Electrostatic Precipitators Performance Evaluation, Prediction and Data Extrapolation

A White Paper

The method of predicting precipitators performance has traditionally been based on preserving of the precipitation characteristics using sizing factors (effective migration velocity), derived from efficiency measurements using precipitators operating on similar process plants. Originally, the approach was based on the Deutsch equation, but as higher efficiency/lower emissions were demanded to satisfy legislative levels, sizing based on the Deutsch equation was found unsatisfactory and over the past 30 years, suppliers have found it necessary to use a modified equation, such as those derived by Maats-Ohnfeld of ABB Flakt or other.

Pilot precipitators are often used in the case of existing plants, or where new technological processes are being developed, as a means of determining the designs of full-scale precipitators and discovering any peculiarities of the particles. The main problem in the pilot precipitator technique is determination of the scale-up factor to be used in going from the pilot unit to the full-size precipitator, since it is well known that pilot units have the potential of operating much better per unit size than do full-scale precipitators. Particularly, the pilot unit will usually exhibit better electrical characteristics, gas velocity distribution and in many cases lower rapping re-entrainment losses than a full-scale unit. On the other hand, gas sneakage past electrical regions is usually greater in the pilot unit than in the full-scale.

The science and understanding of electrostatic precipitation has in recent years reached a high level. The physics of the electric fields, the charging of particles within the field, their migration velocity and collection, and the effect of the charged particles have become well understood. The mathematics that describes the physics has evolved. Low-cost, powerful personal computers (PCs) that are capable of finding solutions for the ESP‟s mathematical physics have become readily available. Software programs to perform the complicated calculations and predict the ESP‟s performance have been written. Electrostatic Precipitator models are based theoretical relationships, which accurately describe the individual

physical mechanisms involved in the precipitation process and on incorporating these relationships into a complete mathematical model for electrostatic precipitation.

CHAPTER 1. THE ELECTROSTATIC PRECIPITATION PROCESS

The most common form of electrostatic precipitator used for industrial gas cleaning is the so-called single-stage type in which the corona generating electrodes used to charge the dust particles, act also as the precipitating field electrodes.

The flow in such a precipitator is in fully turbulent range and the turbulence is further increased by the effect of electric wind resulting from the corona discharge. The turbulent velocity is thus high compared with that of the velocity of particles through the gas under the influence of the electric field. For this reason, the fundamental electrostatic equations cannot be used to calculate precipitator performance.

There is a further important effect: due to the turbulence, the probability of a dust particle being caught is determined by a number of factors, one of which is the frequency with which it is brought into proximity of the receiving or collecting electrode (CE). This is the reason why a precipitator, although somewhat less effective on fine fume particles, does not fall off so badly as the theoretical migration velocities calculated from pure theory of the motion of a charged particle in an electrostatic field would suggest.

Following, is a brief outline of generally accepted basic principles of the electrostatic precipitation process.

1.1 BASIC PRINCIPLES

An electrostatic precipitator must provide three essential functions:

- the suspended particles must be given an electric charge;
- the particles must be subjected to an electric field to enable them to migrate from the gas stream to a suitable collecting electrode, and
- the collected material mush be removed from the collecting electrode in an efficient manner and deposited in a receptacle with the minimum amount of loss.

The generally accepted theory of electrostatic precipitation states that as particles enter the electric field they become polarized, and, since the high-voltage (high-tension or discharge electrodes-DE) are generally negative, the particles are oriented with the positive zone opposite these electrodes. Electrons discharged from the DE quickly attach themselves to

gas molecules, which then become gas ions and begin to move under the influence of the electric field towards the collecting (grounded) electrodes/plates (CE). In so doing some of them collide with the positive zones of the polarized particles neutralizing these zones and leaving the particles with resultant negative charges. The particles now carry negative charges and in consequence move towards the CE under the influence of the electrostatic field. Laws, developed from the above concept and other similar concepts, generally refer to single particle charged in a known field, not necessarily the same field. No account has been taken quantitatively for the following:

- The interference of particles with one another. They are present in very large numbers and moving at different velocities.
- The electric field varies very much in the inter-electrode space and it is difficult to accurately predict even for cylindrical (pipe) type of the precipitator.
- Particles of equal size entering the field at different distances from the DE will carry different charges.
- The erosion or stripping/scouring of particles from the CE by the gas.

Next stage of the precipitation process is the deposition of the charged particle under the influence of the electric field. Dust is deposited predominantly on the receiving (hence, the name: „collecting") electrodes but there is a significant deposit of DE as well. Following, is dislodgement of the dust deposited by rapping or vibrating the electrode system. Only dust that falls into the hopper contributes to the efficiency of dust collection of the precipitator. Hence, ensuring the maximum amount of dust reaching the hoppers is one of the most important steps in achieving the highest possible efficiency

In practice, dislodged dust particles and agglomerates follow a trajectory determined by the horizontal gas velocity and the free-falling velocity in the vertical plane. The dust not falling into the hoppers is re-charged by the corona discharge, and re-deposited on the collecting electrodes. Subsequent rapping blows repeat the process until the dust either reaches the hopper or reaches the end of outer field and is carried by the gases out of the precipitator to the stack.

1.1.1 Deutsch Formula

The Deutsch formula based on statistical factors describes the efficiency of the electrostatic precipitator:

Equation 1. Deutsch Formula

$$E = 1 - e^{-\frac{\omega A}{V}}$$

where: E – Efficiency of dust collection;

e – exponential;

A - Receiving or Collecting Area

V - Gas volume to be treated;

ω - Effective Migration Velocity

The effective migration velocity used for design purposes is based on the measured efficiency of the precipitation determined by the dust sampling. It bears no relationship to values calculated from theoretical equation of the velocity of charged particles in an electric field. In practice, the use of the term migration velocity is highly misleading. The „Effective" migration velocity depends on the

- charging of particles and deposition on the collecting plates, and
- dislodging of deposited dust in agglomerates large enough to reach the hoppers.

The efficiency of dust collection clearly improves with increased rate of deposition on the CE and dislodgement of the dust layer in the form of the largest possible agglomerates.

It is commonly held belief that the effective migration velocity is constant for a given gas and dust condition and is determined only by these factors. In practice, both the essential stage described above, rate of deposition and agglomerate size dislodged, are also dependent on the design of the precipitator. Thus data obtained using one particular design should only be used in Deutsch formula calculations when the new plant is the same design.

The principle use of the Deutsch formula is to permit the use of measured data on a precipitator to be used to calculate the size of precipitators for different dust removal efficiencies. It is generally recognized that even for this purpose the formula has severe limitations and a number of modified versions are in use currently aimed, in particular, at correcting for the degradation of effective migration velocity, which occurs as the design efficiency of the precipitators increases.

1.2 FACTORS AFFECTING THE PRECIPITATION PROCESS

The factors affecting the efficiency of dust removal by a precipitator can be briefly grouped as follows:

- The property of the gas which determines to some extent the voltage which can be applied to the electrode system and hence the forces acting on the particle which affect deposition rate.
- The resistivity and thickness of the deposited dust, which also affects the corona discharge and the voltage, can be applied to the electrodes.

- The cohesive forces between the dust particles deposited on the electrodes and the means used to dislodge the dust layer. These determine the size of the agglomerates released and hence their free- falling velocity.
- The design of the discharge and collecting system, it"s spacing and geometry.

The list can be broken down into a much larger number of individual effects but the four listed above are the most relevant to the precipitator performance.

None of these is determinable with any accuracy by direct measurement and calculation from fundamental properties of the gas and dust. This makes it clear why, even if the fullest knowledge currently available on both dust and gas, it still does not make it possible to design precipitators for specific duties without actual precipitator efficiency tests, either on the application concerned or from accumulated data on closely similar duties.

CHAPTER 2. ELECTRICAL RESISTIVITY

Resistivity of the collected particulate layer has a significant importance on the operation of electrostatic precipitators. The amount of useful electrical power that can be supplied to a precipitator is limited for the most part by the electrical resistivity of the fly ash layer of the collecting plates.

Corona current from the discharge electrodes must pass through a collected dust layer on the plates to reach grounded collecting plate surfaces. Passage of the current builds up a voltage across a dust layer according to Ohm's law. Theory and experience suggest that when the dust resistivity exceeds a critical value of about mid 10^{10} Ohm-cm, corona current is limited by electrical break down in the collected dust layer. This, in turn, limits useful operating voltage and reduces precipitator efficiency. The loss in performance increases quite rapidly for resistivity greater than 10^{10} Ohm-cm, and resistivity is therefore a major factor in precipitator design [3]. Following is the generally accepted dust resistivity classification [1] in Ohm-cm:

Conductive:	10^4	to	10^8
Normal:	10^8	to	10^{10}
Moderate:	10^{10}	to	10^{11}
High:	10^{11}	to	10^{13}

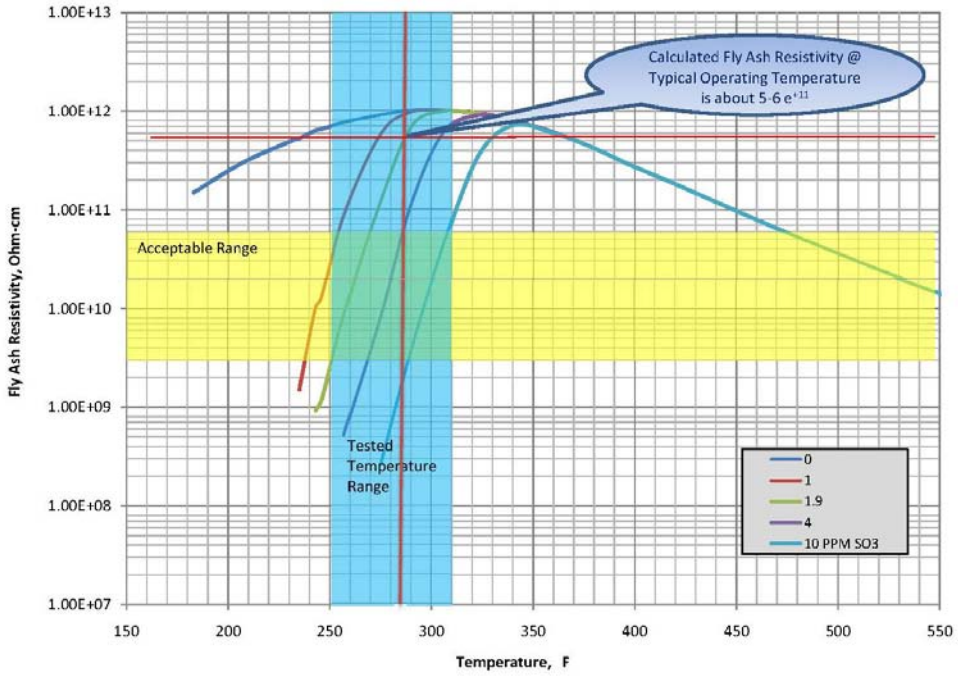
2.1 PREDICTION OF FLY ASH RESISTIVITY.

It is frequently necessary to estimate the resistivity to be expected from fly ash from

coals that may not be available for such measurements until the ESP and/or FGC system have been sized, designed, and installed. The U.S. EPA has sponsored development by Dr. Roy E. Bickelhaupt at the Southern Research Institute (SoRI) of a method for fly ash resistivity prediction using analysis of coal and ash [1]. Resistivity calculated by this method is in good agreement with actual field measurements, and form the basis for estimating of ESP performance.

Figure 1 presents fly ash resistivity calculated using this procedure. The right-hand portion of the traces is essentially a straight line descending from left to right, and represents the effect of volume conduction through the body of the fly ash material. Five lines are shown which descend from right to left. The leftmost line shows the effect of water vapors present in the flue gas, depicted as though no SO_3 were present. The inner lines illustrate the added effect of SO_3 for different concentrations. It is seen that the chemical composition of the ash and the water vapor content of the flue gas act to determine an upper bound for the resistivity values. The SO_3 quantities present, on the other hand, reduce the resistivity below the boundary values. Thus, if the resistivity resulting from the combination of flue gas and ash properties with the SO_3 naturally produced by combustion is higher than desired for best ESP operation at a particular temperature, a suitable lower value can be obtained by the introduction of additional SO_3.

Figure 1. Predicted Fly Ash Resistivity for Mingo Logan Coal.



2.2 FLUE GAS CONDITIONING

By far the largest body of work in the art of the fly ash gas conditioning has been de-

voted to attempts to lower the dust resistivity. Conditioning is as old as the art of precipitation itself. As early as 1912[3,4] it was discovered that copper converter dust precipitation was considerably enhanced by the presence of sulfur trioxide or increased moisture of exhaust gases. Water injection into gases from cement kilns and steel refining vessels has been used for many years, and ammonia treatment of catalyst dust in petroleum refineries was begun in the 1940's[2,3,4].

Introducing additives into flue gas to enhance the performance of electrostatic precipitators is well known and has been applied in commercial installations since the early part of this century. Commercial conditioning of fly ash usually involves the injection of a chemical into flue gas stream to control an electrical resistivity of a dust and improve its collection in an electrostatic precipitator. Currently, however, this term is assuming a much broader meaning, for conditioning involves processes other than resistivity modification (i.e., coagulation, agglomeration, cohesiveness improvement, etc.).

Flue gas conditioning of fly ash relies on one or more of the following effects:

- ✓ Modifying the surface electrical conductivity of the dust;
- ✓ Increasing the inter-electrode space charge, and/or
- ✓ Increasing dust cohesivity to reduce losses during rapping.

It has been proven now that chemical conditioning affords an alternative to increased precipitator size as a solution to fly ash collection form boilers burning low sulfur coals.

2.3 CONDITIONING BY SULFUR TRIOXIDE

The most common conditioning agent used for modifying high dust resistivity is sulfur trioxide [2]. In a typical utility application, two major factors control dust resistivity: the sulfur content of a coal, and the overall elemental composition of a dust.

Sulfur occurs in coal as organic and inorganic compounds - notably pyrite and sulfate salts. When coal is burned more than 95% of the sulfur appears in the flue gas in the form of sulfur dioxide. The kinetics of sulfur oxidation in boiler flue gas does not allow more than a small fraction of the oxides to appear as sulfur trioxide. When the temperature of flue gas drops to around 300 °C (about 572 °F), a significant fraction of the sulfur trioxide gas reacts with water vapor to produce sulfuric acid vapor. This process is essentially complete at temperatures around 150 °C (about 300 °F) where electrostatic precipitators normally operate (Table 1) [6].

The sulfuric acid vapor is adsorbed or condensed on an otherwise poorly conducting dust surface and directly participates in the electrical conduction process. At very low concentrations of sulfuric acid, vapor conduction in dust is principally influenced by the charge-

carrying ability of the alkali metal ions as affected by the interaction of water vapor and the dust surface. At high concentrations of sulfuric acid vapor, the conduction process is principally controlled by the adsorbed acid. At intermediate concentrations of acid vapor, both mechanisms contribute to the conduction process. Thus, in a strict sense, in cold-side precipitators resistivity modification results from sulfuric acid, rather than sulfur trioxide, effects.

The acid may, however, react with basic constituents of the dust and thus undergo conversion to a poorly conducting layer of sulfate salts. Calcium oxide, a fairly common component of dust from many coals, is a probable cause of acid neutralization and its nullification as a conductor. Thus, two materials similar in chemical content may produce similar concentrations of sulfur trioxide, but the one containing a more alkaline dust is likely to have a substantially higher resistivity.

Table 1. Equilibrium Distribution of Oxidized Forms of Sulfur at Various Temperatures[(a)]

Temperature		Relative Concentration of Sulfur Compounds, %		
°C	°F	SO_2	SO_3	H_2SO_4
1,400	2,552	99.7	0.30	0.00
1,000	1,832	97.6	2.4	0.0
800	1,472	88.7	11.3	0.
600	1,112	42.2	57.7	.1
500	932	12.3	87.3	.4
400	752	1.6	94.8	3.6
300	572	.1	59.3	40.6
200	392.	0.	6.5	93.5
100	212	0.	0.	100.

[(a)]Calculated from the data in JANAF Tables [2], assuming concentration of oxygen and water vapor equal to 4% and 10% by volume, respectively.

The sulfur trioxide conditioning is effective at flue gas temperatures below about 204 °C (400 °F) where surface conduction prevails. At higher temperatures, effectiveness of sulfur trioxide conditioning is decreased because the dust resistivity is partly or wholly determined by volume conduction, and also because the fraction of the available acid which condenses on the particles is reduced due to vapor pressure and equilibrium characteristics.

2.4 SO_3 Injection Rates Prediction

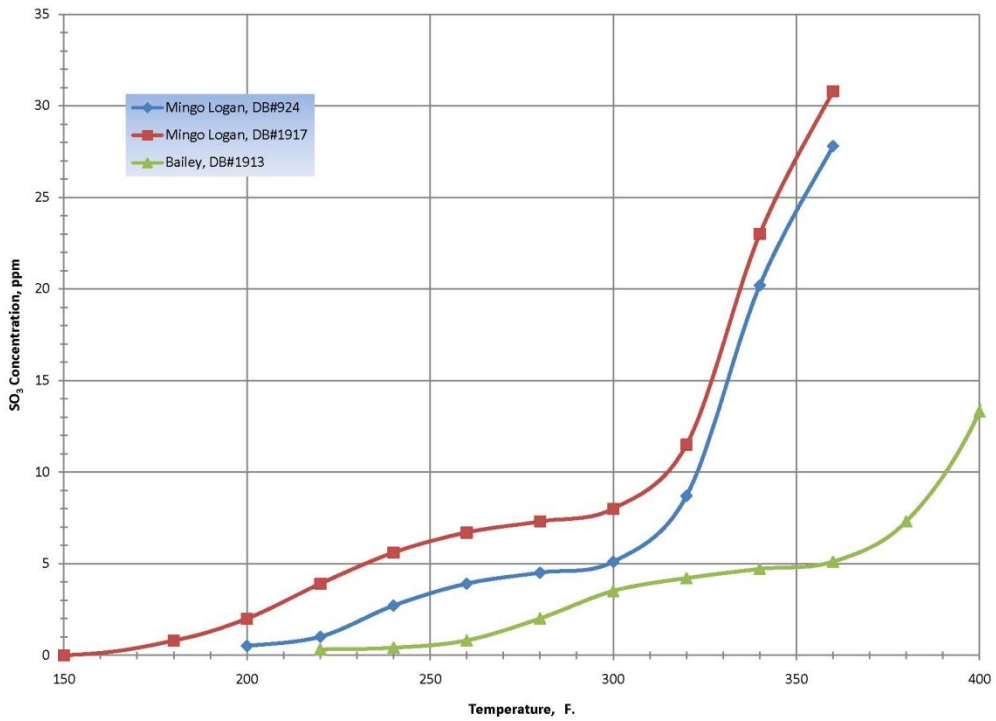
Since it is possible to make empirical estimates of the quantity of SO_3 naturally generated from fuel sulphur, the expected resistivity of the ash without addition of a conditioning agent can be estimated, and a decision can be made regarding the necessity for reducing re-

sistivity to improve collection.

The Bickelhaupt method cannot be directly applied to determining SO_3 injection rates because the SO_3 quantities used in the method are amounts in equilibrium with the gas-and-ash environment of a laboratory vessel, and these differ from injection requirements for flue gases containing suspended fly ash. Having an estimate of the ash resistivity without conditioning and knowing from experience the desired final resistivity to obtain best ESP performance, both at the intended operating temperature, simple subtraction gives the amount the resistivity is to be changed, and common sense says that the injection rate will be a function of this change. Similarly, the required injection will be a direct, but not necessarily linear, function of the quantity of ash to be treated. Other factors than these two will enter into determination of injection rates[5, 7].

Figure 2 presents predicted injection rates for the subject coals under evaluation. In essence, these are the iso-resistivity curves constructed based on the design fly ash resistivity of $1x10^{10}$ and $5x10^{10}$ Ohm-cm. Each of the plots shows a low temperature region that is essentially a reflection of the ash resistivity curve. As temperature is increased, both curves come to an inflection point at which transition is made to a rapidly rising characteristic that approximates a straight line. At temperatures below the inflection, point nearly all of the injected SO_3 attaches to the ash. At higher temperatures SO_3 injected in excess of the SO_3, level at the inflection point is necessary to provide partial pressure for attachment of sufficient SO_3 to the ash to obtain the desired resistivity.

Figure 2. SO_3 Injection Requirement



The difference between the injection level at low temperatures and that at a high temperature is a measure of excess sulfur trioxide that will escape from the stack at the higher temperature. The excess SO_3 above the inflection point level remains in the gas stream and, if the excess is about ten (10) parts per million or more, may be visible as a white-blue condensation plume from the stack.

It seems logical that the temperature at which inflection occurs is a function of ash surface conditions. It is a measure of susceptibility to attachment of acid, perhaps, inasmuch as the lower inflection temperatures occur for ashes having low base-to-acid ratios and the higher points correspond to higher ratios. The traces having the inflection point at lower temperatures represent coal ashes having very low base-to-acid ratios, typically, if Si + Al more than 85% and/or Si + Al + Fe are over 90-91%. The characteristics having the higher inflection point is for coals with lower Si + Al ratios. Although it is convenient to refer to these effects in terms of base-to-acid ratio, it should be remembered that this is only a rough general index to the inflection point temperature for discussion purposes; other factors appearing in the injection rate equation must be included for accurate determinations.

The inflection point effect explains some difficulties many experimenters have encountered in attempting adjustment of ash resistivity with a sulphur trioxide alone. In some low sulfur coals, the percentage of acidic compounds in the ash (aluminum oxide, iron oxide, and silicon oxide) is high (above about 90%). Here, the injection of a sulfur trioxide alone to reduce resistivity loses some of its effectiveness because the acidic sulfur trioxide cannot readily attach to the highly acidic ash at higher temperatures. Substantial amounts of excess sulfur trioxide must be injected while treating such ashes to produce a conductive film on the surface. If the operating temperature is much higher than the inflection point, no reasonable amount of injected SO_3 will be effective in reducing the resistivity

2.5 AMMONIA FLUE GAS CONDITIONING

Following is a brief discussion of the Ammonia Conditioning. Many investigators reported use of the ammonia conditioning with various degrees of success. Ammonia conditioning usually works best with the acidic fly ash. If injected ahead of the air heater tendency to plug (unless air heater temperatures were unusually high – 204 °C [>400 °F]) the air heater was reported as an additional, but unwanted result. Ammonia injection downstream of the air heater was reported to be unpredictable [8].

The use of ammonia (NH_3) for modification of dust resistivity has not been developed to the same degree as SO_3. Some experiments have shown that ammonia injection improved the collection of fly ash in ESP's, but it is not clear whether the improvement resulted from resistivity modification or other effects [9]. Other trials have shown almost no change in fly ash resistivity or ESP performance [10].

No effect of the ammonia on the fly ash resistivity was reported with any degree of certainty. There has been much debate regarding the use of ammonia alone for modifying the electrical resistivity of fly ash. One argument suggests that for high resistivity ashes a reduction in resistivity might be produced, permitting higher voltages and currents to be maintained without sparking or back corona. On the other hand, for lower resistivity ash an increase in resistivity due to neutralization of excess acid might permit a sufficient electric field to exist in the ash on the precipitator collection electrodes to overcome losses from rapping re-entrainment. The effect of ammonia appeared to be an enhancement of the space-charge component of the electric field. In addition, increase of the cohesiveness of collected ash and a reduction of the re-entrainment might be another "major player" in successful application of the ammonia conditioning.

While successes have been reported using ammonia as the sole conditioning agent for some low sulfur Australian coals, U. S. experience has been improved precipitator performance for some low sulfur coals and not for the others. It has been theorized that ammonia conditioning is more effective for acidic ashes in terms of the relative concentrations of acidic and basic oxides present (acid/base ratio) but this has not been true in every case [9]. Ashes having high acid/base ratios with small to moderate amounts of sulfur trioxide present in the flue gas typically have high resistivity. Thus, it may be that resistivity is reduced because of ammonium bi-sulfate acting to facilitate sulfur trioxide attachment. If little or no sulfur trioxide were present, ammonia alone might have little effect.

2.6 DUAL FLUE GAS CONDITIONING

Simultaneous injection of SO_3 and NH_3, arbitrarily called *Dual* conditioning, was mentioned earlier as assisting in obtaining attachment of SO_3 to fly ash at temperatures above the inflection point of the injection rate curve. Therefore, one may define a Dual FGC as a system that simultaneously and independently injects two conditioning agents, SO_3 and NH_3, into the flue gas stream. These agents work together in a variety of ways. It has been demonstrated that it may be used to control rapping and reentrainment losses from ESP's. It appears that the process can be crudely visualized as reacting the two conditioning gases to form ammonium bisulfate that has a melting point close to typical ESP operating temperatures. This is thought to act as a binding agent increasing the cohesivity of the ash particles so that they adhere to each other and fall into the hopper with reduced dispersion into the gas stream.

From the preceding description of the inflection point which appears in the injection-rate-versus-temperature curves it is clear that one criterion for needing dual conditioning is flue gas temperature exceeding the inflection point temperature. Criteria for advance determination of a need for dual conditioning to suppress excess rapping and reentrainment losses by means of fuel and ESP data have not yet been developed, partly because the factors affecting ash cohesivity in the ESP have not been explored or defined, and partly because the me-

chanical and fluid dynamic characteristics of the ESP which affect the magnitude of rapping and reentrainment losses may differ radically from one installation to the next and have not been subjected to any investigative procedures capable of developing applicable loss factors.

CHAPTER 3. PRECIPITATOR PERFORMANCE EVALUATION AND DATA EXTRAPOLATION

In general, three basic categories of pilot testing are of interest in connection with electrostatic precipitators:

- RANKING of an unknown dust – more difficult to precipitate or easier than other dusts in the ranking list.
- Obtaining the full-scale SIZING DATA for a new application or fuel source.
- Investigating the performance of novel precipitator HARDWARE or SOFTWARE.

Precipitator performance is conveniently described in terms of the migration velocity for the dust under prevailing operating conditions.

3.1 PILOT PRECIPITATOR FOR SIZING DATA

There is a potential possibility to calculate a basic migration velocity for most precipitators, using complex formulas, computers, and numeric analysis. The results may be off by a significant amount due to a lack of accurate input data. Specifically, the following properties (addressed above) of the dust have a great influence on the migration velocity and they cannot be predicted (as yet) by theory:

- Agglomeration, and
- Segregation.

As discussed, agglomeration plays an important role in dry precipitators. The precipitated dust is held in place on the collecting electrode surface by the interaction of the electric field and the current (continuing flow of charges through the dust layer). Rapping of the collecting electrode loosens the dust cake, which then slides down into the precipitator hoppers.

The effectiveness with which the dust cake is transported into the hoppers depends on how well the dust is agglomerated. Some dusts yield very coherent and heavy cakes that slide down without much re-entrainment into the gas steam. Electric particle alignment may cause other dusts to agglomerate into porous and lightweight aggregates, which are easily re-entrained on their way to the hoppers. The mode and timing of the rapping impulses will naturally make a great difference in this respect.

After a short time of operation, all internals of a precipitator will have a residual dust layer. The composition of this residual dust (grain size, chemistry, etc.) may be different from that of the bulk of the dust. Differences also occur between front, rear, upper and lower sections inside the precipitator. The dust has *segregated*. The residual dust tends to change the current distribution along the electrodes and increase the probability for sparks. To prevent continuing growth of the residual dust layer, the rapping should be frequent. To minimize re-entrainment, the rapping should be infrequent. A compromise must be found.

Model laws do not provide any numeric means of translating the influence of agglomeration and segregation from one geometry or a simulated operating condition to another. For this reason, the simulated (or pilot precipitator) used to yield sizing/evaluation data must be full-scale in as many respects as possible. The value of the migration velocity obtained in the simulated or pilot precipitator should be directly applicable to the full-scale plant.

Deutsch"s formula implies, however, that dust fractions with high migration velocity will be precipitated to a higher degree than those with low migration velocity. Then the catch will show over-representation of dust with high ω at the low precipitator efficiency, and the apparent ω value will be too high.

3.1.1 The Modified Deutsch formula

The modified Deutsch formula was designed to account for the dust fractionalization.

Equation 2. Modified Deutsch Equation

$$E = 1 - e^{(-\omega_k * SCA)^k}$$

where: ω_κ – dust constant = "modified migration velocity"

SCA - Specific Collecting Area (or $\frac{A}{V}$ as defined in the original Deutsch equation)

κ - a factor ranging from 0.4 (coarse grinds) to 0.8 (fumes).

The value of „ω_k" varies much less for different efficiencies than does „ω".

3.2 ESP COMPUTER MODELING

The science and understanding of electrostatic precipitation has, in recent years, reached new heights. The physics of the electric fields, the charging of particles within the field, their migration velocity and collection, and the effect of the charged particles have become well understood. The mathematics that describes the physics has evolved. Low-cost, powerful personal computers (PCs) that are capable of finding solutions for the ESP"s mathematical physics have become readily available. Software programs to perform the complicated calculations and predict the ESP"s performance have been written. Electrostatic Pre-

cipitator models are based on theoretical relationships, which accurately describe the individual physical mechanisms involved in the precipitation process and on incorporating these relationships into a complete mathematical model for electrostatic precipitation. From a practical standpoint, a reliable theoretical model for electrostatic precipitation would offer several valuable applications:

i. Precipitator design could be easily and completely performed by calculation from fundamental principles;

ii. A theoretical model could be used in conjunction with a pilot plant study in order to design a full scale precipitator;

iii. The optimum operating efficiency of an existing precipitator could be established and the capacity to meet particulate emissions standards could be ascertained; and

iv. An existing precipitator performing below its optimum efficiency could be analyzed with respect to the operating variables in a procedure to troubleshoot and diagnose problem areas.

In addition to its many applications, a mathematical model can be a valuable tool for analyzing precipitator performance due to its cost and time savings capability. ALENTEC employs several computer models including a revised model of electrostatic precipitation developed by Southern Research Institute and EPA‟s ESP-VI Windows version. The Southern Research Institute (SoRI) ESP performance model was the first ESP computer model developed and was originally designed to run on mainframe computers. ALENTEC had revised some of the routines based on our field operating experience and fitting the models to the “real” world and converted it to operate on a Windows PC. The ESP-VI 4.0W Performance Prediction Model (ESP-VI 4.0W) is an advanced and accurate ESP model capable of predicting the performance of an ESP.

The models offer the following basic features:

a) They predict collection efficiency as a function of particle diameter, electrical operating conditions and gas properties;

b) They can calculate clean-plate, clean air voltage current characteristics for discharge electrode-plate geometry;

c) They determine particle charging by unipolar ions as a function of particle diameter, electrical conditions, and residence time;

d) They can estimate the effects of particles on the electrical conditions under the assumption that effects due to the particulate layer can be ignored;

e) They account for electrical sectionalization;

f) They predict particle capture at the collection electrode based on the assumptions of completely random, turbulent flow, uniform gas velocity and particle migration velocities which are small compared to the gas velocity;

g) They employ empirical correction factors which adjust the particle migration velocities obtained without rapping losses;

h) They account for the non-ideal effects of non-uniform gas velocity distribution, gas by-passage of electrified regions, and particle re-entrainment from cause other than rapping by using empirical correction factors to scale down the ideally calculated particle migration velocities;

i) They account for rapping re-entrainment by using empirical relationships or the quantity and size distribution of the re-entrained mass;

j) They allow modeling the effects of the Flue Gas Conditioning on the outlet emissions and the stack opacity.

Both models also have the capability of predicting trends caused by changes in Specific Collection Area (SCA), applied voltage, current density, mass loading, and particle size distribution. Numerous comparisons of the predictions of our model with full-scale precipitators collecting fly ash from coal-fired boilers resulted in a very good agreement.

3.2.1 Non-Ideal Effects

The non-idealities which exist in a full-scale electrostatic precipitator is one of the outmost important factors, for it will reduce the ideal collection efficiency that may be achieved with a given specific collection area. The non-ideal effects of major importance are

(i) Non-uniform gas velocity distribution,

(ii) Gas sneakage, and

(iii) Particle reentrainment.

3.2.2 Particle Reentrainment and Dual FGC

Particle reentrainment alone is, perhaps, one the most degrading non-ideal parameters influencing the precipitator performance.

Particle reentrainment occurs when collected material reenters the main gas stream. This can be caused by several different effects and, in most cases, severely reduces the collection efficiency of a precipitator. Among causes of particle reentrainment are:

(i) Rapping which propels collected material into the inter-electrode space;

(ii) The action of the flowing gas stream on the collected particulate

layer;

(iii) Sweepage of material from hoppers due to poor gas flow conditions, air in-leakage into the hoppers, or the boiling effect of rapped material falling into the hoppers; and,

Excessive sparking which dislodges collected material by electrical impulses and disruptions in the current which is necessary to provide the electrical force which holds the material to the collection plates.

Numerous studies have been made to determine the effect of particle reentrainment on precipitator performance. In studies where the rappers were not employed, real time measurements of outlet emissions at some installations showed that significant reentrainment of mass was occurring due to factors other than rapping. These same studies also showed that for high efficiency, full-scale precipitators, approximately 30-85% of the outlet particulate emissions could be attributed to rapping reentrainment. The results of these studies show that particle reentrainment, especially rapping reentrainment, is a significant factor in limiting precipitator performance.

Dual FGC by creating moderate amounts of binding material (essentially acting like glue) improves the particles-to-particle adhesion, thus creating much better conditions for the reentrainment suppression.

CHAPTER 4. REFERENCES

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