

ENHANCEMENT OF ELECTROSTATIC

PRECIPITATOR PERFORMANCE

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INTRODUCTION

In order to understand how the operation of an electrostatic precipitator may be improved, it is necessary to understand the basic principles upon which these devices operate. An electrostatic precipitator consists basically of a large chamber through which the flue gasses pass in a horizontal direction en route to the chimney.

Mounted in this chamber are vertical plates which are electrically earthed and charged to a positive potential.

Spiked wires are suspended between the plates and are negatively charged to a potential of about 40 000 Volts.

The separation of the particulate matter from the flue gas stream is accomplished by the particles acquiring an electrical charge during their passage through the precipitator and they are then attracted to the plates by coulomb force. The captured particles are temporarily retained on the collector plates forming a dust layer which is periodically removed by shear rapping. The dust then falls into a dust hopper for removal to a disposal area.

MECHANISMS AFFECTING PRECIPITATOR PERFORMANCE

Two main mechanisms affect the operation of an electrostatic precipitator :-

1. The Particle Migration Velocity

This may be defined as the velocity of drift of the particle towards the collecting plates. The greater the migration velocity the smaller the collecting surface for the same overall collecting efficiency.

Migration velocity is a function of the coulomb forces and the viscous motion of particles through the gas.

The coulomb forces of attraction are influenced by the efficiency of particles charging. Two distinct charging mechanisms exist. The larger particles are charged by direct ion bombardment which is the dominant mechanism and results in the highest migration velocity and collection efficiency.

Smaller particles of less than 0,2 micron in diameter are charged by a random collision between ions which share the thermal motions of the gas and dust particles suspended in the ionised gas. This is called diffusion charging. An electrostatic precipitator will therefore be more effective in collecting the larger particles.

2. Particle Adhesion to the Collecting Surfaces

Once having arrived at the collecting surface the particles will gradually equalise their negative charge against the positively charged collecting plates and so may be dislodged by rapping in a shear plane.

The dust then falls in a hopper for removal to a disposal area.

If however particles have a high electrical resistance they will retain their negative charge with respect to the positively charged plate this creating a strong adhesive bond and the dust cannot be dislodged by rapping.

This layer of negatively charged dust on the collector plates will tend to repel other approaching negatively charged dust particles into the gas stream.

On the other hand, particles having a low electrical resistivity will prematurely lose their negative charge and re-enter the gas stream before being dislodged by rapping. This is called re-entrainment.

There is therefore a critical dust resistivity at which the precipitator will function most effectively.

This is normally of the order of 1×10^9 .

Fly ash resistivities exceeding this value will tend to collector plates fouling and eventual back corona.

Fly ash resistivities much lower than 1×10^8 will result in poor collector plate adhesion and re-entrainment.

EFFECT OF DUST RESISTIVITY

Low dust resistivity may be caused by high sulphur content in the coal or by a high level of unburnt carbon in the ash.

Ashes from South African coals usually have a resistance higher than the critical resistivity resulting in a build up of dust on the collecting surfaces. This dust layer will prevent the ionic current from leaking away to earth and a high voltage gradient will build up across the dust layer.

Based on a typical precipitator performance a dust layer of about 3 mm will result in an effective voltage gradient of about 1kV which is the threshold value for a just significant loss in collection efficiency. However, the more the resistivity of the collected dust exceeds the critical value, the greater the loss in effective voltage and of collection efficiency.

The voltage gradient across the collected dust layer will build up until the interstitial gas in the dust layer begins to be ionised by the same process as that taking place near the corona wire itself. As a result a back corona current begins to flow in the opposite direction to the normal corona current and the observed precipitator current will increase substantially with a drop in applied voltage.

The effect of back corona over an area of plate at least means that the collection efficiency is impeded to the degree of the loss of applied voltage.

In addition the effect of back corona is to neutralise the charge on oncoming particles by slowing their approach to the collecting plates. If the neutralisation is complete the particles may be recharged in the opposite sense and return to the corona wire. Here they may either attach to the corona wire and act as an insulator to suppress forward corona formation, or again reverse charge and shuttle back and forth until they leave the precipitator.

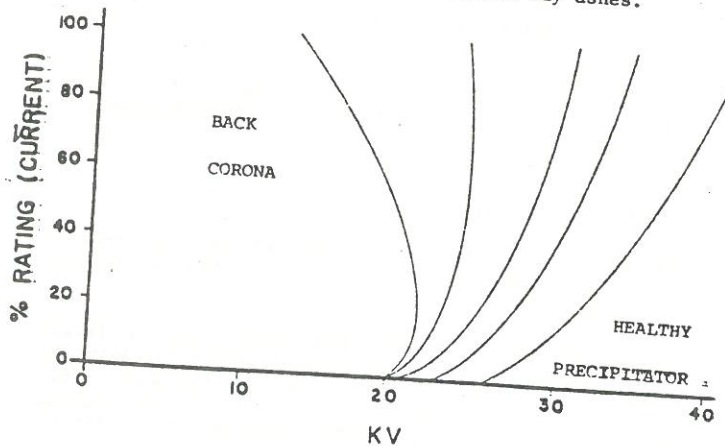
THE CONTROL OF DUST RESISTIVITY

The critical dust resistivity for optimum precipitator performance is usually about 5×10^9 . Resistivities exceeding this value will result in a lowering of efficiency due to collecting surface fouling and creation of back corona while with lower resistivities problems will be experienced with re-entrainment.

Many of these problems may be controlled to some extent in the specification stage by changing parameters in the precipitator design.

However when a precipitator already exists it is virtually impossible to change most of the design parameters with the possible exception of the charging mechanism. This can be achieved using the latest generation of microprocessor controls which monitor the onset of back corona on a continuous basis and also achieve improved particle charging by pulsing. The older analog controller on the other hand by striving for maximum voltage will drive a precipitator "round the bend" further into a back corona condition once it has commenced.

A significant improvement in precipitator performance can be achieved by means of chemical conditioning agents such as sulphur tri-oxide and ammonia. SO₃ in particular has been shown to be remarkably effective in dealing with high resistivity South African fly ashes.



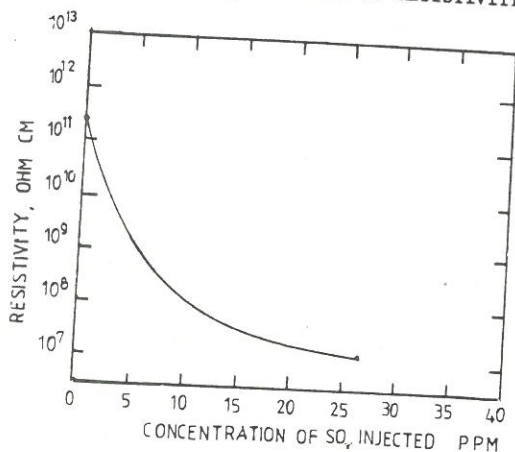
PREDICTION OF FLY ASH RESISTIVITY

The dependence of fly ash resistivity on the percentage sulphur in ash is well documented. However low resistivity is not necessarily associated with low sulphur in coal as other elements such as sodium have also been found to have an effect.

The burning of coal in a boiler yields sulphur dioxide a small portion of which is converted to sulphur tri-oxide in the boiler due to a combination of flame temperature and trace catalytic elements existing in the metals of the boiler and it is the sulphur tri-oxide which is effective in controlling ash resistivity. Recently Bickelhaust and Sparks (EPA Report 600/7-79-204, 1979) published a comprehensive technique for predicting fly ash resistivity from the fly ash elemental analysis.

This report includes a computer program to calculate bulk resistivity and then allows adjustment for flue gas moisture concentration, applied electrical stress and SO₃ content in the flue gas.

EFFECT OF SO₃ INJECTION ON RESISTIVITY



The output printout provides the anticipated resistivity including and excluding the effect of conditioning over a range of temperatures, and is able to predict whether SO₃ conditioning is likely to be effective.

A second computer program has been developed by Southern Research Institute (SRI) to predict the effect of fly ash resistivity on precipitator collection efficiency by estimating the resulting migration velocity.

In addition the effects of "agglomerating" agents such as ammonia can be determined by their effect on particle size distribution.

MECHANISM OF CONDITIONING AGENTS.

The operation of an electrostatic precipitator can be described by the Deutsch equation written as :-

$$\text{Efficiency} = 1 - \frac{(AW)}{e(V)}$$

where e = natural logarithm base
 A = effective plate area
 V = gas flow through precipitator
 W = migration velocity

The collection efficiency is therefore dependant upon the exponent $\frac{AW}{V}$.

This demonstrates that for any given efficiency specific collection area of a precipitator may be decreased in proportion to the increase in migration velocity, and the migration velocity is great dependant upon two factors, i.e. :-

(a) The effectiveness of the corona charge

This can be favourably influenced by sophisticated control systems.

(b) The electrical resistance of the dust particle

This can be best controlled by flue gas conditioning.

The two main conditioning agents are :-
 Sulphur tri-oxide
 Ammonia

CONDITIONING WITH SULPHUR TRI-OXIDE

Sulphur tri-oxide was one of a long series of conditioning agents investigated by Chittum between 1942 and 1945 at the Western Precipitation Corporation.

Chittum found that in conditioning basic dusts (such as magnesium oxide) sulphur tri-oxide and other acidic compounds were the most effective conditioning agents. On the other hand in conditioning acidic dusts (such as boric acid, ammonia and other basic compounds) were most effective.

He concluded that the conditioning agent activated the absorption of water vapour to provide a conductive surface layer on the suspended particles and that the activation process was favoured by the use of conditioning agents that opposed the dust in acid-base character. It was later demonstrated by White, the interrelationship between water vapour and sulphur tri-oxide in conditioning fly ash and the importance of flue gas temperature in determining the concentration of sulphur tri-oxide needed for efficient conditioning.

During the decade between 1960 and 1970 practical interest in sulphur tri-oxide as a conditioning agent accelerated with the increasing use of low sulphur coals by the Utility Industry. The various types of injection system investigated produce equally effective results when properly engineered and maintained. These systems may be based on anhydrous sulphur tri-oxide concentrated sulphuric acid or catalytically oxidised sulphur dioxide as source materials.

Regardless of the type of source material used, careful attention must be given to the design of the interface of the injection system with the gas stream both regarding effective mixing and residence time before the precipitator.

If the mixing is inefficient sulphur tri-oxide will combine with water vapour and condense as a mist of sulphuric acid and will not collect uniformly on the surfaces of individual fly ash particles.

In order to function effectively the sulphuric acid must evenly occur as a surface film only a few molecular layers thick.

It has further been shown that two mechanisms exist for the control of resistivity by means of SO₃ conditioning.

One mechanism is the condensation of a mixture of sulphur tri-oxide and water vapour with fly ash particles serving as condensation nuclei. This phenomenon results in the formation of a liquid layer on the particles but this can only occur if the temperature is below the acid dew point of the vapours existing in the duct. Other mechanisms involve adsorption of sulphur tri-oxide and probably the concurrent adsorption of water as well.

Perhaps the reason that SO₃ injection has been so successful in improving precipitator efficiency is that in addition to controlling fly ash resistivity experiments have indicated that it has a secondary function to increase the cohesiveness of the particles. This has a dual function by changing the particle size distribution and by generating effectively a greater percentage of larger particles as well as minimising rapping re-entrainment.

Not only does conditioning with SO₃ modify the ash surface properties but achieves a space charge effect within the gas improving the charging mechanism applicable to the smaller particles.

CONDITIONING WITH AMMONIA

Conditioning with ammonia can be effective under certain circumstances but the mechanism does not appear to involve the resistivity of ash, but instead to consist of a space charge effect and an increase in the cohesiveness of the ash and in fact in some experiments the disappearance of fine particulates has been noted by condensation nuclei counting.

In fact there is evidence that ammonia conditioning may be more effective in overcoming loss of collected fly ash by rapping re-entrainment, a problem expected to be more severe with low resistivity ash than with high resistivity ash.

With low resistivity ash the electric field retained in the collected ash is often insufficient to bond the ash to the plate surface pending removal by rapping and the effect of ammonia conditioning appears to maintain the physical integrity of aggregates on the collection surfaces of the precipitator.

In applying ammonia conditioning to a precipitator with abnormally high resistivity ash the effect could well be deleterious unless SO₃ is used in addition to lower the resistivity of the ash.

There is also evidence that the injection of ammonia may eliminate part of the sulphur tri-oxide gas that has been condensed to sulphuric acid mist by the formation of ammonium salt and actually cause an increase in the surface resistivity of the ash.

CONDITIONING WITH AMMONIUM SULPHATE

The effect of conditioning with ammonium sulphate was noted during a visit to the United States of America during March 1982 where this substance was used at the J.E. Corette Power Station of the Montana Power Company.

Without conditioning this precipitator suffered from

back corona and with the addition of ammonium sulphate this disappeared and it was found possible to raise the impressed voltage from 30 kV to 47 kV.

The ammonium sulphate was injected before the air heaters where the temperature was about 400°F which permitted decomposition of the ammonium sulphate to take place.

However, it was found that a greater portion of the SO₃ and some of the ammonium disappeared across the air heater and in fact what was happening was that the ammonium sulphate was re-combining and attaching itself to the particles of ash in the airheater.

This caused blocking of the airheater by material which could not be removed by sootblowing.

In the words of one of the power station staff "Three months and twenty tons of concrete later the experiment was terminated".

The result should not have been unexpected as the temperature to be found at the cold end of the airheater is well below the recombination temperature of ammonium sulphate.

PRACTICAL RESULTS OBTAINED WITH FLUE GAS CONDITIONING

The effect of gas conditioning of electrostatic precipitators was investigated during a study tour of the United States of America during March 1982.

Here it was found that initially gas conditioning was primarily resorted to to bring underdesigned precipitators where the performance had deteriorated with time into compliance with the EPA regulations. Recent developments however, have indicated the merit of applying gas conditioning to a new installation which technique results in not only a very much smaller precipitator at lower capital cost but provides the unit with flexibility to an extent not obtained in an unconditioned unit.

One interesting installation investigated in the U.S.A. was at the Big Brown Power Station of the Texas Utility Company. This power station consisted of two 600 MW sets burning lignite coal with an ash content of about 12%.

The problem at Big Brown was the change to low sulphur coal compounded by the emissions gradually increasing with the ageing of the precipitators.

By conditioning with SO₃ using a Wahlco unit it was found possible to reduce the opacity considerably but not to within the legal limits.

One possible reason was that due to the duct configuration it was not feasible to inject after the airheater and obtain adequate residence time. Injection was before the airheater at the rate of 12 ppm, and ammonia was also injected at the rate of 5 ppm at the precipitator inlet. This combination was successful in bringing the precipitator into compliance. For comparison the other unit was conditioned using Appollo chemicals and similar results were achieved.

However, Big Brown appeared to be a somewhat unusual situation and many other installations were gas conditioned very successfully.

Following on these experiences gas conditioning experiments were carried out by ESCOM on the Hendrina and Kriel Power Stations.

At Hendrina a SO₃ dosing rate of 30 ppm reduced actual emissions by seven fold and surprisingly even better results were obtained at the Kriel Power Station using a lower injection rate. This was surprising because it was anticipated that the higher calcium oxide content of the ash at Kriel would neutralise the coating of sulphuric acid on the ash particles.

However the early work of Chittum established the opposing acid base relationship and in those early days

demonstrated that a basic dust could best be conditioned using an acidic conditioner.

RECOMMENDATIONS FOR USING GAS CONDITIONING AGENTS

Before resorting to gas conditioning an electrostatic precipitator it must be established that the problem is due to fly ash resistivity.

High resistivity ashes could best be conditioned using sulphur tri-oxide or other acidic chemicals while problems due to very low resistivity may be more amenable to ammonia.

It is also most essential that gas conditioning of a precipitator is not attempted as a "do it yourself job" as disaster is likely to result. The manufacturers of the equipment have had years of experimentation resulting in successful application behind them. Inexpert applications of conditioning agents can result in, at

very best, failure to be effective and further in corrosion problems, plugging of airheater and precipitators and the release of dangerous gases.

REFERENCES

EGENES, H.O. "Enhancement of electrostatic precipitator performance using flue gas conditioning agents", May 1982.

EGENES, H.O. "Flue gas conditioning applied to particulate control", January 1983.

DISMUKES, Edward B. "Conditioning of fly ash with sulphur tri-oxide and ammonia", Southern Research Institute. August 1975.

THE CAPE POINT TRACE GAS MONITORING PROGRAMME

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World-wide concern about the possible environmental influences of certain atmospheric trace gases gave rise to the International Conference in Stockholm in 1976, where a call went out to nations to participate in a Global Environmental Monitoring System. In 1977 Dr Halliday took the initiative on behalf of the CSIR and established a small baseline station at Cape Point, which satisfies the essential requirements for the background monitoring of the trace gases. During most of the time, measurements are made in air derived from the South Atlantic.

The analytical instruments are housed in a little building kindly rented to the CSIR by the Department of Transport, whose light-house generator also supplies the electricity. After a very modest beginning with the occasional air sample being collected and mailed to Pretoria for analysis, the project has grown considerably over the past five years mainly with the assistance obtained from the Max Planck Institute in West Germany. The Cape Point team now comprises two researchers, one technician and a data processor, who have office, laboratory and computer facilities at the National Accelerator Centre/Faure. At present CO and O₃ are being measured continuously and F-11, CCl₄, CH₄ and N₂O on a semi-continuous basis. In addition, an automatic anemometer records wind velocities and directions on magnetic tape. Meteorological parameters such as temperature and pressure are obtained from the light-house staff, who collect these data for the Weather Bureau. The hourly averages of the 11 parameters measured, comprises 77 745 data points per year, which are handled by the CSIR's computer in Pretoria.

The environmental importance of the six trace gases being monitored can be divided into two categories:

- * those which directly or indirectly attack the stratospheric ozone layer; the earth's UV filter
- * those which absorb IR radiation, thereby contributing to the 'greenhouse effect'.

The CO measurements made in Cape Point since 1978, represent the longest and only continuous CO record in the Southern Hemisphere. The main interest in CO, is that its dominant link is the reaction with hydroxyl radicals, which is the primary absorber of many pollutants including 'greenhouse' and 'O₃-destroying' gases.

In the Northern Hemisphere fossil fuel use is believed to be responsible for 23% of the total CO source

strength. The ambient CO level at Cape Point displays a repetitive annual cycle with a spring high (82 ppbV) and a summer low (53 ppbV). Various arguments suggest that this seasonal variation is a function of the annual ITCZ shift. As a consequence, it is impossible at this stage to say whether the CO level is rising or not.

Atmospheric CH₄, which has a mean tropospheric mixing ratio of 1,6 ppmV, has in recent years aroused considerable interest, because it is considered to be the second strongest IR absorber after CO₂. In addition, CH₄ is also an important remover of OH during which reaction CO is generated. Methane is produced in swamps and rice fields and by the digestive processes in cattle and termites. These processes are largely coupled to the world's increasing food production and as such it is not surprising that scientists elsewhere around the globe have observed a CH₄ increase ranging between 1 and 2% annually. As our data base at Cape Point is only 1,5 years old, no such inferences can yet be made.

The tropospheric O₃ cycle must be viewed in conjunction with those of CO, CH₄ and OH. Ozone, which is a small IR absorber, does not solely originate from the stratosphere as has previously been assumed, but is also produced in the unpolluted troposphere. Together with sunlight and water vapour it forms the major source of tropospheric OH. Ambient O₃ concentrations have been monitored at Cape Point since 1979, but unlike CO, no repetitive annual cycle has been observed. During the years 1979 and 1981, however, a spring high was recorded, which is believed to be the result of stratospheric-tropospheric air exchange. The 1982 O₃ mean (21 ± 1 ppbV) compares favourably with those annual means reported by other global baseline stations such as the one in Tasmania (23 ppbV) and the one at the South Pole (20 ppbV).

Freon-11 is a man-made gas which is mainly used in aerosol cans. When F-11 reaches the stratosphere it is photolyzed, whereby O₃-destroying Cl atoms are liberated. Additionally, F-11 also absorbs some IR radiation. Carbon tetrachloride, which probably has both natural as well as anthropogenic sources is, like F-11, a potential destroyer of stratosphere O₃.

The halocarbon means for the first five months of 1983 were: F-11 (196 pptV) and CCl₄ (150 pptV). The annual growth rate of F-11 (1979 - 1980) was 11,8 pptV, but has since come down to 8,6 pptV. This decline in the atmospheric accumulation rate of F-11 is to be expected