# EXPERIENCE WITH BAFFLE-FREE COLLECTING PLATES IN AN ELECTROSTATIC PRECIPITATOR

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## Abstract

The present standard for collecting plates used in industrial precipitators of European type is vertical strips with stiffening edges. The edges are generally considered to act as baffles providing shelter zones improving the precipitating process close to the wall. This paper describes the use of baffle-free collecting plates.

Laboratory measurements indicate that without baffles, the turbulence generated by the wall will be reduced thus increasing precipitator efficiency. Further, results from field measurements on a precipitator installed after a furnace and an acid gas absorber on an incinerator plant in Denmark are presented.

The very satisfactory emission level and the small rapping peaks demonstrate that baffle-free collecting plates for this application are superior to traditional collecting plates with baffles.

## Introduction

Recently FLS miljø a/s have introduced a new collecting plate curtain. The following objectives motivated the new design:

With still increasing precipitator heights, up to 20 [m], inherent problems with the European type vertical strip plates complicate fabrication, transportation and erection. Furthermore the plate length and the moderate plate thickness make it necessary to construct the strips with still stiffer edges. This means that the gross plate width increases and that the edges act as still higher baffles.

Moreover the traditional vibration system with rappers at the plate bottom does not create adequate acceleration level with high resistive dust. An improvement is needed to provide for the huge collecting areas of the fields operating as effectively per [m$^2$] as the fields of former, smaller precipitators.

Few workshops can handle 20 [m] long strips and in several countries the transportation creates tremendous problems as the plants are often placed in relatively desolate areas with narrow roads and small villages. Many plate designs are difficult to pack, and the single packages become rather voluminous. To this is added that strips 20 [m] long and 500-750 [mm] wide made out of 1.25-1.50 [mm] thick steel plate are very fragile and during erection the risk of plastic buckling is very high.

## Flow considerations

In literature it is often claimed that baffles have a positive effect on the dust precipitation. [1], [2] and [6]. Figure 1, from [6], shows examples of collecting surfaces with stiffening edges or with regular baffles. Behind the baffles a leazone is claimed to be created by the flow where the particles are mainly influenced by the electrical Coulomb forces. Some authors also imagine the leazone to shield the falling dust against flow erosion and reentrainment during rapping.

It is known that already Walther Deutsch in 1922 was aware of the intense turbulence field in the electrode space, where he assumed the dust profile to be even. At the same time he implicitly presumed the existence of a laminar area using Stokes' formula for a quiesent gas to express the balance between the forces from field and charge and from gas friction.

The bulk flow in the precipitator is driven by the pressure difference between inlet and outlet faces. The Reynolds' number based on the duct width is of the order 10,000, above the laminar to turbulent transition regime. Internal structures, frame parts and discharge electrode bodies produce turbulence due to shear and the friction at the collecting surfaces also contributes to the turbulence production. Furthermore an energized precipitator field has a flow of electrons, ions and charged particles, which induces vortices that are transformed into turbulence before their energy eventually decays to heat. At very low axial velocity, where the ratio between the kinetic energi and the ionic wind velocity is low, there is a three dimensional flow pattern dominated by rolls with vertical axis. This ratio is the electrical Froude number: $F_e$. At very high $F_e$-values, i.e. high axial velocities or low current densities, this results in turbulence, while the moderate $F_e$-interval is characterized by rolls of secondary flow with almost horizontal axis.

Let us look at the two dimensional flow past a surface with protrusions or baffles, simplest very thin fins. The flow pattern between fins is determined by bulk velocity, fin height and fin pitch. Upstream of a fin the wall flow separates from the surface in order to pass over the fin top. Inside the cavity confined by the boundary stream line, by the wall and by the upstream face of the fin there is an enclosed vortex, or a set of vortices, which are moving due to shear from the bulk flow. This picture is time-dependant: fluid lumps escape the recirculating region and are convected downstream, and similarly fluid elements are entrained from the bulk into the recirculating zone.

At the fin top the flow detaches and is displaced a little upwards. But right downstream of the fin the flow turns towards the wall, where it reattaches. Enclosed by the solid walls and the bulk flow we have the downstream bubble with recirculating flow. Fluid elements are exchanged between the two regions and the reattachment point or -line oscillates with time towards and away from the fin. The flow picture is shown in Figure 2. The difference between two and three dimensions is the fact that discrete tip vortices, changing position with time, are generated from the fin top and stretched downstream thus contributing to the turbulence level in the near wall zone. The extension of the two recirculation bubbles depends on the Reynolds' number based on the axial velocity and the fin height, $Re_h$. $Re_h$ is typically of order 1,000. The upstream bubble is much smaller than the downstream one, why we only show the position of the reattachment point in dependence of $Re_h$ in Figure 3; from [10]. Figure 4 shows the turbulence level of a given flow case indirectly as the heat transfer coefficient, which increases with turbulence intensity, revealing that the baffle plate contributes to the wall turbulence. Therefore it is dubious to claim that baffles have any positive effect on the precipitation at the wall due to a shelter effect. Also Researchers from Stanford University have questioned the use of baffles due to the turbulence generated. [4], [7].

Precipitators may be designed with a perfect global gas distribution, and with a minimum of internals. Avoiding or minimizing internal struts, internal rapper bridges, heavy frame structures etc. is part of these efforts. However, it is not possible to eliminate the turbulence generated by the collecting surfaces, avoid the turbulence from the discharge electrode body or from the corona wind generated.

FLS miljø design does not comprise internal struts, but it's rigid frames and discharge rapping bridges are bound to create some turbulence. Rigid discharge electrode bodies apparently create a lot of turbulence, although L.S. Sørensen et al., [8], have demonstrated that the interaction between wake and ion wind extinguishes the secondary flow and thereby reduces the turbulence level. Yet, it must be noticed that due to mechanical considerations a precipitator cannot be designed without a minimum of internals, promoting turbulence.

## Flow during rapping

Now turning to the assertion that baffles have a positive effect during rapping. When the vibration wave passes a given place of the collecting plate, the stress in the dust layer breaks loose lumps of dust, which slide down the surface and eventually fall down due to gravity. The main point is that the dust falls as lumps limiting the particle reentrainment because the surface to mass ratio is much smaller for a lump than for a similar sample of single particles.

During the fall the lump induces secondary flow velocities considerably higher than the nominal axial flow velocity. This is due to the fact that the flow resistance of the lump is very small compared to the gravitational force. Neglecting fluid resistance, the velocity of a free falling lump after a 2 [m] drop is $\sqrt{(2 \cdot g \cdot h)} = \sqrt{(2 \cdot 9.8 \cdot 2)} = 6.3$ [m/s], i.e. several times the axial gas velocity of most precipitators.

Thus the conclusion is that normal baffles which protrude 20 - 60 [mm] from the surface are unable to shield the falling lump from its own induced velocity field.

## Electrical considerations

It is obvious that the minimum sparking distance is higher for plane collecting plates than for strips with heavy protrusions. Furthermore the lack of field enhancement of the protrusions gives a more smooth current distribution which increases the efficiency and hampers the formation of back corona. [9].

With vertical plate strips the discharge electrodes may be arranged as one, two or three per plate, depending on the strip width and on the demands of voltage and current as well as current distribution. The horizontal plate curtain does not put any restriction to the discharge electrode arrangement. As there are no stiffening edges the electrode distance can be chosen freely based on current and voltage considerations.

Some precipitator designs have used different types of discharge electrodes inside the single field in order to adapt the current density to the particle space charge. As the particle density is high at the field-inlet, compared to the density at field-outlet, it appears advantageous to have an electrode geometry giving higher currents for a given voltage in the front end. However, in practice, such differentiation is normally avoided as it requires special attention during erection.

With the new curtain design the discharge electrode distance can be differentiated applying horizontal frame tubes with support points placed optimally. This is done in the workshop and does not really influence the fabrication price.

In order to illustrate the effect of electrode distance we have performed calculations using a new computer code taking the true 3D-field, the gas flow and the particle space charge into consideration. [11]. The programme calculates the current density and the efficiency. The effect of differentiated electrode distance is revealed in Figure 5 showing the axial current density at constant field voltage. The calculated emission is 5 times lower with the special arrangement as compared to the equidistant arrangement.

## Laboratory measurements

At the laboratories of FLS miljø tests have been made with a two-field one-duct precipitator operating with ambient air and redispersed lime dust or fly ash. A special feature of the precipitator is a set of collecting plates, which are electrically heated from the back thus allowing control of the dust resistivity, within limits, by varying the plate temperature.

In order to have the best possible global velocity distribution the inlet cross section has the full width and height of the precipitator duct. The electrode system has been designed to minimize the boundary effects, considering the effective plate height of only 1.5 [m]. Furthermore plates of electrical isolating material at top and bottom enclose the duct to ensure that sneakage is minimal. This provides for a 99% efficiency with one field of 1.8 [m] length, corresponding to an A/Q of 9-18 [s/m], and a 99.9-99.99%. with two fields, giving A/Q = 18-36 [s/m].

Results of penetration in dependence of the Deutsch number for plane collecting plates are seen in the plot of Figure 6. The Deutsch number is an equivalent precipitator length, equal to $w \cdot l/(v \cdot d)$, w being the measured migration velocity, l the precipitator length, v the axial gas velocity and d half the ductwidth. The electrical Peclet number, $P_e = w_e \cdot d/D$, is a parameter in this plot. $w_e$ is the electrical average migration velocity calculated by means of the SoRI code, and D the diffusion coefficient, $D \approx 0.002$ [m²/s].

The calculated migration velocities give Peclet numbers from 10 to 20, which is still in the high turbulent regime as $P_e \to \infty$ for laminar flow and $P_e \to 0$ for 100% turbulence. Yet small differencies in $P_e$ in this range give big changes in the attainable efficiency. It is interesting to note that the measured penetration drop below the value predicted by the Deutsch formula at Deutsch numbers above 4.5. This complies well with the theory of rolls stated in [5], where the efficiency at moderate Froude numbers is limited by dust particles trapped in the core of the horizontal rolls.

In the laboratory the axial velocity was decreased in order to raise the Deutsch number to values of long full scale precipitators. This means that secondary flow with high roll strength may have been created, because the current density was maintained between 0.05 and 0.20 [mA/m²], thus giving pessimistic test predictions compared to full scale installations.

## Field installation

A precipitator with horizontal collecting strip plates is installed after a gas suspension absorber on an incinerator furnace burning municipal waste at "Aarhus Nord" in Denmark.

The incinerator furnace is of type Vølund with a capacity of approx. 200 [t/24h] with a 16.5 [MW], 20 [bar] hot water boiler for city central heating. The semi-dry scrubber is an FLS miljø type GSA for removal of HCl acid with an efficiency of 90-98%, [12].

Gas and particle data, and precipitator data are:

| | | | |
|---|---|---|---|
| Gas temperature | | 135 | [C] |
| Gas volume flow rate | | 32 | [$m^3$/s] |
| Gas composition | $H_2O$ | 15 | [%] |
| | $CO_2$ | 9 | [%] |
| | $O_2$ | 11 | [%] |
| | HCl | ≈700 | [mg/$m^3$ NTP] |
| Inlet dust loading | | 2.7 | [g/$m^3$] |
| Grain size median | | 15 | [μm] |
| Standard deviation | | 3.1 | [ ] |
| In situ resistivity | | ≤10 | [GΩ·cm] |
| Gas axial velocity | | 0.63 | [m/s] |
| Total field length | | 2·3.6 | [m] |
| Field height | | 7.0 | [m] |
| Collecting area | | 1814 | [$m^2$] |
| Discharge electrode | | Fibulax 2525 | |
| Rectifiers | | | |
| field#1/field#2 | | 90 | [kV] no-load |
| | | 300 | [mA] |

The plates are supported between a vertical rapping bar and a vertical guiding bar, both bars consisting of two angle-iron hanging from the precipitator top. The plates are bolted on to the rapping bar, but free to move at the guiding bar. The anvils for the hammers are placed on the rapping bar, giving the possibility of intense multilevel rapping in case of sticky or high resistive dust. The tumbling hammers rotate round a horizontal shaft and hit the anvils vertically after a drop of 90°. Figures 7 show the plate- and discharge systems. Figure 8 demonstrates the plate profile. The strip height is 500 [mm] in this case, and the protrusion peak to peak measure is 7.5 [mm]. Figure 9 show the hammer bridge in front of the plate leading edges, and in Figure 10 the anvil design is seen. Even though the resistivity is moderate, two rappers per plate curtain were installed, in order to test the multilevel rapping system.

## Erection

The plates were fixed to the leading edge rapping bar and the trailing edge guiding bar in a jig on the ground. After having assembled a full curtain, the jig was raised to the vertical position and the curtain left, leaning against the precipitator compartment. Later on the plate curtains were lifted up by a crane and put into position in the precipitator.

Erection can also be performed without a crane. This is especially advantageous in cases where the free space around the precipitator is sparse, where the winds are heavy or where rain or snow make it preferable to mount the internals inside the compartment. In this case the rapping bar and the guiding bar are supported by two tackles from the ceiling. The bars project down into the bottom hopper and after having fixed the horizontal plate strip the bars are hoisted up for the next strip to be fixed. With tall precipitators the bars are prolonged by means of fishplates thus giving no restrictions to the precipitator height.

## Preliminary measurements

The gas distribution was checked in order to ensure that the emission was not influenced by poor gas distribution. The inlet funnel is an almost central cone and the outlet funnel a downward (bottom) type. In this case, when reentrainment is of special interest, the bottom oulet funnel is indeed not the best choice, but was dictated by the lay-out.

If reentrainment should be moderate, high rapping intensity is not desired. But in order to test the multilevel vibration system for cases with high resistivity, the high intensity rapping system was chosen. Field testing with a small 3 [g] accelerometer was performed and the results are shown in Figure 11. The numbers indicated are peak values in [g*] normal to the plate surface. The unit 1 [g*] is the gravity-field acceleration = 9.8 [m/s$^2$].

## Emission measurements

The precipitator A/Q at nominal production is approx. 57 [s/m]. Typical operating average voltages are 60-70 [kV] and typical current densities are of the order 0.25 [mA/m$^2$].

At nominal maximum production the particulate emission is about 6.0 [mg/m3] giving an efficiency of 99.78%. Evidently part of the emission is due to reentrainment, sneakage and rapping losses, and a theoretical calculation of the emission (omitting the influence of these parameters) gives about 2.4 [mg/m$^3$] corresponding to 99.91% efficiency.

By means of an opacimeter the output signal was recorded on a strip chart recorder. Figure 12a. The system time response was about 60 [s] meaning that the peaks shown should be multiplied by a factor 1.28 considering the rapping puff being a step signal of 90 [s]. The corrected peaks are less than 0.15 [mg/m$^3$]. With reduced current, i.e. 0.01 [mA/m$^2$] on field 1 and 0.25 [mA/m$^2$] on field 2 the average emission was 20 [mg/m$^3$], and the rapping peaks from field 1 and field 2 were 6 and 13 [mg/m$^3$] respectively.

As the rapping frequency of the first field is 20 [h$^{-1}$] and about 10 [h$^{-1}$] in the second field and the duration of a puff is 90 [s] per rapper rotation, the contribution of rapping reentrainment should be about $2 \cdot 0.15 \cdot 90 \cdot 15/3600$ or 0.2 [mg/m$^3$] of the measured total of 6 [mg/m$^2$]. This is 3% of the average value. The factor 2 reflects the presence of 2 rapper shafts per curtain. Similarly we find 3 [mg/m$^3$] or 15% of the average in the case with only 0.01 [mA/m$^2$] on field 1.

## Field results with vertical strips

At a precipitator installation for an identical furnace, boiler and gas suspension absorber at "Reno Nord" in Denmark, similar measurements were made. The A/Q is the same as above, 57 [s/m]. The recording from the opacimeter is shown in Figure 12b. The rappers are placed at the bottom of each 7.0 [m] high field giving a lower rapping intensity.

The rapping puffs from the baffle plates were of the same order, 3.5% and 12.5% respectively, as found with the baffle-free horizontal plates at the same current density.

This shows that rapping peaks with the baffle-free horizontal plates is not the problem as often stated in literature.

## Conclusions

The horizontal strips have several advantages compared to the traditional vertical strips with stiffening edges. This includes fabrication, packing, shipping and erection.

The new design makes it possible to use multilevel rapping for applications with sticky and high resistive dust.

Without baffles the flow turbulence generated is limited, providing for the efficiency to be higher. Laboratory measurements show that the efficiency with plane collecting plates may be well above the Deutsch limit.

Field testings have revealed a satisfactory collection efficiency for a precipitator with baffle-free horizontal strips after an incinerator furnace with gas suspension removal of acid gases.

Comparison with a baffle-type vertical strip precipitator after an identical incinerator furnace installation shows that the baffle-free type in fact is superior to the standard type. Even though the resistivity of the dust is moderate, and a two-level high-intensity rapping was utilized on the horizontal plate curtain, almost no rapping peaks have been recorded.

On this background it is concluded that baffle-free horizontal strip collecting plates may be a very viable choice for many precipitator applications.

## References:

1. H.J. White: "Industrial Electrostatic Precipitation". Addison Wesley Publish.

Company Inc. 1963. Pp. 349-354.

2. Sabert Oglesby, Jr. and Grady B. Nichols: "Electrostatic Precipitation". Marcel Dekker Inc., 1973. Pp. 277-279.

3. Leif Lind: "Heat Transfer from a Plate with Transversal Ribs". Dept. of Fluid Mechanics. Techn.Univ. of Denmark. AFM76-08. June 1976.

4. G.L. Leonard, M. Mitchener and S.A. Self: "Precipitation from Turbulent Flows". Stanford University. 1st ICESP, Monterey Oct. 1981.

5. Poul S. Larsen and Søren K. Sørensen: "Effect of Secondary Flow and Turbulence on Electrostatic Precipitator Efficiency". DACAMM Report No. 279, February 1984. The Technical University of Denmark.

6. T. Palotai et al.: "Space Charge Effects in Electrostatic Precipitation". Tungsram Co. Ltd. and Techn. Univ of Budapest. 3rd ICESP, Abano, Oct. 1987.

7. S.A. Self, K.D. Kihm and M. Mitchner: "Precipitator Performance Improvement Through Turbulence Control". Stanford University. 3rd ICESP, Abano, Oct. 1987.

8. L.S. Sørensen et al.: "Secondary Flow and Turbulence in Negative Corona Precipitator with Large Diameter, Barbed Electrodes". The Technical University of Denmark. 3rd ICESP, Abano, Oct. 1987.

9. C.E. Åkerlund: "A Method for Calculating Electric Field and Current Distributions along Profiled Collecting Electrodes in a Wire-Plate Electrostatic Precipitator". Fläkt Industri AB. 3rd ICESP, Abano 1987.

10. F. Durst, M. Founti and S. Obi: "Experimental and Computational Investigation of the Two Dimensional Channel Flow over Two Fences in Tandem". Trans. of the ASME, Vol. 110, March 1988.

11. Jamshid Zamany: "Modeling of Particle Transport in Commercial Electrostatic Precipitators". Dept. of Fluid Mechanics, DTH and FLS miljø a/s, Denmark. (Ph.D. thesis to be published March 1993).

12. "Acid Flue Gas Cleaning Systems". FLS miljø brochure.

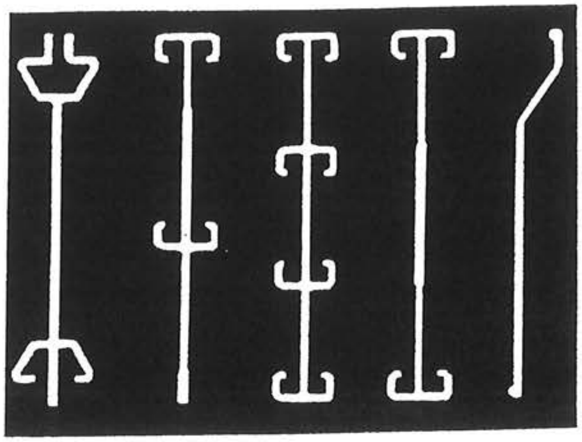

Figure 1. Baffle-plates. From [6]

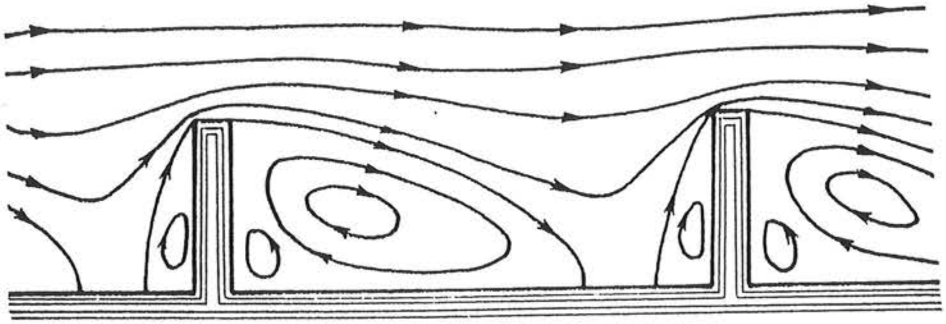

Figure 2. Flow around finned plate. From [3].

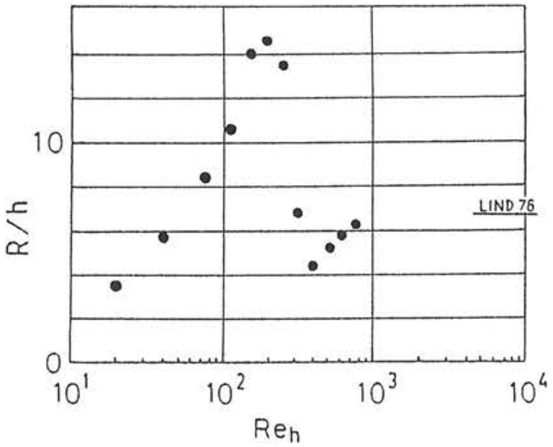

Figure 3. Reattachment length, R/h versus Reynolds' number, $Re_h$. From [10].

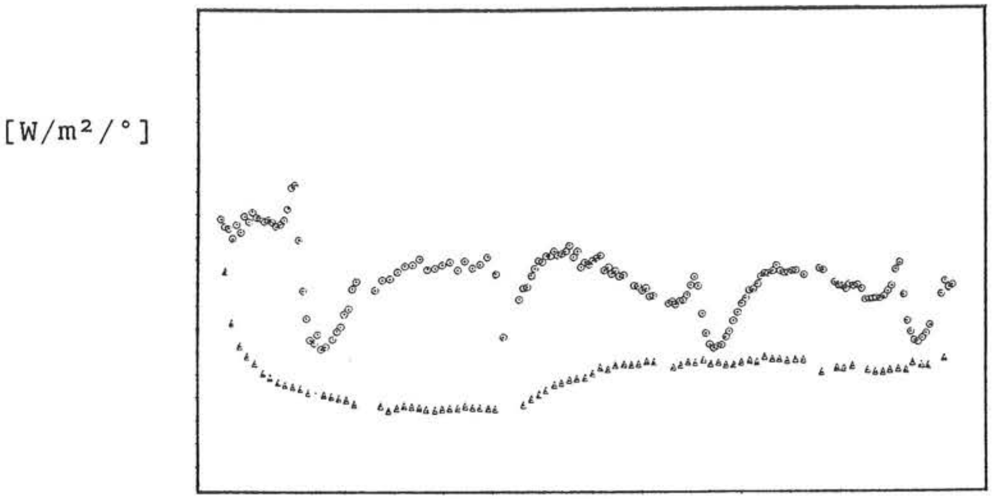

Figure 4. Heat transfer coefficient versus length.
Upper points: finned plate with P/h=20.
Lower points: plane plate. From [3].

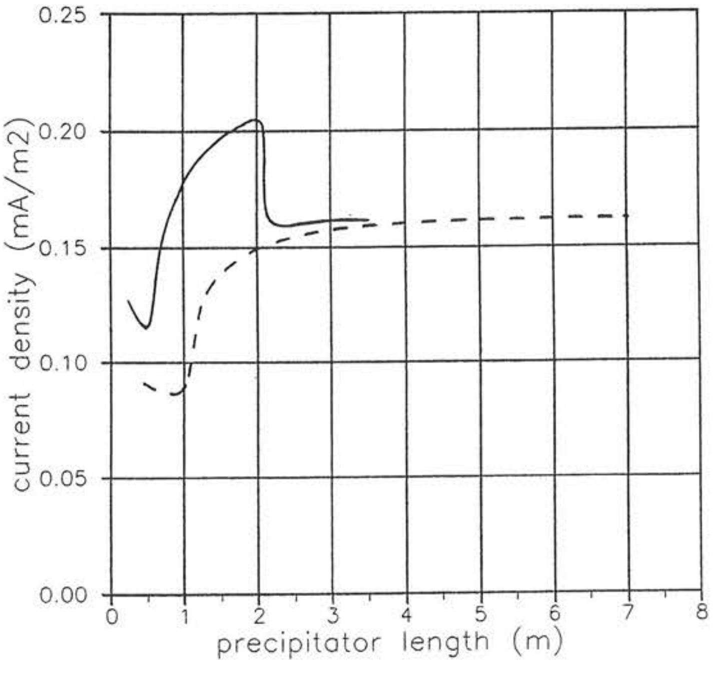

Figure 5. Current density versus precipitator length.
- - - Electrode pitch 440 [mm]
——— Electrode pitch 220/440 [mm]

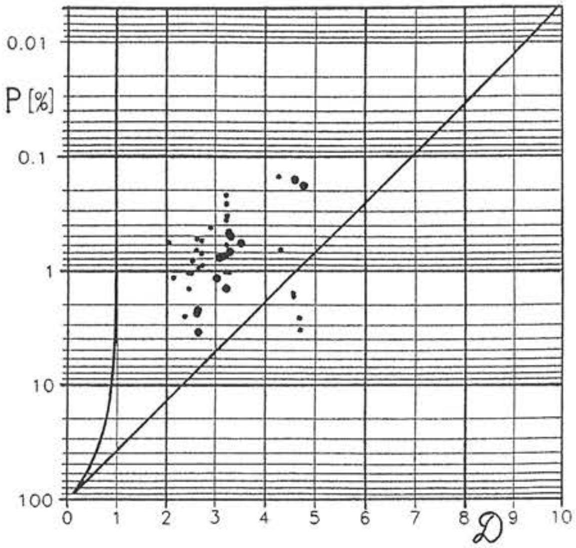

Figure 6. Penetration versus Deutsch number. Curve is laminar and straight line is fully turbulent (Deutsch) theory. Points from lab.tests.

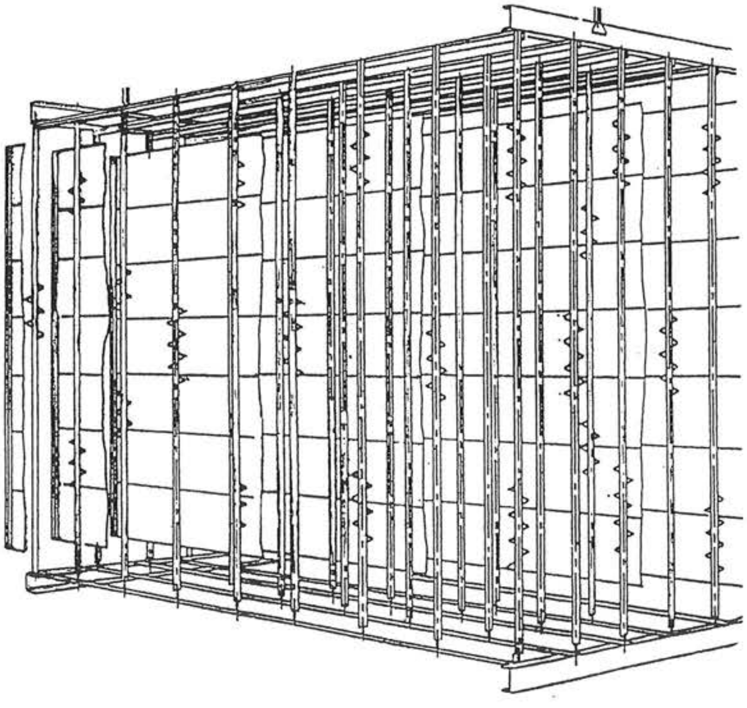

Figure 7. Horizontal strips and vertical Fibulax discharge electrodes.

Figure 8. Plate strip contour.

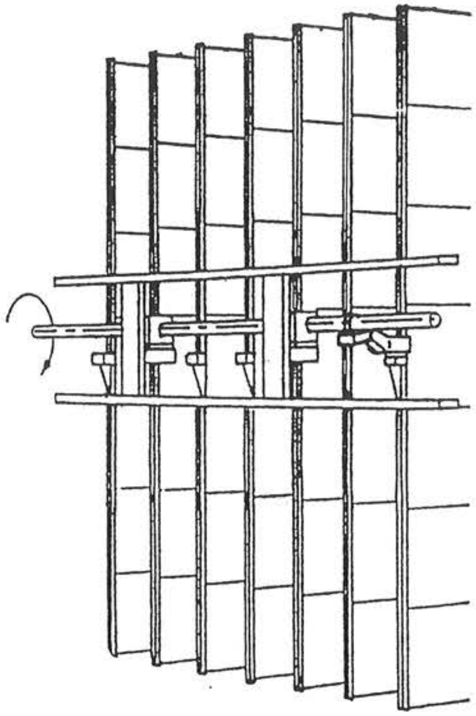

Figure 9. Tumbling hammer bridge in front of collecting curtain leading edge.

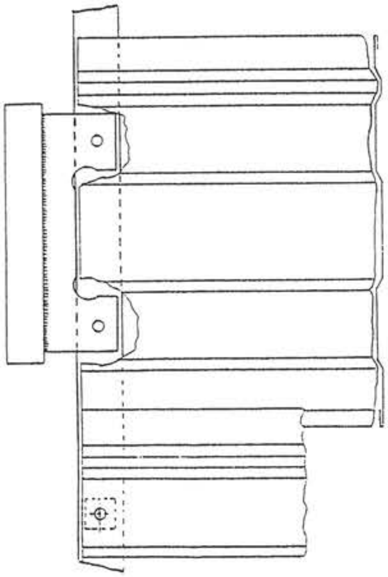

Figure 10. Anvil bolted on to angle-iron rapping bar.

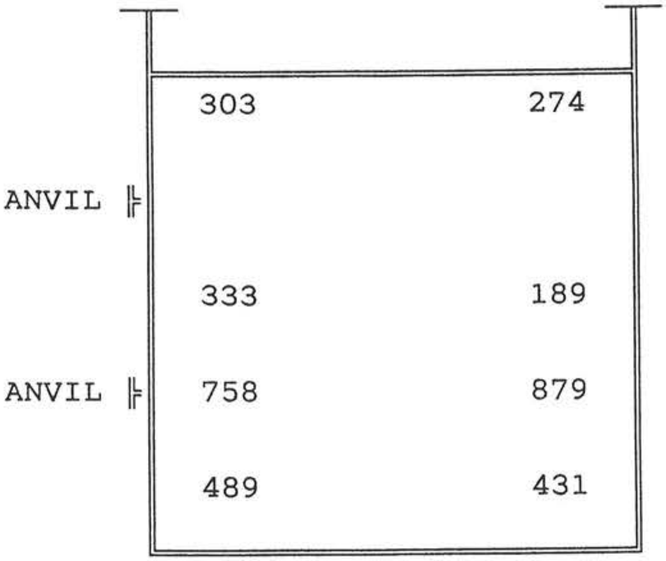

Figure 11. Normal peak accelerations in [g*]. 1 [g*]= 9.8 [m/s²]. "Aarhus Nord". Clean curtain.

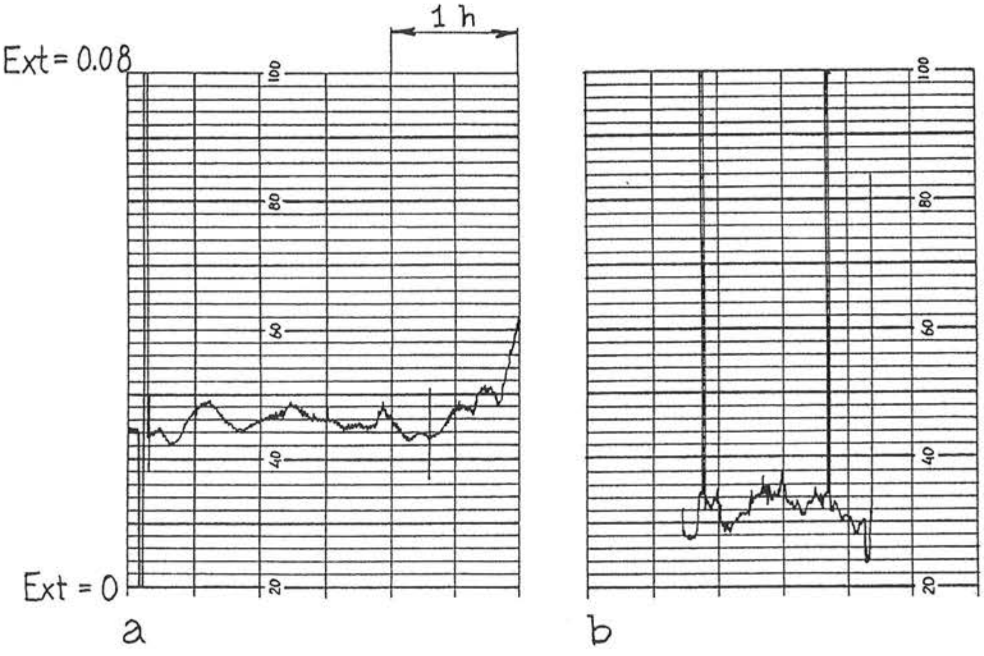

Figure 12. Recorder reading of opacimeter signal.
a. Horizontal plates at "Aarhus Nord".
b. Vertical strips at "Reno Nord".