IT AIN'T NECESSARILY SO

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Abstract

The intent of the paper is to share some thoughts on electrostatic precipitation that the author has, after more than 25 years activity in the field. Today, 70 years since Deutsch published his precipitator formula, it and its modified version dominates literature on the subject. The original formula is, for instance, used to calculate the emissions of fine particulate i.e. such that contain higher percentages of toxic material than coarser particles. There are however indications that, for such calculations, it would be advisable to use the modified version or a totally new formula. There are other so called facts that are very persistent although it would seem that enough material has been presented to make them obsolete. One is the resistivity level above which back discharge is supposed to influence efficiency. Another is that this level is looked upon as being constant regardless of gas temperature and/or gas composition. The author will show a few examples of a different way to look at trends and distributions, particularly such given as percentages. They should indicate that a new look at old material can be warranted.

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Introduction

During the main part of the sixties, the author sized most of the ABB Fläkt ESP's. This work included studies of trends in test results from pilot and full-scale ESP's in order to improve sizing rules. Although the direct responsibility then passed on to others, the interest in trends and phenomena, that were not explained by theory or common practice, continued.

In the mean time much progress has been made, but it is claimed that there is even now reason to look at old material from a different angle. Present practice or so called established facts can perhaps be improved upon. It is with this attitude that some personal comments are given on sizing formulas and resistivity related questions.

Formulas for sizing and evaluation of test results

The original Deutsch and the modified Deutsch formula still dominate the industry although many, including the author, have tried to introduce other modifications, variants or new concepts. These have been presented usually in order to explain phenomena like reentrainment.

The use of the Deutsch and the modified Deutsch formula

The development of the modified Deutsch formula, which was originally named the Wk-formula, has been described at some length elsewhere (1). Its continued use by many, as documented, for instance, at the ESP conference in Beijing, is an indication of its merits. To those unfamiliar with its use, and also in order to help those that like to study papers where it has not been used, the following comments are given.

$$\ln (1/(1-E)) = \frac{w\,L}{R\,v}$$ The Deutsch formula

$$(\ln (1/(1-E)))^2 = \frac{Wk\,L}{R\,v}$$ The Modified Deutsch formula

Thus $Wk = w \times \ln (1/(1-E))$

Gas velocity changes. Until about 30 years ago it was considered by many that the effective migration velocity w, in the following called emv, was constant i.e. not influenced by gas velocity. Yet it had been documented already then in tests with pilot ESPs that emv, when studied over a wide range of gas velocities, would increase from a low value at low velocity and high efficiency, level off in some intermediate velocity and efficiency range and then decrease at even higher gas velocities. The latter phenomena, rare in todays high efficiency full-scale ESP's, has usually been referred to as reentrainment.

Acc. to the modified formula, Wk is constant with gas velocity, at least in the high efficiency range i.e. in this range it describes the increasing trend of emv with increasing gas velocity. It is of interest then to calculate emv's for a few gas velocities at constant Wk. Then not only Wk, but also R and L are constant.

This can be made by first calculating efficiencies using the modified formula at say four gas velocities. Then insert the values into the Deutsch formula and calculate the corresponding emv's for each gas velocity. Alternatively the two formulas can be combined. The result will be the same: Changes in gas velocity in an ESP will, in the high efficiency range and using the modified formula, result in emv's that are proportional to the square root of gas velocity.

Figure 1.

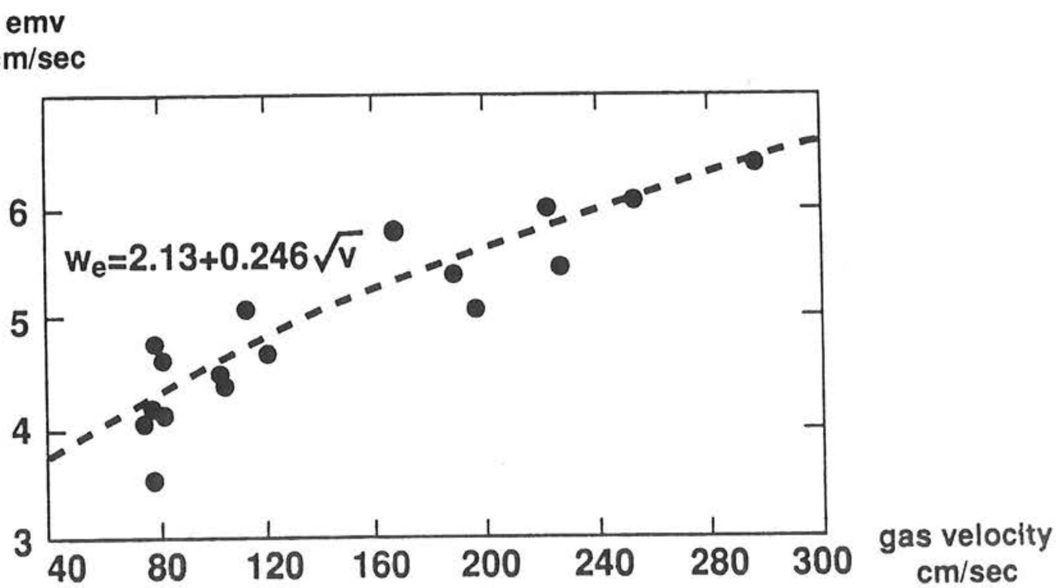

Figure 1. Variation of effective migration velocity (e. m. v.) with gas velocity for a duct pilot precipitator. The curve was fitted by the original investigators.

There are many examples of this trend in literature. One is shown in fig. 1 which was referred by Robinson (2) in a paper in 1967. This was before the modified formula was introduced in the US at a conference in 1974. In other papers the same trend has for instance been presented as an addition to emv, when SCA decreases.

When Wk-values are calculated from a series of tests over a wide gas velocity range, the result will be that they will be constant up to some gas velocity and then decline at even higher gas velocities.

Changes of effective length. It has been documented by many that the Deutsch formula describes the length-wise collection in an ESP with some accuracy. In the modified formula, the relationship between efficiency and ESP length has changed. Thus Wk should be a function of ESP length. The relationship would be complicated, at least for short lengths, and require access to test data from a number of ESP plants to be established.

The two formulas and influence of spacing. As has been documented for instance in (3) it is commonly agreed by the ESP industry that, at least in the spacing range commonly used today and with certain provisions, both the emv and Wk are directly proportional to spacing.

Fractional migration velocities

Calculation of fine particulate collection has grown in importance during the years as the emission of trace metals shall be minimized. For such calculations the Deutsch formula and the corresponding emv's are frequently used.

Doubts about the correctness of this calculation procedure have been expressed on several occasions (4). Then reference was made to results from pilot plant testing in Australia and Great Britain which included the determination not only of total but also fractional emv's for several particle sizes at different gas velocities. Further evidence has now been discovered in a test series involving a vertical flow pilot ESP run without rapping by König (5).

In all three cases total as well as fractional emv's increased with gas velocity in the low gas velocity range approximately acc. to the modified formula. During the test in Great Britain, the gas velocity was increased to and over the point at which both the total and fractional emv's leveled off and then started to decline, as described above. It is suggested therefore that fractional emv's follow the same gas velocity trend over a broad gas velocity range as total emv's, i.e. they:

- increase with increasing gas velocity in the high efficiency range acc. to the trend of the modified formula.
- decrease at a too high gas velocity, i.e. are subject to reentrainment.

An acceptance of the principle that fractional efficiencies also follow the modified formula in the lower gas velocity i.e. high efficiency range, would mean the determination of a fractional Wk for each particle size. It would, as a first stage, involve the correction of test data to common conditions i.e. power input, size of ESP etc.. In a second stage a typical standard deviation in the inlet grain size distribution could be assumed. Then a sizing curve could be calculated for total Wk against mean grain size of the dust. That curve would be valid for:

- one typical standard deviation in the grain size distribution.
- one typical ESP size and design.
- a typical set of technical data i.e. temperature, gas composition etc..

In order to use the curve, the mean grain size of the dust would have to be known or assumed. It would yield a total Wk to use for sizing, which would have to be corrected to the data valid for the ESP to be sized. These corrections would have to be the same as those used in order to arrive at the curve for fractional Wk's. It is obvious that, when the basic fractional Wk-values have been determined, the whole procedure can be computerized.

The mathematics of percentages

Percentages are encountered daily in business, technology and in private life. When trends in percentages are studied they are drawn in different scales: linear, logarithmic, probability etc.. When a regression analysis, for instance on efficiency test results shall be made, nobody versed in ESP technology would use efficiency figures as such, but a converted number such as ln (1/(1-E)).

Another method, used in other fields of science, is to convert percent into "fraction" defined as percent/(100-percent). This converts percentages into numbers which are mirrored around 50 percent. This is also a feature of a probability diagram, but the scale is different, particularly in the high and low percentage range.

Percent	10	20	50	60	80	90	95	99	99.9
Fraction	0.11	0.25	1	1.5	4	9	19	99	999

The originators use fraction instead of percent to describe market penetration of new technology. They claim that it will transform any S-shaped curve on percentages drawn in linear scale into a straight line, with fraction in logarithmic scale against years in linear. The method is also used by IIASA to make predictions on energy use.

A new ESP formula

The inability of the Deutsch formula and the modified formula to cover the extreme conditions of reentrainment has intrigued the author. A new formula that "explained" reentrainment, could perhaps have benefits also at "the other end", i.e. when sizing for very high efficiencies. A concept of a new ESP formula, which uses fraction as the measure for efficiency, has been presented earlier (6). The proposed formula reads:

$$E/(1-E) = A \times SCA^{Wn}$$

where: A is a constant and Wn a new "migration velocity".

It was shown that such a formula can:

- simulate the changes in efficiency with gas velocity in one ESP over the whole gas velocity range, i.e. include reentrainment.
- simulate the efficiency-gas velocity relationship of the modified formula in the high efficiency range.
- simulate that lengthwise collection in an ESP follows the Deutsch formula, with about constant emv.

The writer has, at least so far, been unable to develop the concept into a formula that can be used for sizing purposes. As a plea for further investigation by others has remained unanswered, a new effort will be made. It is intended that a new formula would also be used for the calculation of fractional collecting efficiencies.

Electrics

In operation, an ESP is like a black box. Communication with the inside is through the electrical data read off increasingly more sophisticated instruments and involves computers in regulation devices etc.. One disturbing factor is the resistivity of the dust and the detoriation of electrical conditions within the ESP connected with back discharge.

Questions:

- can the method used to predict the resistivity level of a future dust i.e. from a coal-fired boiler, be improved?
- can measured resistivity levels given in papers be trusted?
- how shall back discharge be detected?
- at what resistivity level will back discharge occur for i.e. after a coal fired boiler and how will this level vary with gas temperature and gas composition?

Resistivity and ash composition

The best known formula used to calculate the resistivity of a fly ash i.e. dust from a coal-fired boiler, based on its chemical composition, has been presented by Bickelhaupt. It was derived using the percentages of the components in a number of US fly ashes determined using the conventional method of representing them as oxides. The result emphasized the importance of sodium, one of the components in fly ash that decreases its resistivity.

When using percentages, the importance of the high resistivity components SiO_2, Al_2O_3 etc. tend to be underestimated relative to components like sodium etc.. In order to describe the argument two fly ashes can be compared, one were the sum of the high resistivity components is 80 percent and another where the same is 90 percent. Assume also that content of sodiumoxide is 1 and 0.5 percent respectively.

Mathematically a change from 80 to 90 percent is not seen by a computer to amount to much, but the decrease from 1.0 to 0.5 is another matter. The use of fraction changes the situation: 80 becomes 4 and 90 becomes 9. Thus a sort of equilibrium is achieved. That a new regression analysis, on the same data as those Bickelhaupt used, could show an influence of the high resistivity components, is indicated by the following:

Figure 2.

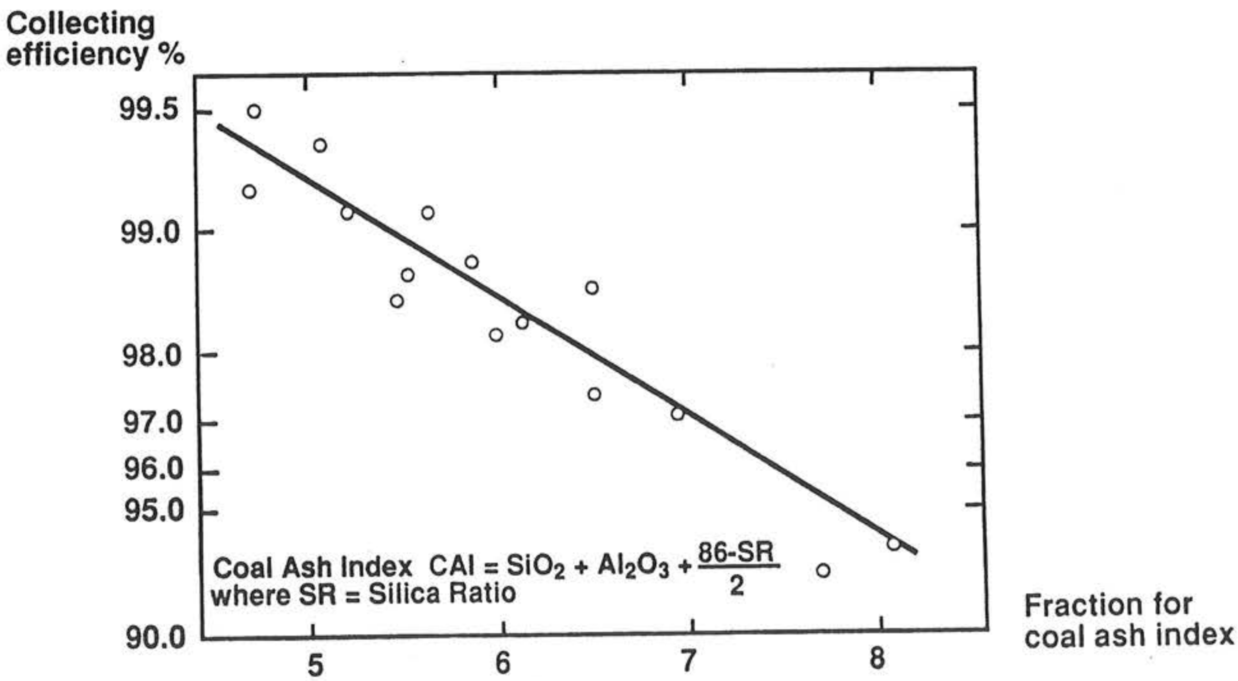

Figure 2. Variation of the collecting efficiency of a tubular pilot ESP against a coal ash index of the coals fired in an experimental furnace.

Figure 2 shows the results of an old investigation on data reported by CSIRO (7) in a prestudy of coals to be fired at the then future Liddell power station, Australia. 17 different coal samples were fired in a mini-furnace and the collectability of the flyash measured in a pilot ESP.

Here fraction is used both for the collection efficiency of the ESP and a local Ash Index (CAI). With this complicated index it was possible to fit all results except two into a clear trend. Note that the sodiumoxide content of the coal ash, which was between 0.07 and 0.9 percent, is not included in the index.

Resistivity measurement

A number of years ago a s.c. Round Robin was organized. The resistivity of several fly ashes was determined by a number of laboratories around the world. The results agreed rather well according to an IEEE paper (8).

What became of this effort? It seems that the ESP industry would benefit from a measuring standard to adhere to and make reference to. Then resistivities measured by laboratories all over the world could be compared, a situation that does not appear to exist today. It might mean the establishment of a "resistivity measurement meter" against which a test would have to be performed.

Detection of back discharge

A study of current/voltage characteristics in literature, for instance from the ESP conference in Beijing, shows that linear scales dominate. Back discharge is said to start when voltage does not increase any more with increased current.

Figure 3.

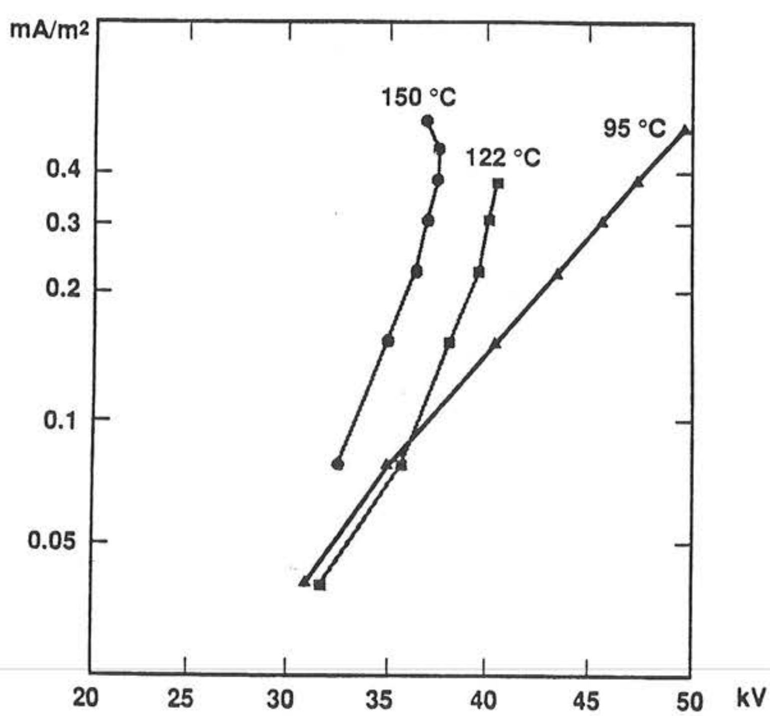

Figure 3. Current-voltage characteristics of a pilot ESP collecting fly-ash at different gas temperatures.

If the characteristic is drawn with theoretically appropriate scales, a deviation could be interpreted as a sign of back discharge. The writer prefers to use semi-logarithmic scales as shown in fig. 3. The data are from tests, using a ABB Fläkt pilot ESP, for the Liddell power station. At 95 deg. C the characteristic is almost a straight line, but at 122 deg. C a deviation from the straight line appears. This should indicate that back discharge has started in the area with highest current density. Fully developed back discharge i.e. constant voltage at increasing current density, does not appear until at 150 deg. C.

Winterhager (9) used a power function for the characteristic. His work was done using a point to plane apparatus. The characteristic was a straight line in double logarithmic scales with a clean plate but bent when the plate was covered with increasing thicknesses of a 4x10 exp. 12 ohm cm material.

The scientists of ABB in Växjö tell the writer that today there are much more developed methods to detect back discharge through study of the curves of voltage and current pulses.

Resistivity, back discharge etc.

Problems connected with too high resistivities continue to be a problem for ESP suppliers and users, however not to the extent of the hot ESP's of the 70-ties. And - today there are other measures to use than a larger ESP, conditioning or rebuild to a fabric filter. Semi-pulse i.e. intermittent charging or even pulsed rectifiers have simplified matters and given large savings, above all in power consumption.

2x10 exp. 10 ohm-cm is still said by some to be the value at which resistivity starts to affect ESP operation, in spite of that efficient ESP operation has been documented above this level. Nichols (10) calculates that back discharge should start when the resistivity is above 10 exp. 11 ohm-cm.

Whatever the correct level, the value must be linked with the gas temperature and gas composition at which it shall be valid. The level decreases when gas temperature increases above the resistivity peak, as the hot ESP experience has documented, but with which relationship? On the other hand conditioning, i.e. an increase in water vapour content and a decrease in gas temperature, will decrease back discharge in the high temperature range, although resistivity increases! Some consideration must also be given to the design of ESP internals and their ability to give a good current distribution. The author feels that a summary of past experience, with a theoretical background, is lacking.

Conclusion and recommendations

In this paper the writer has had the intent to show that a few of the s.c. facts of ESP technology can be looked at from a different angle. Through the use of fraction instead of percent, a new type of formula for sizing of ESP's could be developed that would cover phenomena not covered by the formulas used today. Fraction could also be used instead of percent in other instances, for example to investigate the influence of coal ash constituents on the resistivity of fly ash.

In the search for material for this paper the author has experienced that some has been lost forever - an author, who had made tests on fractional efficiencies of a pilot ESP, had left the institute and no-one could find the test data.

This points to a need of the ESP industry: Documentation. A system should devised according to which it is ensured that background material used for presentations of papers at this and future conferences, can be made accessible for future study. A lot is proprietary, but could perhaps be released at some future date. The intent would be to then let others than the author study the background material.

Harry J. White used to write summaries on ESP technology. The writer feels that today the industry needs a kind of "white book" on the State of the Art of ESP's. Hopefully such a book or paper could summarize todays knowledge on some key issues and be used by researchers around the world. ISESP could act as consultants in the same way as in the summary on wide spacing.

In this regard reference is made to the activity of the Battelle Stack Gas Emissions Control Coordination Centre Group in the field of reduction of sulphur and nitrogen emissions. It issues a bi-monthly report on visits to plants, important papers as well as answers on queries on technology etc..

The particulate control industry would also benefit from an organisation that could attend to matters of common interest. Its tasks re ESP's could involve for instance:

- standardization of certain methods. Resistivity measurement is one example.

- development of a literature bank. This should in particular include doctor thesis's in all languages and the test reports which were distributed to a number of suppliers in the "old days". Data bases do not include such material and seem to regard anything older than 1970 as obsolete.

- establish a method to make data used for presentations at conferences available to researchers at some future date. Unless a system is worked out they risk, in a number of years, to have been lost forever.

- issue summaries on the State of the Art.

The group for sulphur and nitrogen emissions is funded by organisations all over the world. Surely the same organisations and others are interested in the control of particulate emissions!

Acknowledgement

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References

1. S. Maartmann. "A New Precipitator Formula?" Paper presented at the Third International Conference on Electrostatic Precipitation, Albano, Italy. (October 1987).

2. M. Robinson, " The Role of Turbulence in Electrostatic Precipitation". Paper No. 67 - 34, presented at the 60th Annual Meeting, Air Pollution Control Association, Cleveland, Ohio, (June 1967).

3. S. Matts. "Reentrainment - The major problem in precipitators designed for high efficiency". Paper presented at the Third International Conference on Electrostatic Precipitation, Albano, Italy. (October 1987).

4. S. Maartmann. "Möglichkeiten zur Feinstabscheidung mit trockarbeitenden Elektroenstaubern". Staub-Reinhaltung der Luft. Vol. 34, No. 10, p. 353 (1974).

5. W. König. "Zum Verhalten des Staubes im Elektrofilter". Energie. Vol. 18, No. 5, p. 199 (1966).

6. S. Maartmann. "Can Reentrainment be explained using a new Precipitator formula?" Paper presented at the Transfer and Utilization of Particulate Control Technology Conference, Orlando, Fla., (1981).

7. Investigation of the Electrostatic Precipitation of the Fly-Ashes from Coals to be supplied to the Liddell Power station. Chatswood, N.S.W.: CSIRO, June 1968. Investigation Report 72.

8. "Recommended Practice for Measuring and Reporting Fly Ash Resistivity". Prepared by the Working Group of the IEEE Power Engineering Society. 1980.

9. Forschungsberichte des Landes Nordrhein-Westfalen. No. 1684. Untersuchung des Rueckspruehens an Modell-Elektrofiltern unter besonderer Beruecksichtigung der mit Rueckspruehen verbundenen, kurzseitigen Stromimpulse. Köln and Opladen: Westdeutscher Verlag, 1966.

10. G. Nichols. "Interpreting Electrical Data from Electrostatic Precipitators". Paper presented at the Fourth International Conference on Electrostatic Precipitation. Beijing, China, (September 1990).