SESSION 1C

ELECTROSTATIC PRECIPITATION FUNDAMENTALS

AN EXAMINATION OF THE FULL ELECTROSTATIC PRECIPITATOR PROCESS FOR THE CLEANING OF GASES

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ABSTRACT

Studies of the electrostatic precipitation process have largely concentrated on the charging of the dust and its deposition on the plates.

Dust is only collected when it reaches the hoppers. The dust movement from the point of release on the plate until it arrives in the hoppers has received less attention, probably due to the practical difficulties involved.

This paper discusses the release and movement of the dust and suggests ways this could progress.

Apart from the well-known effect of high resistivity on dust, the dust resistivity for surface conditioning is considered to be a measure of dust cohesivity. Hence the lower the resistivity the stronger and possibly larger will be the agglomerates released from the plate. The effect of this on precipitator performance is discussed.

INTRODUCTION

The removal of dust from gas treated by an electrostatic precipitator is carried out in three basic stages.

1. Charging of the dust particles by the corona discharge.
2. Deposition of the charged particles on the collecting plates.
3. Release of dust from the plate and deposition in the hoppers.

Only when the dust reaches the hoppers can the dust be regarded as 'caught' by the precipitator. This paper examines each of the three stages, but concentrates mostly on the third stage, dust release and transfer to the hoppers which is probably the most important part of the total dust collection process.

Generally dust resistivity is recognized as an important factor. However, all dust particles are charged and deposited regardless of resistivity - it is the deposited dust which creates the problems. Based on simplified assumptions of the effect of the deposited dust layer it can be shown that there is a critical resistivity above which two effects can become apparent.

1. The dust acts as a series resistance giving apparently normal electrode voltage with reduced current and reduced dust collection efficiency.
2. Reverse ionization when positive corona takes place from the plates giving sub-normal electrode voltage with very high corona current and reduced dust collection efficiency.

It has generally been supposed that increased rapping forces would improve dust removal efficiency by reducing the resistivity effect. This is not necessarily so as dust can be released without mechanical rapping; furthermore high 'g' rapping may even be disadvantageous.

Below the critical resistance range as resistance decreases, precipitator performance continues to improve; based on observation of large numbers of precipitators it is possible to suggest reasons for this which involves consideration of the size and strength of agglomerates/dust released from the plates and their subsequent behavior. This is an area where little work has been carried out, due to the difficulties of carrying out measurements inside operating precipitators.

COLLECTION OF DUST BY A PRECIPITATOR

Charging of the Dust Particles

It is generally accepted that charging of the dust particles is effected by a combination of bombardment and ion diffusion charging (1). Bombardment charges predominate for particles over 1μm and 80% of the limiting charge is attained in 0.1 seconds. For particles below 1μm ion diffusion charging predominates.

The figures obtained are theoretical assessments and particularly for ion diffusion charging may be subject to considerable error(2). Generally for all particle sizes a high proportion of the limiting charge is reached in one second; most commercial precipitators have considerably longer contact times, i.e., the time the dust laden gases are exposed to the electric field. In view of the way the dust is deposited, discussed below, reaching the limiting charge may be less important than indicated by the fundamental electrostatic equations.

Deposition of the Dust Particles

The equations for determining the movement of a charged particle, suspended in a gas in an electric field are well established. The so-called 'migration velocities' are closely proportional to particle diameter, hence the rate of collection of fume size particles should be much smaller than for larger particles suggesting that precipitators should be relatively ineffective on fume size particles(3).

This is true for static gas conditions or possibly also stream-line flow, neither of which apply to commercial precipitators. The gas flow is fully turbulent under normal flow conditions. To this must be added turbulence due to electric wind which has been shown to be considerable. For example, in a single stage precipitator in still air, the effect of electric wind was observed to produce vertical velocities parallel to discharge electrodes of more than $2ms^{-1}$.

This effect was described in a Paper by Parker and Hughes (4). The combined effect on the gas turbulence means that migration velocities of the charged dust particles in the electric field becomes small compared to that of the gas. This is particularly true for particles of $10\mu m$ diameter or smaller for which precipitators are particularly used ($10\mu m$ particle-migration velocity $1m/s^{-1}$, gas turbulence velocity of the order of $6m/s^{-1}$, (3).

This applies to all sizes of particle or fume and is not influenced by the electrical resistivity of the dust. Resistivity is regarded as one of the most important factors in determining precipitator efficiency because of its effects on the precipitator efficiency, and this is discussed later.

With highly turbulent flow dust particles will only be collected if they enter the boundary layer, Figure 1. Due to the viscous drag of the gas in contact with, or close to, the plate there is a thin layer of gas in which velocity is zero or low. Any charged dust particles entering this layer will be deposited by the electric field. Since the probability of entering this skin, for particles of the order of $10\mu m$ or less, is virtually independent of particle size, this is the accepted reason for the precipitator collecting fine fume nearly as readily as coarser particles. This is the basis of the original Deutsch formula (3) which considers the dust collection process only as far as the deposition on the plate.

Commercial collector plates which can be 16 meters high x 5 meters in length cannot be constructed as a plane sheet but need stiffening members. Figure 2 shows a plan view of a collecting plate which has vertical 7.5cm channels to provide stiffness and hold the plate flat. Flow visualization tests show that in addition to the static skin in Figure 1, the effect of the channels is to produce a slow moving vortex shown in dotted lines, dust particles entering this zone could be expected to be brought into proximity of the collector plate, and hence deposited. It would appear, therefore, that such projections might be advantageous but the tests did not include the electric wind effect.

In the situation shown in Figures 1 and 2 once the particle enters the quiescent zone, the distance to be travelled by the charged particles under the influence of the electric field is small and reaching the limiting charge would appear to be not so important(1).

TRANSFER OF COLLECTED DUST FROM PLATES TO HOPPERS

Rapping

The simplistic view which has been taken of this part of the dust collection process is:

- Dust is removed by rapping the plate and electrodes and falls into the hopper.
- Cleaner plates should give the best precipitator performance.

As a result the general trend has been to increase the rapping force defined in multiples of 'g', the acceleration due to gravity, to ensure the plates are kept clean. The value quoted being the minimum obtained on the plate. Currently the minimum values of 'g' being specified range from 70 to 100. Since electrode systems are large, uniform distribution of rapping energy is not possible and with these minimum values the corresponding values close to the point of impact of the hammer can exceed 1000 'g'.

Juricic and Hermann (5) produced a high speed film showing the movement of dust following dislodgment by rapping on a Laboratory model. They demonstrated that with the same 'g' value of 100 but with different displacements in the plane of the plate:

With smaller displacement:
- agglomerated flakes which fall steadily with little de-agglomeration.

With large displacement:
- agglomerated flakes which due to the motion of the plates were subject to fairly rapid de-agglomeration.

This is important as it demonstrated that 'g' alone does not represent the effectiveness of rapping. It is generally stated that the specified values of 'g' are in the plane of the collector to achieve the shearing of the dust from the plate. In practice a large collector plate (up to 5m x 16m) constructed from sheet metal as is normal, the acceleration 'g' forces in three planes at 90° are not very different. Hence although the blow is in the plane of the plate the 'g' value normal to the plate will be high also so that increasing 'g' will increase the displacement. Furthermore different collector designs will have different vibration characteristics so that specifying 'g' values only does not fully define rapping effectiveness.

While increasing 'g' would increase the dust release it can also have the effect of causing de-agglomeration of the dust layer released since displacement would also increase. Thus high 'g' rapping could be counter-productive. The size of agglomerate released determine its terminal velocity and hence must influence the time taken needed to reach the hoppers (Figure 3).

The other variable decreasing the time between rapping blows has been shown (6) to result in increased losses by re-entrainment. There is in practice an optimum time interval dependent on the rate of dust collection, i.e., inlet field with high dust concentration more frequent than outlet field with low dust concentration. This is related to agglomerate formation.

The Importance of Agglomerates

Figure 3 shows the free-falling velocity of a range of dust particles. The terminal velocity of even 20μm particles is less than 0.01m/s^{-1} so that with a contact time of 10 seconds using collector plates 10m in height, little of the dust is likely to settle in the hoppers.

Released dust masses would have to be in the form of agglomerates. The graph indicates agglomerate sizes in excess of 1000μm (1mm) would be needed to give terminal velocities of several meters per second which are necessary for the dust to reach the hoppers. This would indicate that the thickness of layer released should not be less than 1mm. Such agglomerates would contain for example many millions of sub-micron fume. Hence a requirement of the dust dislodgment system (rapping) is to ensure the dust is released as large agglomerates, and these stay intact as long as possible.

The Dust Layer on the Collecting Electrode

A representation of the dust layer on the collector plate is shown in Figure 4. It usually consists of a permanent bonded layer resulting from repeated start-up and shut-down when the temperature passes through the dewpoint. Such a layer is unlikely to be removed by rapping; on top of this is a layer of loose dust including some freshly deposited. Part of this layer will shear off, i.e., dust is dislodged from dust, not <u>metal</u>. The presence of the bonded layer further increases the thickness of dust on the collector plate necessary for the release of optimum agglomerate sizes to several millimeters.

There are three modes of electrical operation of precipitators:

- Normal Favorable Dust - corona current flow 8 x 10^{-9} A/cm^{-2}.*
- High Resistive Dust - corona current restricted 3 x 10^{9} A/cm^{-2}.*
- High Resistive Dust - reverse ionization - corona current flows from plates to discharge electrodes in addition to the negative flow. The two currents are additive and millimeters will not discriminate between them. Current can be several times normal, and voltage is very low. Reverse ionization is a complex phenomena and does not lend itself to the approach used for the other two conditions where there is only negative corona discharge.

*These are typical values from fullscale plant tests.

Voltage Drop Across Dust Layer

Assuming the dust acts as a series resistance, the voltage drop across the dust layer on the collector plate is illustrated in Figure 5. For a dust layer of 1 to 3mm thickness the voltage drop is insignificant for resistivities below 10^{11}Ohm-cm, and even for a thickness of 5 to 10mm the drop would be only about 1 kV even with the high corona current possible with favorable dust.

In the case of highly resistive dust, in excess of 10^{12}Ohm-cm, the voltage drop across 3mm of dust becomes considerable, even with the low corona current flow. Since there is likely to be a significant bonded layer, not removed by rapping, the total thickness for the release of agglomerates of sufficient size can readily approach or exceed 3mm.

This might appear to be an over-simplification of the effect of the dust layer but appears to have some credence. For example, in Figure 6 are shown voltage-current curves for a favorable dust (C), and a highly resistive dust (B). Note that the measured electrode voltages, i.e., the breakdown voltages, are approximately the same, but the control level for the highly resistive dust gives less than half of the corona current.

The kilovolt meter measures the voltage from the discharge electrode to earth, but the precipitator voltage is from discharge electrode to the surface of the dust layer. The two are only equal when the voltage drop across the dust layer is small as with favorable resistivity dusts - below 10^{12}Ohm-cm.

The difference in voltage between (B) and (C) for the control setting of (B) is approximately 7kV. Assuming this is the voltage drop across the dust layer, then the precipitator effective field voltage is roughly 80% of that for the favorable dust and the corona current is about 40%. Subtracting 7kV would put the operating level of (B) close to that of (C), giving voltages more representative of the actual value; the lower effective field voltage and consequent lower current could explain the lower performance of (B) compared to (C), both being 120MW units with similar electrode systems and rapping.

Evidence supporting the view that for favorable dust resistivity, less than 10^{11}Ohm-cm, the thickness of deposits on the electrode system has relatively little effect, is illustrated by clean plant and deferred efficiency tests carried out on a 120MW unit in 1960 and 1962. The results are given in the Table below; the deferred efficiency tests took place after about eighteen months without any internal cleaning or maintenance.

This was the first deferred efficiency test carried out by Lodge-Cottrell and the Central Electricity Generating Board. For added information the plant was subject to a crash shut-down of the boiler and precipitator to allow an examination of the electrode system in as close to operating condition as possible.

In the following Table the deferred efficiency tests have been converted to the same gas volume (there was considerable inleakage of air) and the same sulphur content. For similar operating conditions efficiency had fallen from 99.7% to 99.4% but still met the clean plant guarantee.

Blyth Power Station - 120 MW

Precipitator Efficiency Tests - 1960 and 1962

Test A - Plant in clean condition:	99.7%
Test B - After steaming for 18 months:	99.4%
Guaranteed Efficiency:	99.3%

Test B - no internal maintenance or cleaning carried out.
Results converted to same conditions as Test A, i.e., volume and sulphur.

NB The Test Report contained the following note regarding the state of the electrode system:

"Collecting electrodes - build-up 25mm in places"
"discharge electrodes - 10% of electrodes with build-up of
ranging from 15 to 50mm diameter"

The degree of fall-off is surprisingly low in view of the state of the electrodes described in the Test Report as follows: "A large number of catchpocket (collector plates) were blocked by dust and the build-up extended up to 25mm in some places. The discharge electrodes were fairly heavily built-up with 10% of the wires having diameters ranging from 15 to 50mm." This plant had rapping with minimum 'g' values of less than 5 on the plates.

While this degree of build-up is excessive and would not occur with modern rapping systems, this experience supports the argument that for favorable dust with lower resistivity, build-up of dust on the electrode system is not very critical.

These observations are supported on an older plant built in 1948 by monthly tests carried out over a period of two years by the CEGB employees at Croydon Power Station in the UK(7). The precipitator maintained its dust emission level without detectable fall-off. This plant also had, by present-day standards very poor rapping, suggesting dust might be released other than by the rapping.

Summarizing Rapping

- The interval between rapping blows has been shown to be important in controlling re-entrainment (6) due to the need to allow a layer of dust to build-up.
- Due to the need to form large agglomerates to give the necessary high terminal velocity, the thickness of the dust layer will be such that the highly resistive effect will occur (Figures 3 and 5) for dust resistivities in excess of about 10^{11} Ohm-cm. Hence rapping cannot overcome the problem of high dust resistivity.
- Plant built around 1950 with very low rapping 'g' values could maintain performance over long periods(7).

- While the need for the rapping to dislodge dust effectively must be accepted, there is little evidence to support the view that actually increasing rapping intensity has produced significant improvements.
- High intensity rapping increases the risk of metal fatigue failure of the precipitator electrode system.

Forces Holding the Dust on the Plates

The release of the dust from the electrodes, in particular the collecting plates, and its passage to the hopper has received comparatively little attention compared to the deposition, yet this part of the dust catching process largely determines the precipitator efficiency.

The forces holding the dust on the plates are a combination of:

- Electric forces.
- Cohesivity (stickiness) of the dust.

Consider these factors separately.

Electric forces are high for highly resistive dust where the voltage drop across the dust layer is large (Figure 5) but becomes very small for resistivities below 10^{11}Ohm-cm.

Cohesivity, 'stickiness' or tensile strength of dust. This is considered to increase with increasing surface conditioning of the dust. Hence as the electrical forces decrease, the cohesivity increases but only when the resistivity is determined by surface conditioning.

This conclusion is based on observations since measurement of these factors on an operating precipitator present great difficulties and few attempts have been made except in the Laboratory(8). It has been observed for instance that when using SO_3 injection, problems with emptying hoppers increase with increased injection rate, also the electrode system is usually more heavily built-up.

Although Figure 5 indicates that the voltage drop across the dust layer is negligible for resistivities of dust less than 10^{11} ohm/cm, precipitator performance continues to increase probably due to increasing cohesivity which affects the size and strength of agglomerates released from the plates; this is discussed below.

Consider the situation when dust is released other than with reverse ionization.

1. Highly Resistive Dust. The released agglomerates will rapidly assume the same voltage across its thickness so that the strength of the agglomerate depends only on the cohesivity, which will be low.
2. Favorable Dust Resistivity. There will be no significant change in the electric forces since the voltage drop across the thickness is small. Cohesivity will be higher.

Both conditions could need similar rapping forces to shear the agglomerates, but a high rapping force by increasing the displacement of the plate (5) could have an adverse effect on the agglomerates of highly resistive dust due to their low cohesivity (strength). This assumes only rapping releases the dust. Experience on older plants without modern rapping systems, does not support this and the alternatives will be considered later.

Reverse Ionization

The two effects described above refer to favorable and highly resistive dust when the latter acts as a series resistance (Figure 5). The other condition to be considered is where reverse ionization occurs. In this case where the dust is also very high resistive a localized discharge occurs from the earthed plates. According to White (3) this occurs when the voltage gradient in the dust layer exceeds 10kV/cm^{-1}. Reference to Figure 5 shows this would correspond to a dust resistivity in the order of 10^{12}Ohm-cm or higher. With reverse ionization there is corona emission from plates and electrodes of opposite polarity so that the milliammeter simply gives the total.

The effect on precipitator operation is shown in Curves A of Figure 6. Note that the voltage peaks at a small current input. Reverse ionization takes a significant amount of time to become apparent, the reduction in voltage with increasing current occurs without altering power input settings. It is only possible to return to the peak voltage condition by switching off the supply. There is no simple explanation of reverse ionization in terms of resistivity. It has been seen to occur on a pilot precipitator in parallel with a full size unit. With the same dust the full scale unit behaves in the high resistive mode (Figure 6-B). The only differences could be small variations of temperature and particle size. The pilot unit had trace heating to compensate for losses but was lower in temperature than the fullscale unit.

From this experience it was concluded that although the appearance of voltage and current is radically different:

Reverse ionization: low kV, very high current, no arcing.
Highly resistive: normal kV, reduced current, frequent arcing.

The difference in conditions of dust/gas needed appears to be small. There also appears to be no interim stage, i.e., either the highly resistive condition prevails, or the field collapses to full reverse ionization.

In this condition with negative corona from the discharge electrodes and positive corona from the craters in the dust layer on the plate, there is the probability that dust deposited, although highly resistive can have its charge reversed, and hence could be repelled from the plate. The nature of forces holding the dust on the plate is complex and defies analysis. The probability is that:

- The electric forces will be lower than for the highly resistive dust effect.

- The cohesive forces due to surface conditioning will be low.
- The packing density of the dust will be lower than for negative corona only. This would reduce the strength and free-falling velocity of the released agglomerates.

It might be expected that under this condition precipitators cannot effectively remove dust. In practice, although effective migration velocities are among some of the lowest for highly resistive dust, it is in fact possible with suitably sized precipitators to produce very high efficiencies, e.g., 99.9% as illustrated in Figure 7. The very high power input, 1500 watts/Am^3/s, is a result of reverse ionization and is roughly three times that needed for normal dusts more favorable to precipitation represented by the solid curve.

Using the capability of thyristors controlling power input to the TR sets to be switched off for pre-determined numbers of cycle(9), the power consumed was reduced by up to 5:1 with a slight increase in efficiency.

This technique variously referred to as pulse interruption, vario-pulse, pulse modulation, is currently in widespread use. Claims are made(10) for reductions of dust emission ranging from 50 to 80% for high resistivity dust. As might be expected the technique gives limited effect where reverse ionization does not exist (Figure 7).

RELEASE OF DUST FROM THE ELECTRODE SYSTEM

To summarize the conclusions drawn in the previous section, when resistivity is due to surface conditioning.

- High resistivity dust (10^{12}Ohm-cm or higher), no reverse ionization: Cohesivity of the dust is low - electric forces holding the dust on the plates is high.
- High resistivity dust <u>with reverse ionization</u>: Cohesivity of dust is low, electrical forces holding the dust on plate (and packing density) may also be low.
- Dust favorable to precipitation - resistivity below 10^{11}Ohm-cm: Cohesivity of dust is high, electrical forces holding the dust on the plate are low.

The Release of Dust from the Collector Plates

The release of dust from the plates is considered to be only partly due to rapping, a possible major contributor is arcing or flashover. It has been shown that the mechanical vibration caused by a flashover from electrode to plate is greater than 30 'g'(9) and that this will blast off dust in the region where the arc strikes (this will tend to clean both discharge electrode and plate).

It has been a practice for many years for Testing Engineers to run at excessive flashover rates on badly built-up plant (high kV very low current) to effect so-called 'on-line cleaning'.

A precipitator other than with reverse ionization operates with continuous flashover. In fact a common form of Automatic Voltage Control operates to maintain a pre-set rate of flashover. In a correctly designed and reasonably well-aligned precipitator flashover should be random except when rapping occurs. In this situation:

- Dust is released by the rapping which will cause flashover in the associated gas ducts.
- As a result of the flashovers dust will be released in the region of contact of the arc on the plate.
- The voltage on the whole field will collapse to zero and the electric forces holding the dust on the plate will be removed and dust will be released.
- Dust will be released primarily on the rapped collectors which will be vibrating, but also probably to a lesser extent on the unrapped plates in the whole field.

In support of the suggestion that with the collapse of voltage on the unrapped plates dust is released, is the observation that on a few occasions when opening up a precipitator which has been shutdown and de-energized, substantial layers of dust have been observed detaching themselves from the plates. This probably occurs on all precipitators to some degree but has been completed before the casing is opened and is not seen.

It is considered, therefore, that the build-up of dust on the electrode system seen in an inspection following shutdown gives a misleading impression of the operating condition. This applies particularly to highly resistive dust acting as a high resistance where the principal forces holding the dust on the plates are electrical, but also applies to the distribution of dust over the plates for all resistivity values.

In the case of lower resistivities of dust, in the favorable resistivity range the major force is due to the cohesivity of the dust which increases with decreasing resistivity. This resistivity, even below the critical levels shown in Figure 5 is considered important as an indirect measure of dust cohesivity and hence agglomerate strength which results in increasing effective migration velocities (values in excess of $16 cm/s^{-1}$ has been measured on a 120 MW unit with a 2.5% sulphur coal giving dust cleaning efficiencies of 99.9%).

In the case of reverse ionization when no flashover is possible, the cohesivity of the dust is very low, together with low electric forces and low packing density, and in this situation it is possible that the dust strips off under its own weight as thickness increases or indeed in this situation as a result of rapping vibration, since the 'g' forces needed are likely to be low. It is, however, certain that generally the interaction of rapping are proven factors for dislodging dust other than for reverse ionization.

Progress of the Released Dust to the Hoppers

The simplest assumption would be that dust released in agglomerate form would then fall into the hoppers. It has been shown in Figure 3 that for agglomerates with the equivalent terminal velocity of a 1mm sphere or larger, the velocity would be at least $5m/s^{-1}$, and hence dust would fall even if agglomerates left the static gas skin and entered the turbulent gas flow.

The path followed depends on the agglomerates staying intact; it was demonstrated by Hein(11) in a simple experiment that dust released in still air from a plastic compartment 10cm x 10cm x 0.5cm thick remains essentially intact for about 3 meters and in the next two meters had de-agglomerated to the stage where the vertical downward motion had virtually ceased.

This supports the argument that the released dust agglomerates gradually break up as they fall and are re-charged and re-deposited by the electric field.

Figure 8 shows a diagrammatic representation of the possible trajectories of the dust agglomerates taken as represented by the combination of gas flow and terminal velocity.

- Curve A - no de-agglomeration.
- Curve B - low resistivity/high cohesivity dust.
- Curve C - increasing resistivity.
- Curve D - increasing resistivity.
- Curve E - high resistivity/low cohesivity dust.

From the point of release of the agglomerates, the strongest agglomerates (Curve B) will fall greater distances before the center of the mass decelerates to a low value due to break-up when the process of charging, deposition and release is repeated.

In contrast, very high resistivity gives rise to agglomerates of lower dust cohesivity which break up more rapidly with the result that re-deposition occurs after the dust has fallen a shorter distance. This type of dust must be re-deposited a greater number of times and takes longer to reach the hopper.

There is some dust which is de-agglomerated to a great degree possibly by the collector plate motion following rapping and the presence of this is demonstrated by spikes on the opacity meter when rapping occurs, particularly on the outlet field. The magnitude of these spikes tends to increase with increased rapping intensity.

Figure 8 shows the release of dust from one point on the collector plate; in practice dust is released over the whole surface.

Assuming the dust distribution is initially uniform over the height of the collector plate, due to the movement of the agglomerates suggested in Figure 8, the dust will move down the plate as it progresses through the precipitator.

It was shown by Sproull[12] using Konitest samplers to measure the difference in dust concentrations from top to bottom at the outlet end of the first field of a fullscale precipitator that the dust concentration leaving this field varied by 10:1 from bottom to top of the plate which supports the view that the dust moves down the plate progressively.

Distribution of Dust on the Collector Plates

In Figure 9 it is assumed that the dust enters the first field uniformly distributed over the height of the collectors.

Due to the sequence of motion of the agglomerates indicated in Figure 8, the dust on the collectors becomes progressively less uniform in thickness. In Figure 9 it is assumed for convenience that in each field 90% of the dust on the plate lies below the dotted line.

The dust layer on the plates would reduce from inlet to outlet and also from top to bottom, hence at the upper corner of the outlet field the minimum thickness of dust would be present. Any dust leaving the plates in this area cannot reach the hoppers regardless of agglomeration and must pass into the outlet flue. This applies to a considerable part of the upper outlet field, hence high dust collection efficiency can only be possible if the dust deposition in this area is less than the permissible slip, is 99.9% efficiencies: 0.1% slip.

In Figure 9 this could be represented largely by the unshaded portion of the outlet field although this is difficult to prove.

Assuming for simplicity a field efficiency of 90% then the total dust entering the outlet field would be 1% of the burden of which 0.1%, the permissible slip, could be in the no-collection area. There is little recorded evidence that this approximates to the condition in an operating precipitator but it is improbable that high efficiencies of dust removal in excess of 99.9% with collector heights up to 15 meters could be achieved unless some similar pattern of dust distribution occurred.

Measurement of dust thickness on the plates of an operating precipitator is virtually impossible. It might be expected that examination of the plates during a shutdown with rapping isolated before de-energization should give a reasonable idea of the operating condition. Mention has been made earlier of dust layers seen to strip off the plates; personal experience is that there is not a great variation of thickness from top to bottom when examined in this state, although there is progressive thinning of the layer through the field, i.e., the outlet field has normally least build-up.

This is probably due to the fact that on shutdown only the permanent bonded layer plus an additional semi-bonded layer is seen. The remaining dust, probably the newly deposited, falls off into the hoppers during the disturbance caused by shutting down.

Indirect evidence that the dust is distributed in a way represented in Figure 9, is the optimum setting of rapping intervals is shorter than uniform distribution of dust over the height of the collector might indicate, and the need to specify aspect ratio, normally taken as the (field length/field height) is further indirect support of the views expressed above.

Consideration of the situation in Figure 8 indicates that the time the dust takes to fall to the hopper is really the significant factor. This supports the argument for the use of contact time in place of effective migration velocity for design purposes.

CONCLUSIONS

- Dust cannot be caught in a precipitator unless agglomerates of the order of 1000μm (1mm) or larger are released.
- Flashover seems as important in keeping plates 'clean' as rapping when there is no reverse ionization.
- The forces holding the dust on the plates is a combination of electric forces and dust cohesivity.
- High resistivity (10^{12}Ohm-cm or higher) - high electric forces plus low cohesive strength.
  Low resistivity (below 10^{11}Ohm-cm) - low electric forces, high cohesivity.
  High resistivity - reverse ionization - low cohesive and low electric forces, plus lower packing density than for the other two conditions.
- Dust resistivity affects the electrical operation of the precipitator for values higher than about 10^{12}Ohm-cm. For lower values several mm of dust have no effect, for higher values even 1mm can create problems. The release of 1000μm agglomerates requires more than 1mm of dust on the plates, particularly as there is usually a bonded permanent layer present. For this reason rapping cannot overcome the high resistivity effect.
- Dust resistivity affects precipitator efficiency favorably even below 10^{12}Ohm-cm. This is considered to be due to cohesivity, i.e., agglomerate strength increasing with increasing surface conditioning. Hence for surface conditioning dust resistivity is an indirect measure of the cohesive strength of the dust.

Most work to date has concentrated on the deposition of the dust. This is only part of the dust catching process. The most important part is the movement of dust to the hoppers. This has received little attention possible due to the difficulties of such a study on an operating precipitator. It may be that with the development of devices such as miniature television cameras such a study could be made possible, if only to a limited extent.

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11. Arthur G. Hein, "Mechanical Aspects of Electrostatic Precipitation" Presented at the EPRI/EPA International Conference, San Diego, California (September 1990). [conference paper]

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SCHEMATIC VIEW OF DUCT OF PRECIPITATOR

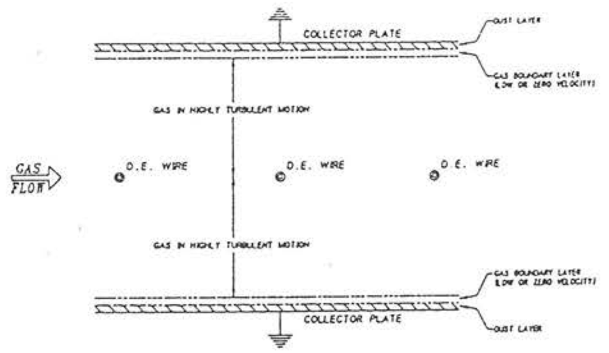


FIGURE 1

CATCH SPACE COLLECTOR PLATE

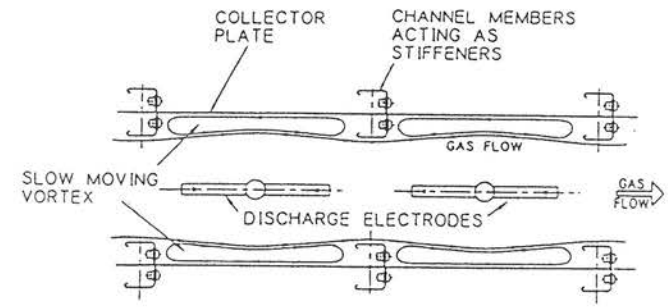


FIGURE 2

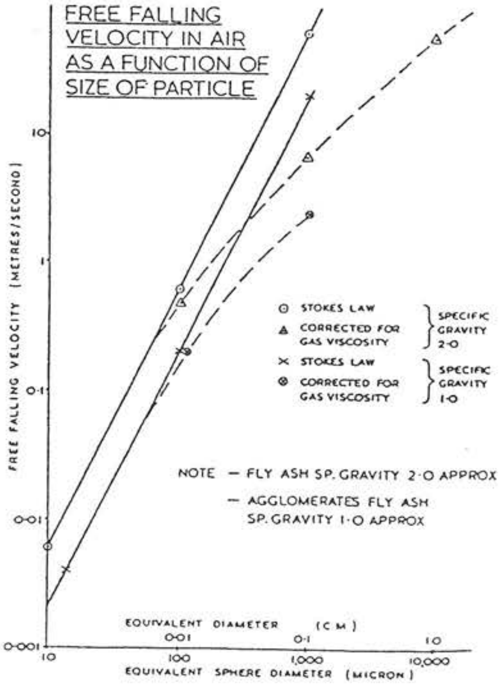
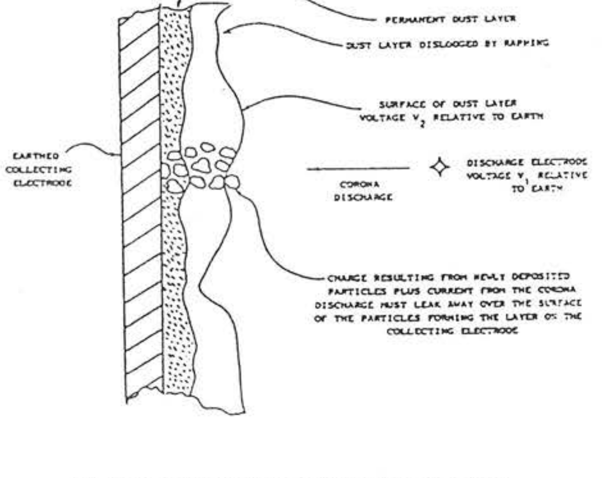


FIGURE 3



DIAGRAMMATIC REPRESENTATION OF DUST LAYER ON COLLECTING ELECTRODE

FIGURE 4

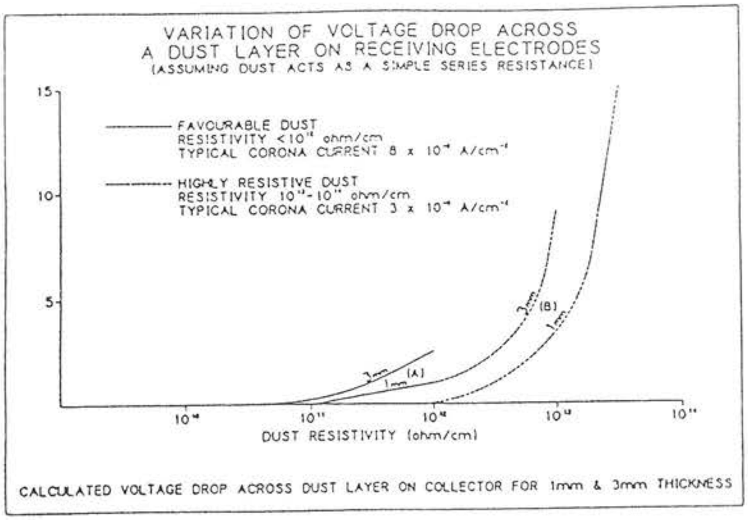


FIGURE 5

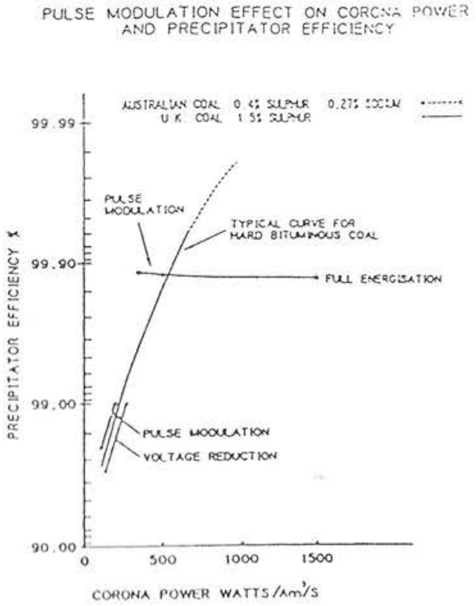


FIGURE 7

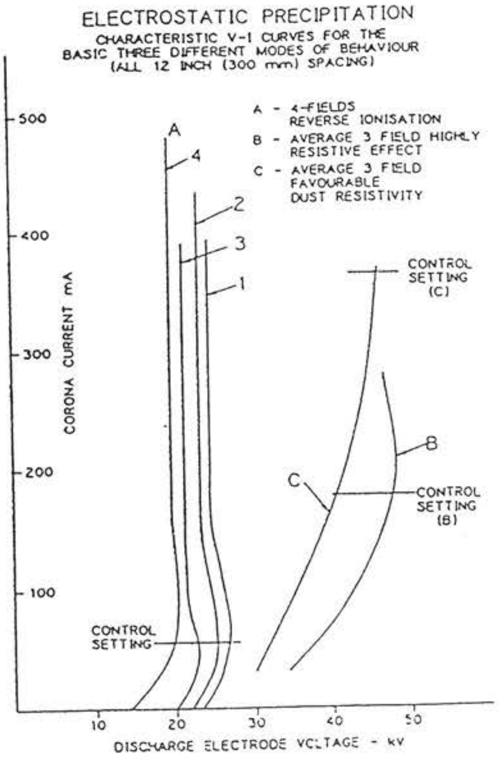


FIGURE 6

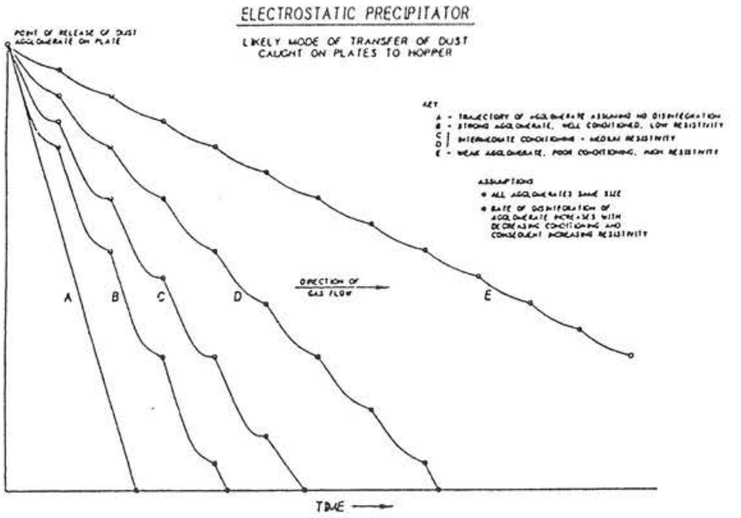
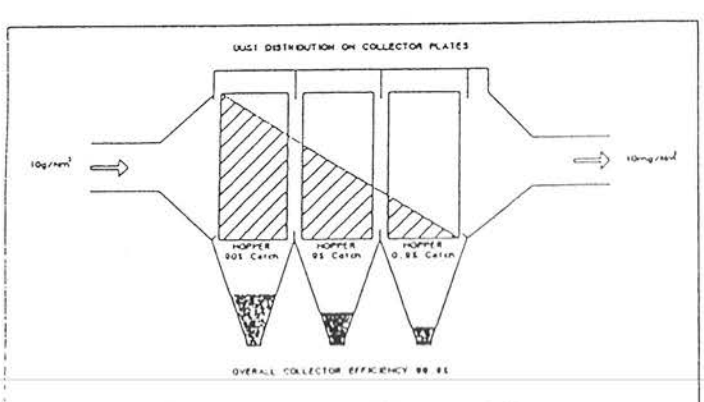


FIGURE 8



ASSUMED - 90% OF DUST ON PLATES IN EACH FIELD
LIES BELOW DOTTED LINE
- 3 FIELDS EACH 90% EFFICIENT - 99.9% OVERALL

FIGURE 9