiler ESP is limited to a review of ESP application to recovery boilers [18], a comparison between the performance of two ESPs from two different recovery boilers [11], and a study on factors affecting the resistivity of fly ash in recovery boilers [19].

Ash particles entrained in the flue gas at the inlet of a recovery boiler ESP are mainly condensed alkali fume that con-



1. Electrostatic precipitator (ESP) operating principle and main components (Adapted from "Conceptual diagram of an electrostatic precipitator" by E. Mason, Wikimedia Commons licensed under CC BY-SA 3.0).



2. Three-step process of particle collection in an ESP.

sists of sodium sulfate (Na_2SO_4) and sodium carbonate (Na_2CO_3) with a small amount of sodium chloride (NaCl) and potassium salts. Such ash composition differs substantially from that of coal-fired boiler ash, which is made of mainly silicates, oxide minerals, and unburned carbon [20]. Recovery boiler ash also has a much smaller and more uniform particle size (typically 0.3–0.6 µm). These differences likely make recovery boiler ash particles behave differently in the ESP than coal-fired boiler ash particles.

ESP DESIGN AND OPERATING PRINCIPLES

As shown in **Fig. 1**, the two main components that make up an ESP are a high-voltage discharge electrode system and a series of neutral grounded collection plates. The high voltage between the discharge electrodes and collecting plates is provided by a transformer-rectifier (TR) set. There are two basic dust removal mechanisms required in an ESP application. The first is a rapping mechanism that dislodges deposits from the surface of the collection plate and the second is a discharge mechanism (typically a hopper and a chain conveyor) that transports the collected particles out of the ESP.

Particles are removed from the flue gas by mean of electrostatic force. The high voltage between the electrode and the collection surface is needed not only to charge the particles, but also to set up an electric field in the space between the electrode and the neutral collection plate. The combination of an electrode and collection plate arrangement is referred to as a field. In a typical ESP design, there are multiple fields in series. The flue gas flow through each field is usually split in parallel chambers to allow for maintenance of one chamber at a time without shutdown of the other chamber.

The removal of a particle in an ESP is a three-step process as shown in **Fig. 2**. In the first step, the particles entering the space between the electrode and the collection plate collect ions generated at the high voltage electrode. There are two main mechanisms through which a particle acquires the charge: diffusion charging and field charging. Diffusion charging is a result of the collision of charges undergoing Brownian motion with the particle. Field charging is a result of charges being driven toward the particles by an electric field created between the electrode and the uncharged particles. Diffusion charging is known to be the dominant charging mechanism for small particles (<0.3 µm) while field charging is dominant in larger particles (>1 µm). Particles in the size range between 0.3 µm and 1 µm are subject to both mechanisms.

In the second step, a force is created by the electric field on the charged particle. This electrostatic force results in the particle accelerating towards the collection plate. As the particle accelerates and gains velocity, an opposing increasing drag force is generated on the particle. The two opposing forces rapidly balance out as the particle reaches its terminal velocity. This terminal velocity is also known as the migration velocity.

In the third step, the charged particle impacts the collection surface where it sticks and loses its charges. As more and more particles impact the collection surface with time, an ash layer is formed, causing the collection efficiency to decrease. For the ESP to perform as designed, the ash layer must be periodically removed from the collection plates.

There are a variety of ESP designs. Geometry is one feature that defines the type of ESP used. The two most common geometries are the rigid tube-and-plate design and the rigid tube-and-cylinder design. Another feature that defines the type of ESP is the number of stages in which the charging and removal processes are carried out. In a single-stage ESP, the charging of the particles and the collection take place in the same stage. In a two-stage ESP, the particles are charged in one stage and collected in another stage. Another feature that distinguishes one type of ESP from the other is the way in which ash build-up is removed from the collection plates. One type of ESP is known as dry ESP and the other type as wet ESP. A dry ESP or wet ESP is used depending on the application whereas wet ESPs are more commonly used to recover liquids. In dry ESPs, which are more commonly used, the removal of particles from the collection plates is carried out by means of mechanical rappers. The impact of the rappers on the collection plates results in vibrations that cause the deposit layer to fall off. In wet ESPs, a liquid (typically water) is sprayed on the collection plate to wash off deposits that build up.

The three design parameters often used to estimate the capture efficiency of an ESP are the particle migration velocity, the gas flow rate, and the collection area. The particle migration velocity is affected by the field strength, the particle size, the particle electric properties, and the viscosity of the gas. By setting a desired collection efficiency and using an estimate of the ash properties and the flue gas flow rate, the required collection area can be determined to size the ESP. A commonly used parameter in ESP design is the specific collection area, which is obtained by dividing the precipitator collection area by the flowrate.

The simplest equation that can be used to estimate the collection efficiency of an ESP is known as the Deutsch-Anderson equation (Eq. 1) [21,22]:

$$\mathrm{Eff} = (1\text{-}e^{-\omega\left(\frac{A}{Q}\right)})\times 100 \quad (1)$$

where ω (m/sec) is the particle migration velocity, Q (m^3/sec) is the flue gas flow rate, and A (m^2) the effective collection area. The migration velocity, as explained earlier, is the velocity at which the electric force applied on the particle is in balance with the drag force. As such, it is expressed as Eq. 2:

$$\omega = \frac{n\,e\,E\,C_c}{3\pi\,\mu\,d_p} \quad (2)$$

where n is the number of charges acquired by the particle, e (C) is the elementary charge, E (V/m) is the electric field strength, C_c is the Cunningham slip correction factor, μ (Pa·s) is the viscosity of the gas, and d_p (m) is the particle diameter.

There are several approaches to determine the number of charges acquired by a particle [4], the simplest of which is using the constant charge model. This model assumes that particles instantaneously achieve their saturation charge as a result of field and diffusion charging, and the number of charges is given by Eq. 3:

$$n = \left[(1+\frac{2\lambda}{d_p})^2 + \frac{2(\varepsilon-1)}{(1+\frac{2\lambda}{d_p})(\varepsilon+2)}\right]\pi\varepsilon_0 E d_p^2 \quad (3)$$

where λ (m) is the ionic mean free path of the gas, ε is the dielectric constant of the particle, and ε_0 (F/m) is the permittivity of air.

The Deutsch-Anderson equation is theoretical and derived from fundamental physical principles. It well describes the charging and collection of the particles. However, when applying it to estimate the collection efficiency of an ESP system, the equation is known to have several deficiencies that prevent it from accurately predicting the actual ESP efficiency. First, the equation can only be applied to particles of uniform size while in reality particles entering the ESP are known to have a nonuniform size distribution. Second, the equation does not consider the re-entrainment of particles after they have been collected. Finally, the equation takes into account the dielectric constant of the particles, but not the resistivity which is the most common factor considered when designing an ESP.

A deviation to the Deutsch-Anderson equation that is more commonly used for ESP design is the Matts-Öhnfeldt equation (Eq. 4) [23]:

$$\mathrm{Eff} = (1\text{-}\,e^{-\omega_k\left(\frac{A}{Q}\right)^k})\times 100 \quad (4)$$

The Matts-Öhnfeldt equation takes a more practical approach to ESP design. As with the Deutsch-Anderson equation, Q represents the flue gas flow rate and A the effective collection area. The migration velocity ω_k uses the subscript to distinguish it from the calculated migration velocity in the Deutsch-Anderson equation. The dimensionless parameter k in the equation varies between 0.4 and 0.6 depending on the dust properties and standard deviation of the particle size distribution. The values for variables in this equation, mainly the migration velocity and the dimensionless k, are based on empirical values obtained from historical data of full installations, and they vary for different ESP manufacturers. The values are determined on the basis of fly ash resistivity and the application.

PROBLEMS IN ESP OPERATION

Despite the wide use of ESPs in recovery boiler operation, there are still problems in operation and maintenance that can affect the ESP efficiency. It is often difficult to fine-tune the ESP operation to respond to large changes in boiler operation, such as increased boiler firing loads, combustion air flowrate changes, and high solids firing. These changes result in changes in flue gas flow rate, temperature, moisture content, particle loading, composition, size, and size distribution. These changes in process conditions inevitably affect the ESP efficiency.

Under normal conditions, the collection efficiency of an ESP is typically >99.5%. This high collection efficiency means, however, that a slight decrease in efficiency can cause particulate emissions to increase several fold, as shown in **Fig. 3**. For example, a 1% decrease in efficiency from 99.5% (point A in Fig. 3) to 98.5% (point B in Fig. 3) results in three times as much particulate emissions. Such a large increase in particulate emissions can cause mills to be out of regulatory compliance. When this happens, mills must lower the black liquor firing load (and hence the pulp production capacity) to keep their particulate emissions under control.

For a given ESP, the collection area and the gap between plates are fixed. The only way to maintain the high efficiency without extensive ESP equipment modifications is to change either the ash cleaning frequency or TR controller settings. Therefore, it is important to consider potential future changes in boiler operation in the design and installation of the ESP.

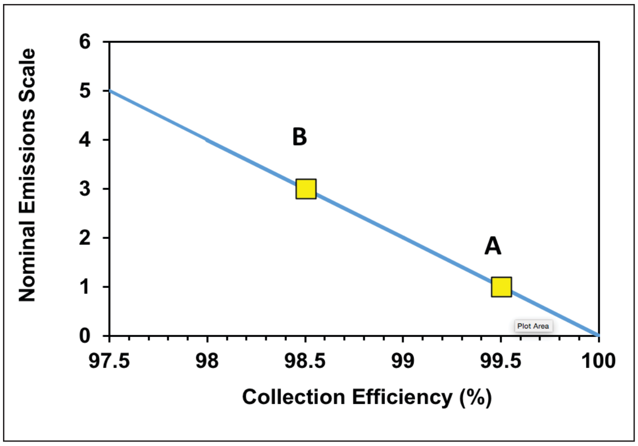
Another common problem in ESP operation is the heavy buildup of ash deposits on the collection plates and flue gas distribution media. This can lead to premature sparking, grounded electrical sections, and flue gas channeling caused by massive ash buildup. All of these can deteriorate ESP performance. Recovery boiler ESPs typically are designed with safeguards such as a larger than theoretically required collecting surface area to achieve emission compliance with one or more TR sets out of service or multiple ESP compartments (usually two), each of which can be isolated from gas flow, allowing safe personnel entry. Typically, each chamber is sized to handle 70% of the full rated gas flow to be able to maintain a high boiler load with flue gas passing through only one chamber while maintenance is performed on the adjacent chamber.

Although the previously mentioned measures are usually sufficient to help mills meet particulate emission requirements, a better understanding of key operating factors that affect ESP performance can help mills to maximize their boiler throughputs.

SENSITIVITY ANALYSIS

Using the Deutsch-Anderson equation (Eq. 1) and other equations needed to calculate its parameters (Eqs. 2 and 3), a sensitivity analysis was performed on a typical recovery boiler ESP to determine the effects of particle composition and flue gas temperature on the collection efficiency. The Deutsch-Anderson equation is used instead of the Matts-Öhnfeldt equation for several reasons, mainly because the purpose of this analysis is to study the collection efficiency without considering the effect of deposit formation or re-entrainment. Also, the Deutsch-Anderson equation does not require the use of any empirical values for the analysis.

A typical ESP requires the specific collection area of 200–600 ft^2 per 1000 ft^3/min (or 656–1968 m^2 per 1000 m^3/min) of flue gas. The voltage applied ranges from 55 to 70 kV, depending on the distance between the discharge electrode and the collection plate. The gap between the two adjacent plates is 6–12 in. (15–30 cm). The ash particle size varies between 0.3 μm and 0.6 μm. In this parametric analysis, the values used in the calculations are as follows: specific collection area (400 ft^2/1000 ft^3/min [1312 m^2/1000 m^3/min]), voltage (60 kV), plate spacing (12 in. [30 cm]), and particle size (0.01–10 μm).



3. Effect of ESP collection efficiency on particulate emissions.

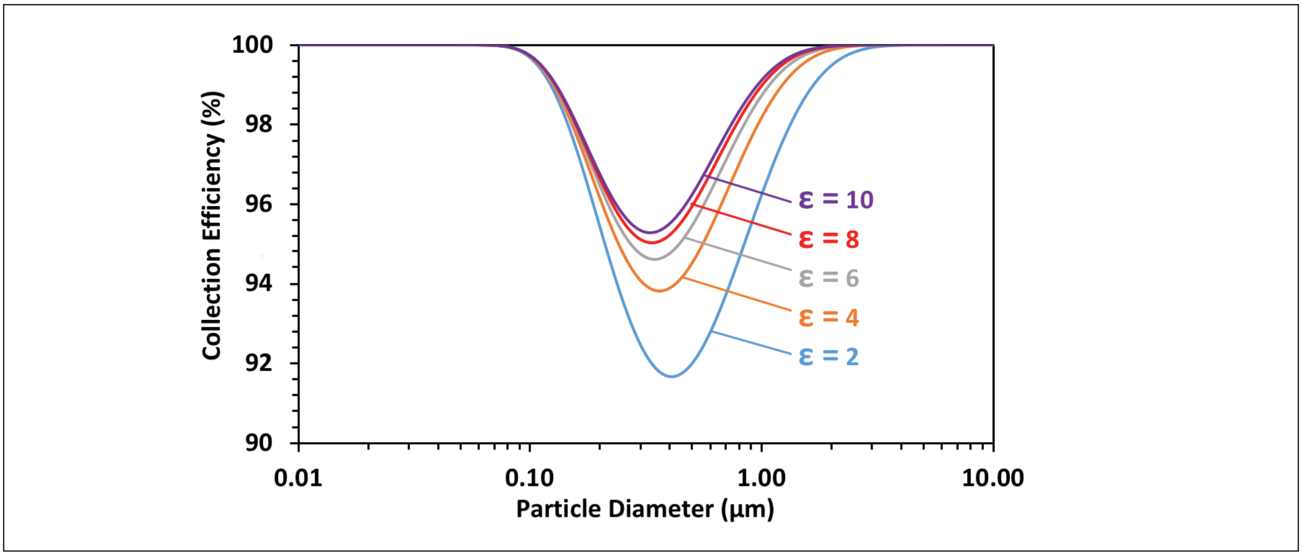
Compound	Dielectric Constant
Sodium sulfate (Na_2SO_4)	2.7
Sodium carbonate (Na_2CO_3)	8.4
Sodium chloride (NaCl)	3.2
Potassium sulfate (K_2SO_4)	5.9
Potassium carbonate (K_2CO_3)	5.6
Potassium chloride (KCl)	5.0

I. Dielectric constants for compounds found in recovery boiler ash.

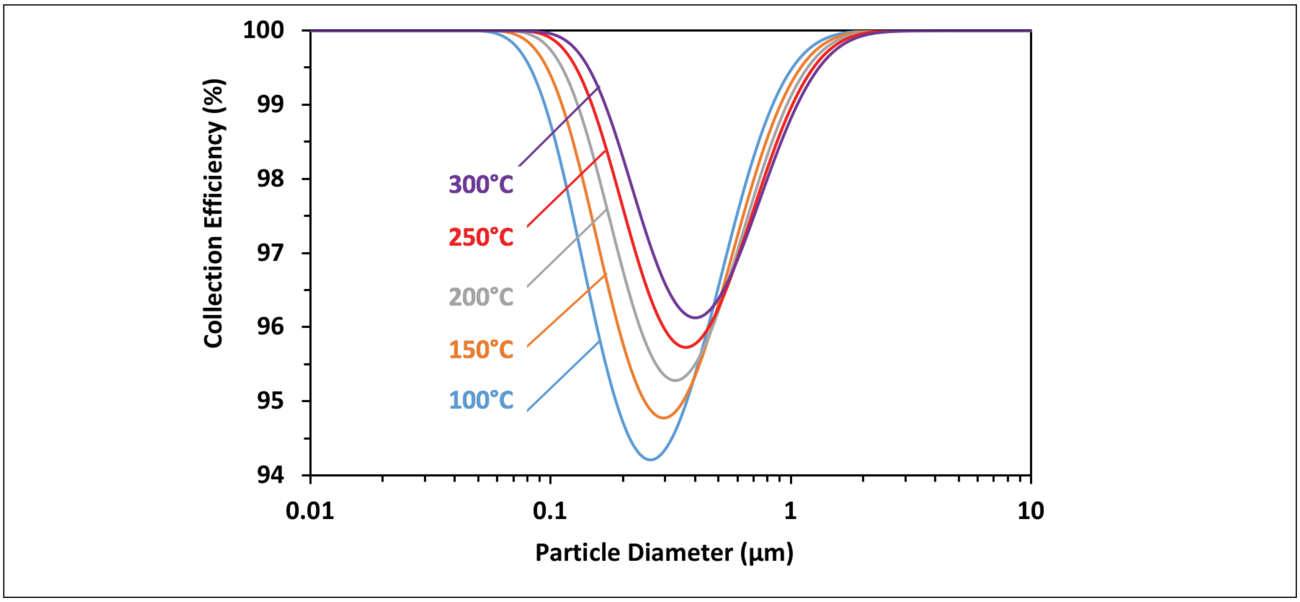
Effect of chemical composition

To determine the effect chemical composition has on the collection efficiency using the Deutsch-Anderson equation, information regarding the dielectric constant is needed. Recovery boiler ash is made up of a mixture of compounds whose dielectric constants are summarized in **Table I**. The dielectric constants for fly ash compounds vary between 2.7 and 8.4. The analysis is therefore done for a dielectric constant between 2 and 10 to cover this range, and the results are shown in **Fig. 4**.

The results show that the collection efficiency is lowest for particles around 0.4 μm. As particle size increases, the collection efficiency decreases for particles less than 0.4 μm, where it reaches a minimum and then increases beyond that point. This is consistent with the charging modes of particles explained earlier. Small particles are dominated by diffusion charging, while big particles are dominated by field charging. The particles in the middle range, even though subject to



4. Effect of the particle dielectric constant ε on calculated ESP collection efficiency.

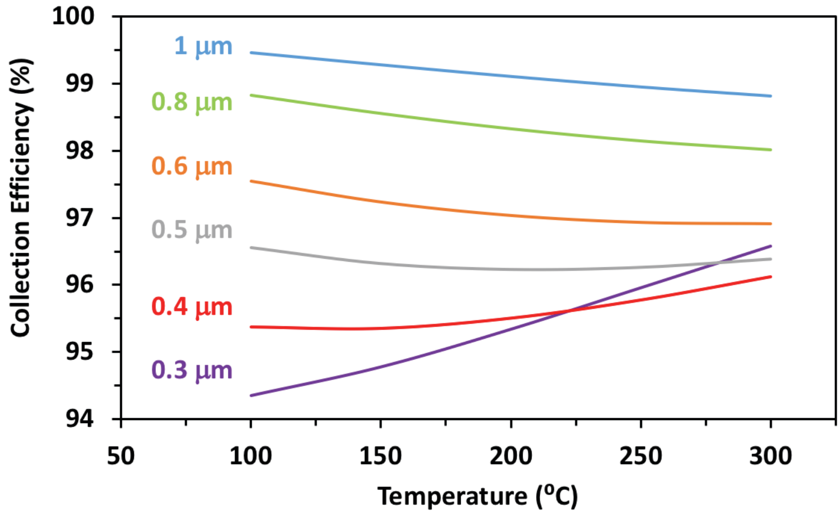


5. Effect of temperature on ESP collection efficiency.

both modes, carry the least charges and therefore are harder to collect.

The Deutsch-Anderson equation predicts that for an increase in dielectric constant, the collection efficiency increases for all particle sizes. A higher dielectric constant means that particles can carry a higher charge leading to a higher migration velocity and ultimately to a higher capture efficiency. This implies that Na_2SO_4, which has a dielectric constant of 2.7, is harder to capture than NaCl, which has a dielectric constant of 3.2. The graph also shows that for the same increase in dielectric value, the difference in collection efficiency is higher for smaller values of the dielectric constant.

The prediction, however, is not consistent with actual experience where ash with a higher NaCl content tends to be more difficult to capture. The discrepancy between the Deutsch-Anderson equation prediction and the actual experience can be attributed to a combination of two distinct factors: Particle composition, and particle size. In the model used previously, the particles are assumed to be pure compounds to determine the extreme scenarios. In reality, recovery boiler ash is mostly made up of Na_2SO_4, and the difference between high chloride content and low chloride content is around 10% by mass. Because of that assumption, the variations in efficiency presented in Fig. 4 as a result of change in dielectric constants are inflated and smaller variation would be expected for the same particle sizes in reality. With that in



6. Effect of temperature on ESP collection efficiency for different particle sizes.

mind, particle size explains why ash with high chloride content exhibits lower collection. Ash with high chloride content typically has smaller particle sizes than ash with low chloride content [24]. That particle size difference is the main cause of the observed decrease in collection efficiency.

An explanation for the discrepancy can be attributed to the fact that NaCl has higher resistivity than Na_2CO_3 and Na_2SO_4 [19,25]. When high chloride ash deposits on the collection plate, its higher resistivity prevents it from losing its charge and being removed, thus causing a reduction in the voltage difference between the high voltage electrode and the plate. The decrease in voltage difference translates into a lower electric field. This, in turn, results in particles carrying lower charge, lower electric force, and eventually lower collection efficiency, as previously explained. Thus, the particle dielectric constant alone may not be enough to determine how the composition of the fly ash affects the collection efficiency.

Effect of temperature

Using the Deutsch-Anderson equation, the collection efficiency for different particle sizes at different temperatures was calculated as shown in **Fig. 5**.

The calculation results also show a shift in the size of particles that have the lowest collection efficiency. At 100°C, 0.25 µm particles have the lowest efficiency, while at 300°C, 0.4 µm particles have the lowest efficiency. For particles between 0.1 µm and 0.4 µm, increasing the gas temperature from 100°C and 300°C can result in an increase of up to 4% in efficiency. However, for particles larger than 0.6 µm, increasing the gas temperature decreases the collection efficiency, but only by about 1%. This change in behavior takes place in the particle size range between 0.3 µm and 0.6 µm. In **Fig. 6**, the effect of the temperature between 100°C and 300°C is shown for different particle sizes according to the Deutsch-Anderson equation. Particles smaller than 0.5 µm show an increase in collection efficiency with increasing temperature, whereas particles 0.6 µm and larger show a decrease in collection efficiency with increasing temperature. Particles around 0.5 µm show a nonuniform trend. The collection efficiency for 0.5 µm particles shows a minimum around 200°C. Before that point, the collection efficiency decreases slightly with increasing temperature, and changes trend after. From field experience, increasing temperature is known to reduce ESP performance, which is consistent with the prediction for a given particle size.

Effect of particle concentration

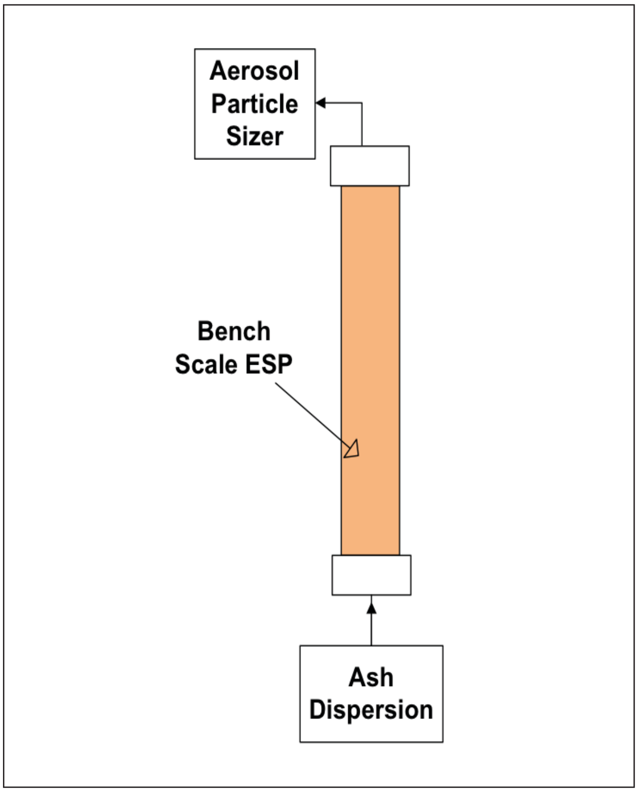
When taking into consideration all the variables used in the Deutsch-Anderson equation to determine collection efficiency, the particle concentration or loading in the flue gas does not alter any terms of Eq. 1 or complementary equations (Eqs. 2 and 3). On that basis, the Deutsch-Anderson equation predicts that particle concentration does not affect the collection efficiency. Similarly, the Matts-Öhnfeldt equation predicts that the particle concentration does not affect the collection efficiency. The only result of increasing particulate concentrations at the inlet is an increase by an equal fraction at the exit of the ESP. There have been previous studies that have considered the effect of particle concentration on the collection efficiency using numerical simulations; however, the predictions obtained were contradictory from one study to another. One study found that the collection efficiency decreases with increasing particle concentration [26], whereas another study found that an increase in particle concentration results in a slight increase in efficiency [27]. The ideal way to investigate the effect of particle concentration on collection efficiency would be through controlled laboratory experiments.

BENCH-SCALE ESP

While the temperature results from the sensitivity analysis performed agree with the common knowledge of ESP performance, other results regarding other factors in the analysis differed. The prediction of the Deutch-Anderson equation regarding the effect of ash composition contradicts experience, and the effect of ash loading also contradicted predictions by other mathematical models. To further explore the effect of the parameters discussed in the previous section, an experimental setup was designed and built in our laboratory at the University of Toronto. As shown in **Fig. 7**, the setup consists of three parts. The first part is an ash dispersion system that uses compressed air to disperse a recovery boiler precipitator ash sample into a cloud of dust particles. The second part is the bench-scale ESP, and the third part is an aerosol particle sizer (APS) that is used to count the number of particles in the gas stream.

The ash dispersion system, shown in detail in **Fig. 8**, uses a shaker to agitate a container that houses a precipitator ash sample collected from a recovery boiler. Compressed air is injected into the container near the sample surface to disperse the ash into a fine particle cloud. This ash cloud is then directed to the bench-scale ESP. Hot filtered air is used to dilute the sample and heat it to the desired temperature before entering the bench-scale ESP. The two control valves at the compressed air inlet and dilution air inlet are used to control total flow rate and dilution.

The detailed design of the bench-scale ESP is shown in **Fig. 9**. It consists of a 2-in. (5-cm) inside diameter by 1-in. (30-cm) long copper cylinder, a copper wire, Teflon caps, and a variable high-voltage power supply. The copper wire runs parallel to the copper cylinder at its center and is connected to the high-voltage supply. The copper cylinder acts as the collection plate of the bench-scale ESP and the copper wire acts as the discharge electrode. Teflon caps are used to enclose the ESP, isolate the copper wire from the copper cylinder, and allow for the sample to flow in from the ash dispersion system and out to the APS.



7. Components of setup for laboratory experiments.

The APS at the exit of the bench-scale ESP is an instrument typically used for ambient air particulate concentration measurements. It provides total particle number count as well as particle size distribution every second for particles in the size range between 0.3 μm and 20 μm.

To determine the collection efficiency at a certain voltage, the particle concentrations measurements are done with the voltage switched off and then with the voltage switched on. The recorded concentrations are then used to calculate the collection efficiency. The copper cylinder is cleaned frequently to prevent any ash buildup that could affect the performance.

To test the performance of the bench-scale ESP and ensure its performance is consistent with theory, experiments are run at different voltages. A curve fit is applied to the data obtained to test how well the data correlate with the theory. The form of the curve fit applied is shown in Eq. 5:

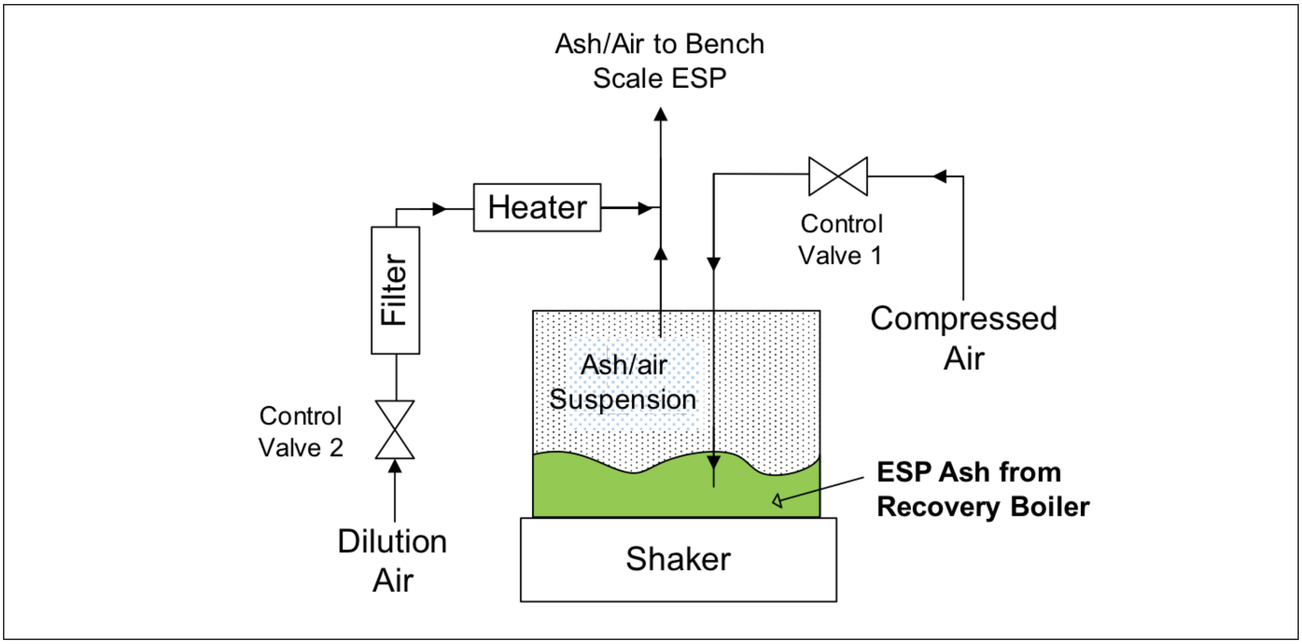
$$\text{Eff} = [1 - c_1 \exp(-c_2 * \text{voltage}^2)] \times 100 \quad (5)$$

The form used for the curve fit is obtained when the Deutsch-Anderson equation is rearranged to separate voltage as the only variable and take into consideration the fact that ash particles in the sample do not have a uniform size. The results are shown in **Fig. 10**. The experimental data correlate well with the curve fit. This indicates that the performance of the bench-scale ESP is consistent with that described by the Deutsch-Anderson equation.

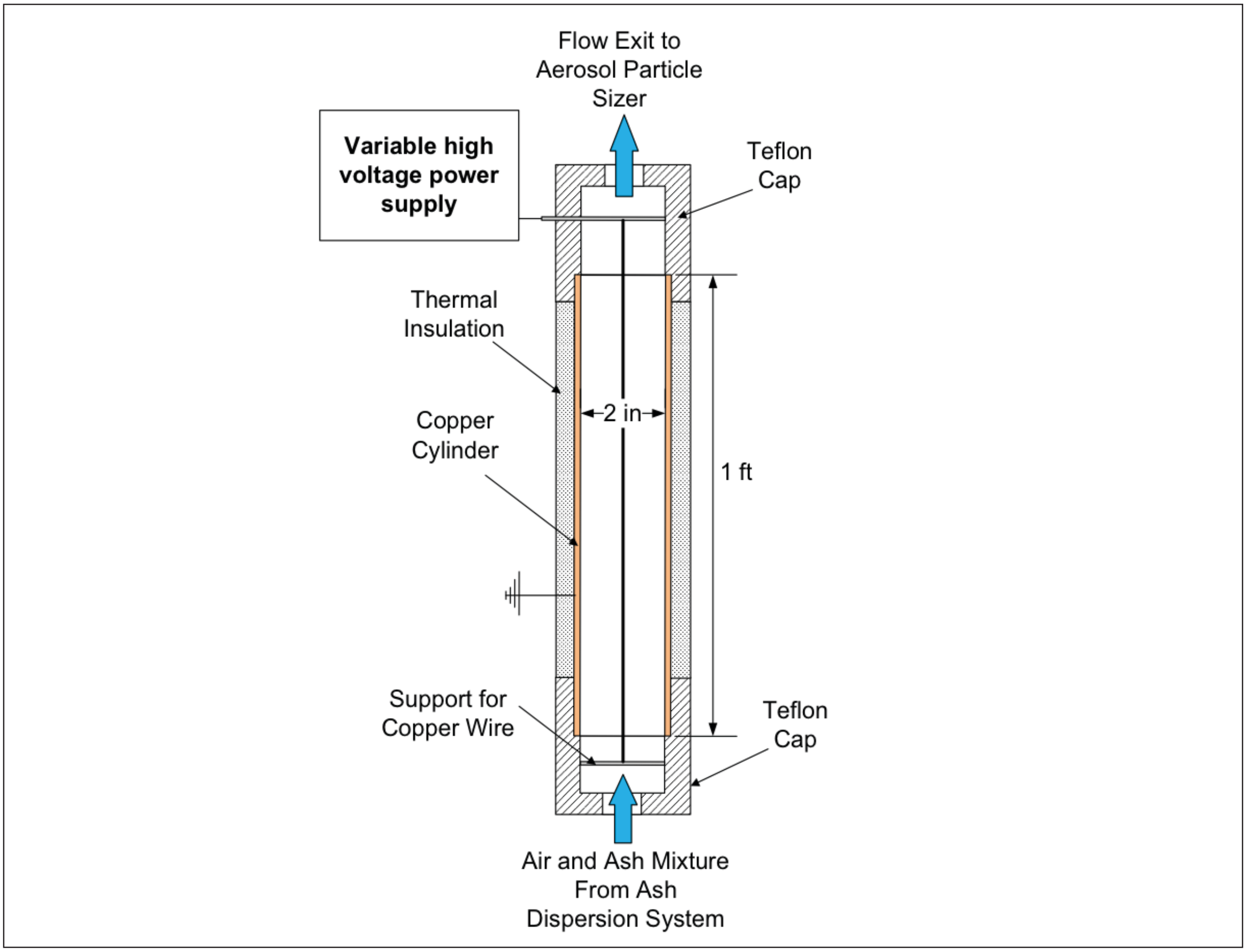
These results show that bench-scale ESP can be used as a reliable experimental setup. The next steps are to use the setup to test the effect of various parameters on collection efficiency. These include the parameters considered in the sensitivity analysis (composition, temperature, and concentration), as well as other potential factors such as applied voltage, moisture content, and sulfur dioxide content.

SUMMARY

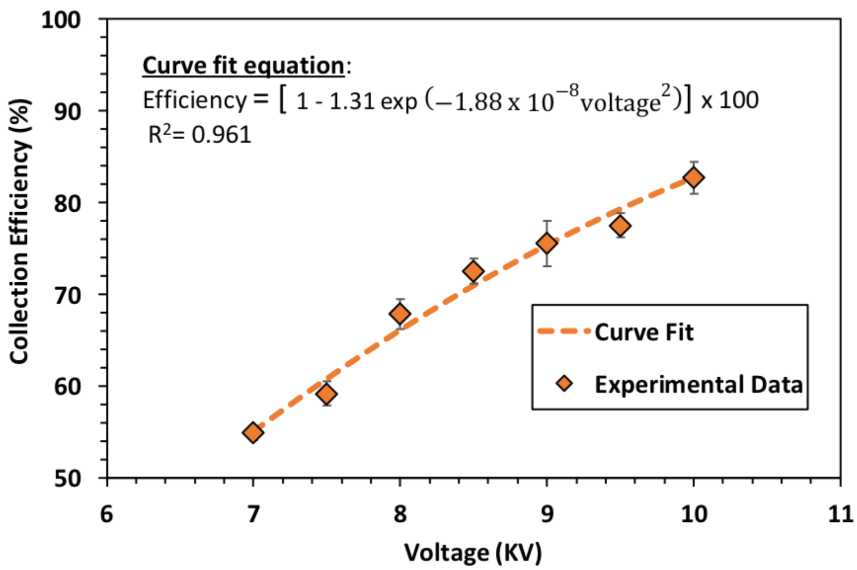
This work involved a literature review of the ESP technology used in industrial combustion units, including recovery boilers, and a parametric study using the Deutsch-Anderson equation to correlate recovery boiler operating conditions with ESP collection efficiency. The results suggest that up to about 0.3 μm, the ESP collection efficiency decreases drastically with increased particle size and with decreased temperature. For



8. Details of ash dispersion system.



9. Detailed design of bench-scale ESP.



10. Experimental data and curve fit of bench-scale ESP.

particles larger than 0.5 µm, however, the trend reverses; the collection efficiency increases with increased particle size and decreased temperature.

Particle concentration (or loading) in the flue gas in theory should have little effect on the collection efficiency; however, no experimental evidence exists to support that. Sodium chloride particles in the flue gas are more readily captured than Na_2SO_4 particles. This, however, appears to contradict mill experience that NaCl particles are more difficult to capture. A bench-scale experimental apparatus is being built to further investigate the effects of particle composition concentration and various ESP operating conditions on ESP collection efficiency. **TJ**

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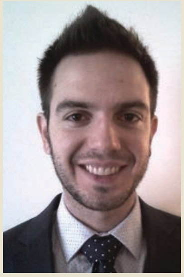
Sretenovic


Evans


Tran

We chose this topic to research because little work has been done to date on the effect of ash properties on recovery boiler electrostatic precipitator (ESP) performance. This is complementary to previous research that measured the recovery boiler ash resistivity and speculated how it might affect ESP efficiency. The current research investigated theoretically and experimentally how various ash properties might affect the efficiency.

The most difficult aspect of this research was to build a bench-scale ESP that could simulate a full-scale ESP. We addressed it by conducting an extended literature review and consulting with ESP experts. We discovered that it is possible to predict the effects of various ash properties and operating conditions on ESP performance using a simple equation. The findings were not surprising as most were expected.

This information can help mills identify the main causes of their high-particulate emission problems. Our next step is to conduct experiments using the bench-scale ESP under controlled conditions to determine the effects of flue gas conditions and fly ash properties.

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