LABORATORY TESTS FOR THE STUDY OF FLUID FLOW AND CORONA CHARACTERIZATION INSIDE WIRE-PLATES STRUCTURES OF ELECTROSTATIC PRECIPITATORS

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ABSTRACT

The present work shows the results of laboratory tests performed in order to analyze the fluid motions and the corona phenomena inside wire-plate structures of electrostatic precipitators.
For this purpose a test chamber equipped with a modifiable geometry structure was arranged. Inside the chamber variation of fluid motion parameters, particulate amount in the gas flow and emitting electrodes voltage characteristics are possible.
The structure was equipped with the devices necessary to measure the most important parameters of the process. In particular it is possible to measure the global corona current as well as the corona current relevant to a single emitting electrode. The gas flow velocity inside the chamber is detected by a laser doppler velocimeter.
The same structure will be utilized to perform other tests that will constitute a valid support to the development of an ESP model, both from the flow dynamical point of view and corona characterization of the wire-plate structures most commonly utilized in industrial ESPs.

INTRODUCTION

Control of solid particulate emissions from industrial plants has become particularly important in last years, and more and more stringent limits are

imposed by authorities on emissions of both total particulate and of peculiar inorganic compounds, like heavy metals.
The most diffused systems for particulate removal from combustion flue gases, the electrostatic precipitators, have reached fairly good collection efficiencies especially by increasing their specific collection areas, but there are many aspects not yet resolved or well understood. One of these problems is the moderate efficiency towards submicronic particles, the most dangerous for human health; another problem is the progressive efficiency decrease presented by the electrostatic precipitators for fuel oil ash. This fact is especially important in the Italian context, since a large percentage of Italian thermal power units burn fuel oil.
The above reasons therefore induced ENEL to start with a series of researches on electrostatic precipitators, both to increase the collection efficiency, when either high resistivity coal fly ash or low resistivity fuel oil ash were concerned, and to better understand the physical processes that are present in an electrostatic precipitator. The former studies on coal ash brought to the successful tests on impulse energization and electrode optimization[1,2]; the latter argument started with the idea of a new numerical model facing from a physical point of view the different processes that are present in an electrostatic precipitator. In order the model, which is described in detail in a companion paper[3], could be built correctly, it was also necessary to have a series of data on the basic physical processes, data that are not easily obtainable on industrial precipitators. Therefore a series of laboratory tests was programmed to study at first the electrical as well as flow dynamical phenomena and in a second time particle collection, reentrainment and back corona.

TEST SET UP

The tests described in the present work were carried out at CESI laboratories, by means of a test set up installed inside the "Powder Chamber" facility[4].
A variable geometry ESP duct simulation was implemented. The electrodic structure was of the weighted wire type (see Figure 1), in which the wires jut out of the plates[5]. The distance (D) between the two smooth plates may be varied ranging from 200 to 500 mm, while the wire spacing (s) may range from 50 to 300 mm. The tests described in the following, when no otherwise specified, were carried out considering D = 300 mm, s = 200 mm and with smooth cylinder emitting electrodes (diameter 5 mm).

The test structure previously described has been placed in the "Powder Chamber" (see Figure 2). Inside this facility it is possible to keep a uniform velocity (v) distribution air flow, in the range from 0 to 1 m/s. The air flow temperature (t) may be settled between ambient temperature and 40°C. The air flows out of the test chamber through an absolute filtering equipment. By sectionalizing the air stream generator and the outlet air conveyor, that are setted in order to maintain a inside the test chamber a pressure lower than the

Table I

Variation ranges of the test parameters in the laboratory test set up

Test structure		Air flow		
D [mm]	s [mm]	v [m/s]	d [g/m^3]	t [°C]
200 ÷ 500	50 ÷ 300	0 ÷ 3	0 ÷ 30	t_{amb} ÷ 40

outside one, the air flow velocity in the ESP duct simulation may be increased up to 3 m/s.

A particulate injection system was developed. It consists mainly in a volumetrical powder batcher, a mixing chamber equipped with a vibrating sieve and an axial fan, and a particulate distributor pipe designed to allow an uniform inlet of particulate (see Figure 2). By controlling the speed of powder batcher electric engine, the particulate density (d) may be varied in the range from 0 to 30 g/m^3 when the air flow velocity ranges from 0 to 2 m/s. Great care was taken in tuning the particulate injection system, in order to guarantee an uniform particulate density in the air flowing through the test structure.
The particulate may be injected into the gas flow both in its original particle size distribution and in fixed particle size distribution, obtained seaving the particulate by means of a vibrating system equipped with micrometric sieves. Table I synthetizes the ranges in which the geometrycal parameters of the test stucture and the parameters characterizing the air flow may be varied.

VELOCITY MEASUREMENTS

A Laser Doppler Velocimeter (LDV) was used: it is essentialy a non invasive optics base device. This instrument was designed and implemented at CISE with the aim to be easily transportable for an use in industrial environments. The measurement principle is based on the interference of two laser beams (schematically shown in Figure 3a): their intersection generates an electromagnetic field fringes system whose spatial frequency depends on light wavelength and on the beams intersection angle.
The particles passing inside the beams intersection (measurement volume) scatter light with a sinusoidally varying intensity whose frequency is proportional to particle velocity (see Figure 3b and 3c).
The employed velocimeter was designed to allows the simultaneous detection of two velocity components and was obtained by superimposing toghether two

LDVs like that schematically shown in Figure 4. For this reason four parallel beams were obtained from the same laser source and focalized into the same measurement volume.
One of the two couples of beams has polarization ortogonal with respect to that of the other, allowing the discrimination of the signals associated with the different velocity components.

ELECTRICAL MEASUREMENTS

The adopted test circuit in shown in Figure 5. The voltage (V) applied to the test structure was detected by a suitable voltage divider.
The test voltage is characterized by the mean and the peak values and by the parameters that qualify the considered voltage wave shape, such as amplitude and repetition rate of the ripple when considering ESP conventional voltage, shape and repetition rate of impulses when considering ESP pulsed voltage.

The total current flowing from the voltage supply to the test structure is detected by means of a mean value ammeter.
A measuring system able to detect the local corona current, both emitted by a controlled section of emitting electrode and collected by a well defined sector of the collecting plates. The developed probes allow the measurements of the corona current relevant to a central portion of the test structure, in which edge effect are avoided.

The wire corona current measuring probe (see Figure 6a) consist in an emitting electrode (smooth cylinder, diameter 5 mm) composed by three insulated sections. The inner part of the probe is feeded by a cable coaxial to the upper part. In this way it is possible to measure the current I_m relevant to the central part of the wire, placed in an uniform electric field zone.
In the same manner, as concerning as the measurement of the current collected to the plates, the measuring probe consists in a plate equipped by one or more insulated sectors (see Figure 6b). Also in this case it is possible the meaurement the corona current I_m relevant to the considered sector.

Both the measurements are performed (see Figure 7) by a coaxial shunt ($R=1\ k\Omega$), utilizing an electro optical decupling system (1 MHz bandwith). The decupling system guarantees a better control of electromagnetic noises and allows the measurements of the corona current from the emitting electrode, that requires the positioning of the shunt at the test voltage V. The shunt and the transmitter (T_x) are positioned inside a metallic screening box provided with waveguides for the passage of the measuring coaxial cable and the optical fibre. The voltage signal across the shunt is reconverted by the receiver (R_x) and measured by a suitable instrument (analogic or digital oscilloscope or mean value voltmeter).

VELOCITY TETS

The goals of experience were to obtain an acceptable repeatability of the velocity measure and to detect the maximum depth at which the velocimeter can operate for various particle concentration.

The tests were performed for the two cases:
1. No obstacles inside the Powder Chamber;
2. Rectangular duct (570mmx1500mm, length 2500mm) inside the Powder Chamber

Coal particles were used as seeding.
In case 1 the velocity profile of Figure 8 was obtained, showing the turbolent nature of fluid motion inside the chamber: this test was performed with very low particles concentration ($<<$ 5 g/m^3).
In case 2 the mean velocity profile inside the rectangular duct was detected: a good repeatibility of velocity measurements relevant to different particle concentration (5; 10; 15 g/m^3) was achieved (see Figure 9).

The maximum measuring depth that the velocimeter can reach was also detected: increasing particle concentration increases the "fog" effect originated by particle light scattering, thus avoiding optical acces to far locations in the rectangular duct. Figure 10 shows the rectilinear dependence of maximum measuring depth versus particle concentration.

These preliminary tests are a guideline for further investigations on ESP duct simulation, with emitting electrodes inside. In particular tests are in progress to characterize the flow dynamic of the duct. The results of the tests will allow to validate the flow dynamic module of the ESP mathematical model described in reference (3).

CORONA TESTS

The test campain which is now being carried out aims to obtain basic information on the corona emission phenomenon that takes place between the electrodes of a wire-plate structure in connection with various test conditions. Feeding voltages of different waveform have been therefore used in connection with different settings of voltage level, air velocity, particle concentration, particle size and so on. All the tests are carried out both at clean air conditions and with a certain amount of particulate dispersed into the flow. The air velocity is varied between 0 and 2 m/s, while the air temperature is always 20 °C. Two different kinds of particulate are used: pulverized coal, with a low electrical resistivity, and coal fly ash coming from an industrial ESP, with a high resistivity, both the kinds having a mean particle diameter of about 20 μm; the particle concentration is varied between 5 and 15 mg/m3. Further tests are also foreseen with particulate having a limited particle size range.

All the tests are carried out at negative polarity, as usual in industrial ESPs. The following waveshapes are taken into consideration:

1. laboratory DC voltage;
2. oscillating voltage, given by a conventional ESP power set;
3. impulse voltage superimposed to a DC base.

A sketch of the three voltage waveform is shown in Figure 11.
The tests with the laboratory DC voltage are taken as a reference and are therefore carried out in a systematic manner, while the other two voltage waveshapes are used to deepen particular conditions.
The voltage-current characteristics are obtained by measuring the current emitted from the discharge electrode and comparing it with the current at the collecting plate. At any rate the current is expressed in nA/cm^2, in the former case with a plate surface corresponding to the double of the wire to wire distance multiplied by the wire active length, in the latter case to the insulated part of the plate. Figure 12 reports, as an example, the voltage current characteristics with clean electrodes, obtained both with DC and with oscillating voltages. The analysis of the obtained experimental data, relevant to an air speed ranging from 0 to 2 m/s, showed a quite similar behaviour, indicating so that the air velocity has no influence on the corona emission in these conditions.
A detailed analysis of the corona phenomenon is performed too, by determining the instantaneous trend of the corona current, characterized by random impulses with variable amplitude that can or cannot be superimposed to a DC base. The current is measured on the emitting electrode by means of fast oscilloscopes. Some oscillograms, obtained at different voltage levels, are shown in Figure 13, while a diagram showing also the current integral is reported in Figure 14.

CONCLUSIONS

Within the framework of the research program on thermal power plants flue gas treatment, ENEL (Italian Electricity Board) has started to develop a numerical model of large scale ESPs. In order to collect basic information on the physical processes involved in fluid-dynamic and electrical aspects inside an ESP, a test program was started in CESI and CISE laboratories.
Preliminary tests showed the feasibility and the repeatibility of fluid-dynamic and corona current measurement, as described in this paper.
The research is still in progress. The first series of tests is programmed to obtain information about the setting up of several modules of the ESP model; a second series of test will be successively carried out to validate the same modules.

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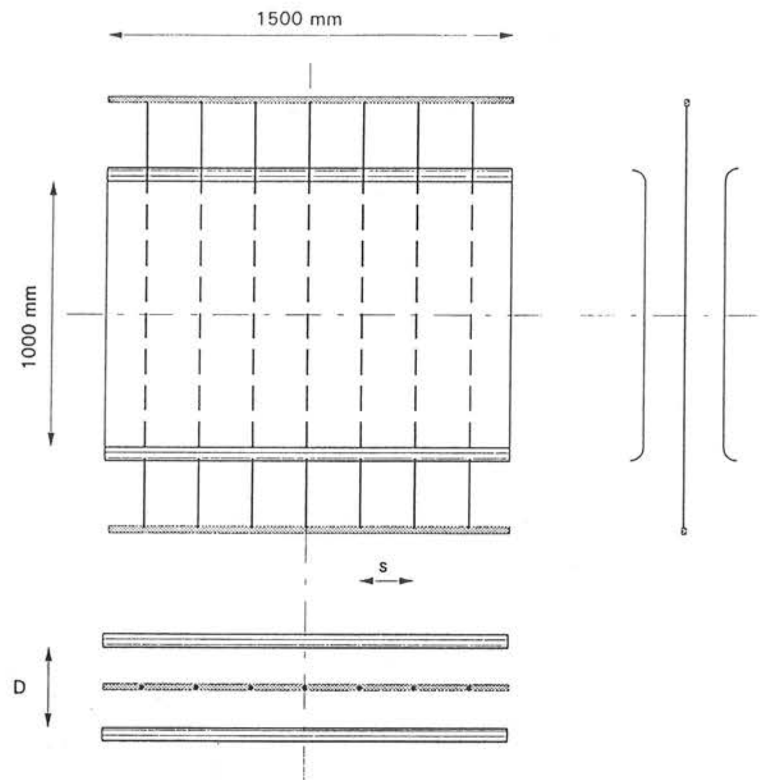


Figure 1 ESP duct simulation employed for the laboratory tests

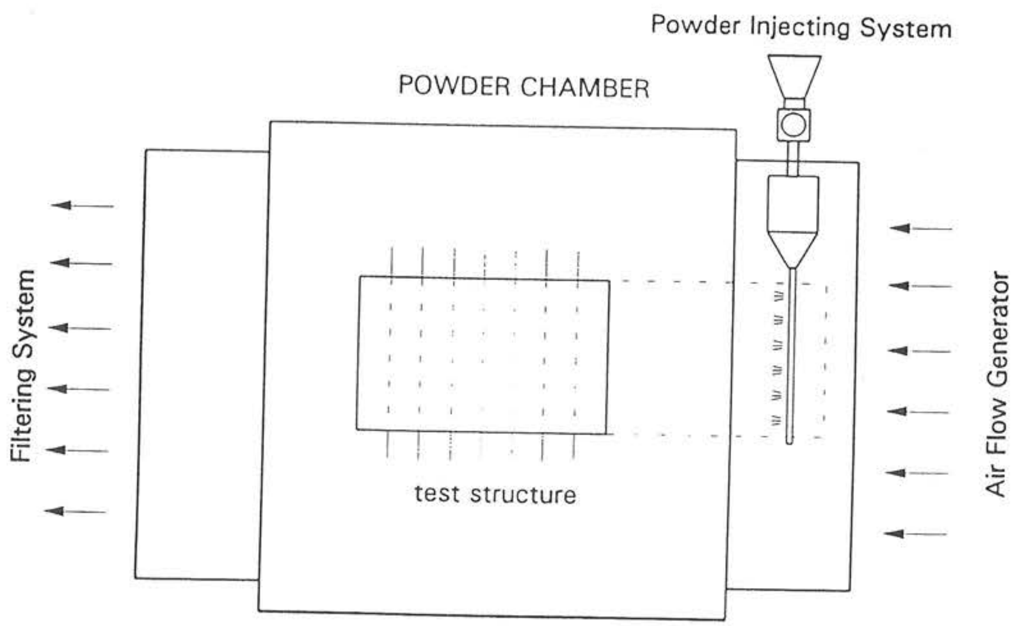


Figure 2 Sketch of the "Powder Chamber"

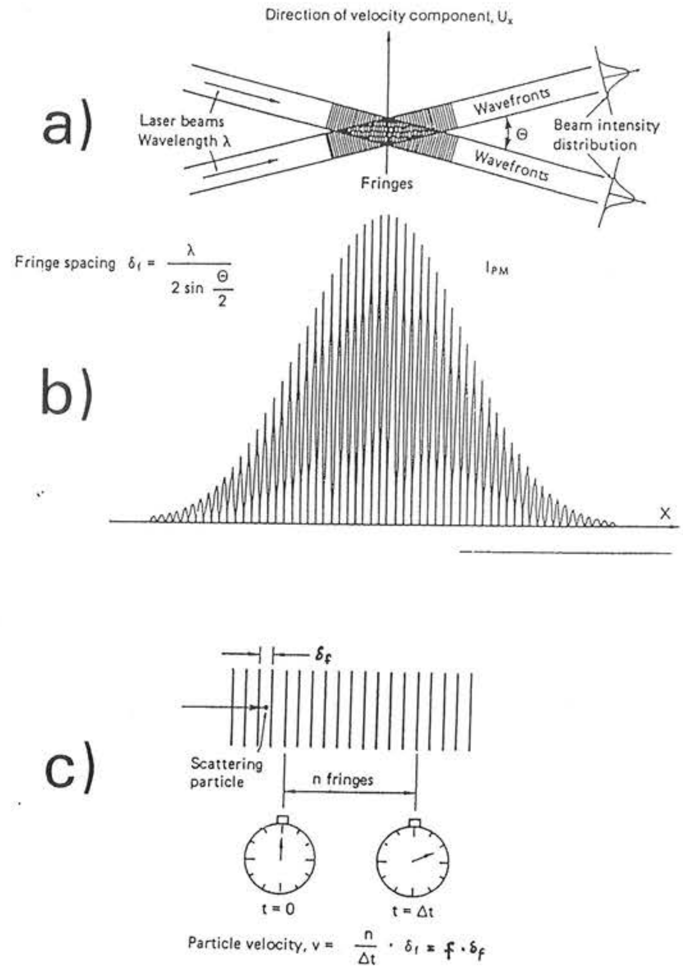


Figure 3 Laser Doppler Velocimeter measuring principle

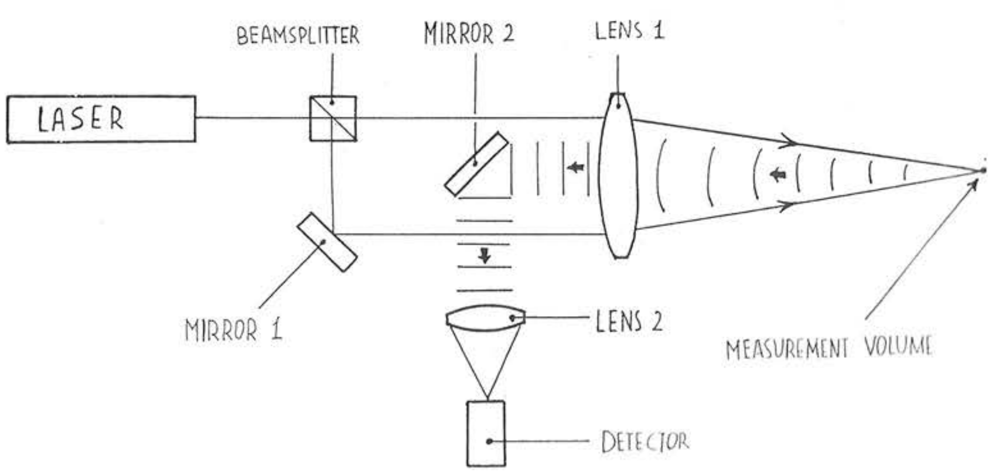


Figure 4 One velocity component LDV scheme

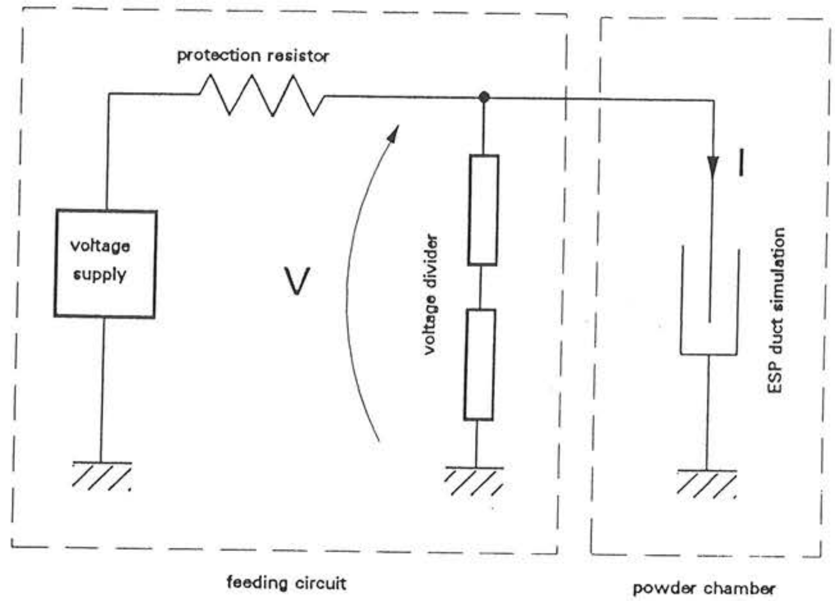


Figure 5 Test circuit for corona current measuremens

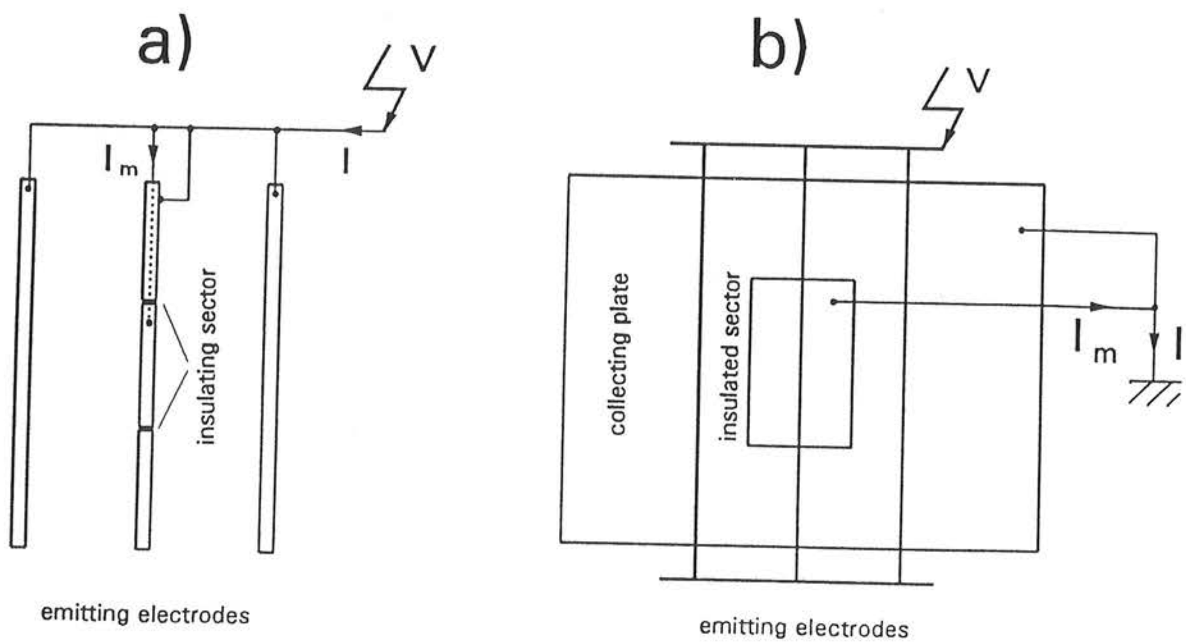


Figure 6 Corona current measuring probes

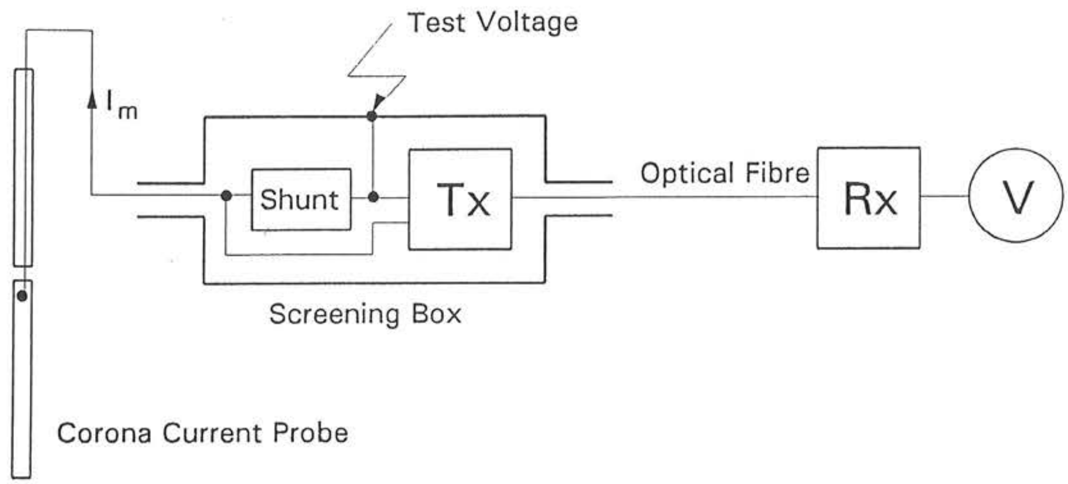


Figure 7 Corona current measuring circuit

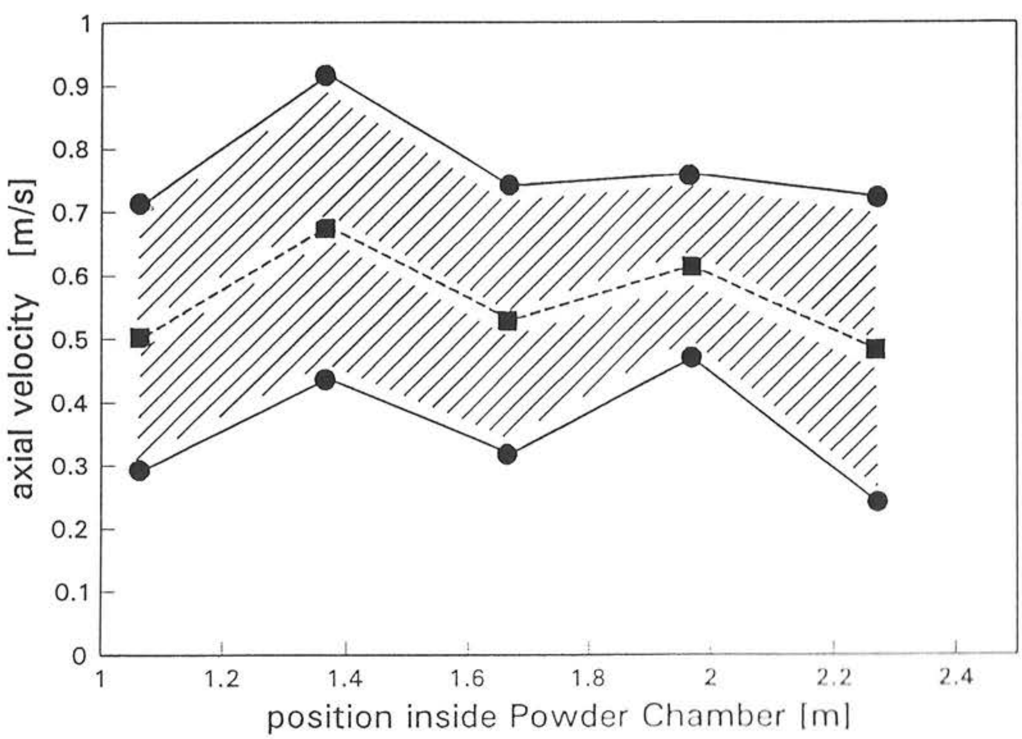


Figure 8 Velocity profile obtained inside the Powder Chamber

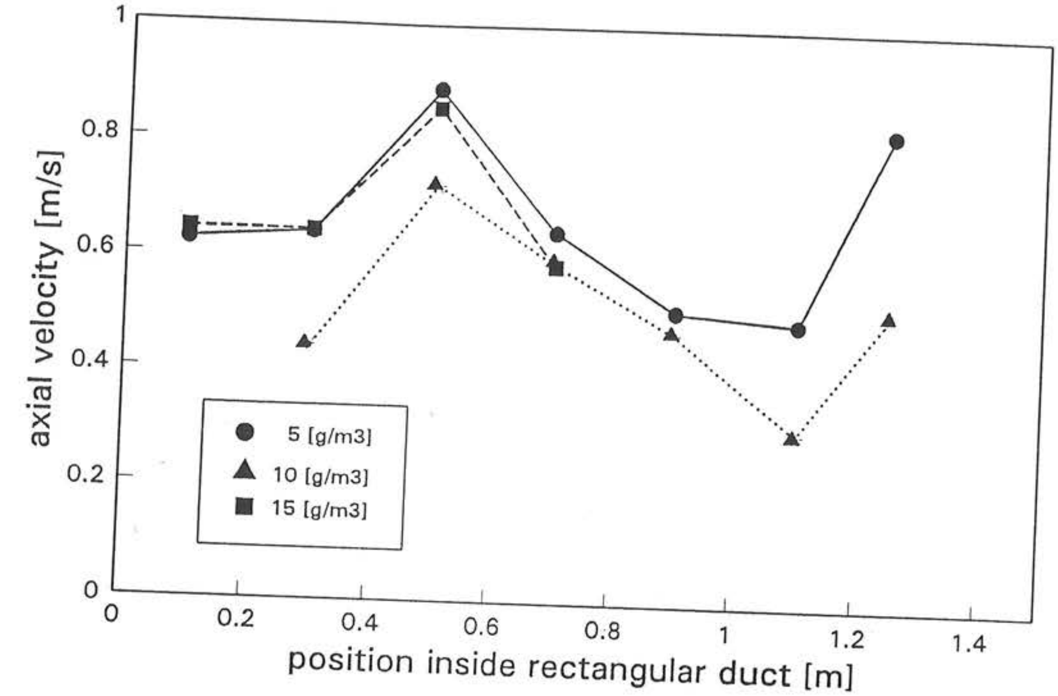


Figure 9 Mean velocity profile in rectangular duct for different particle concentrations

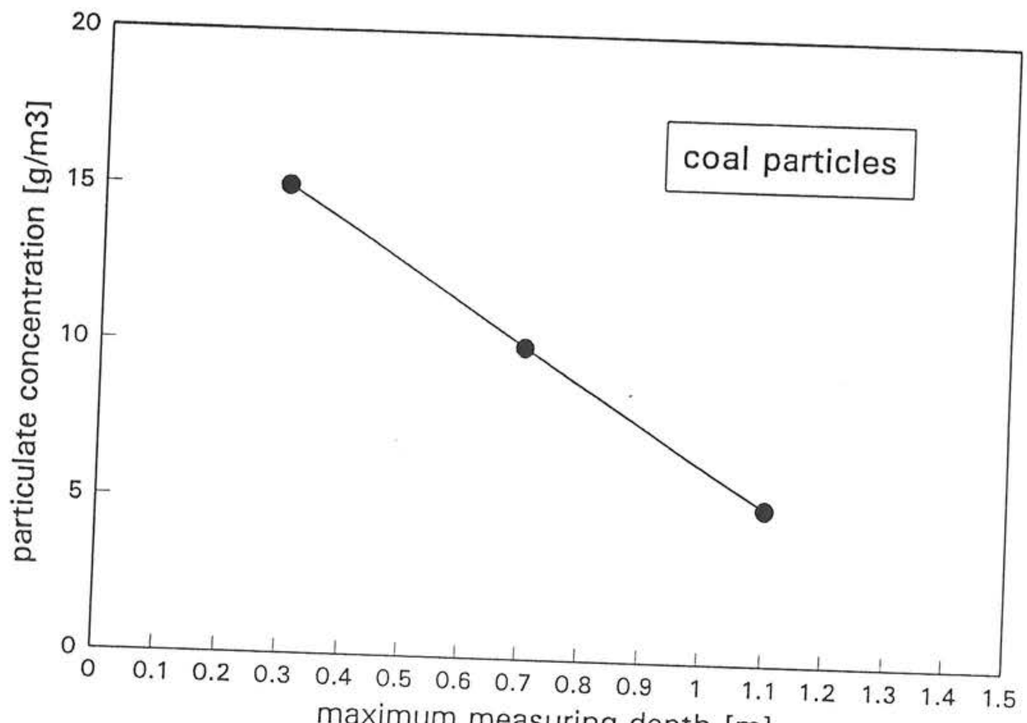
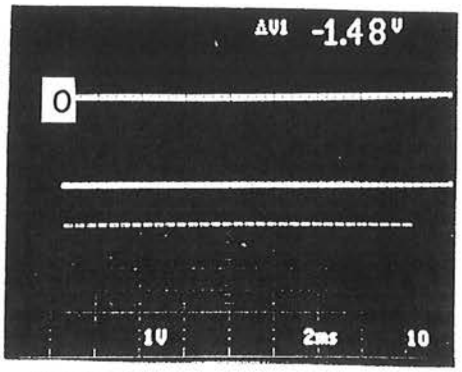
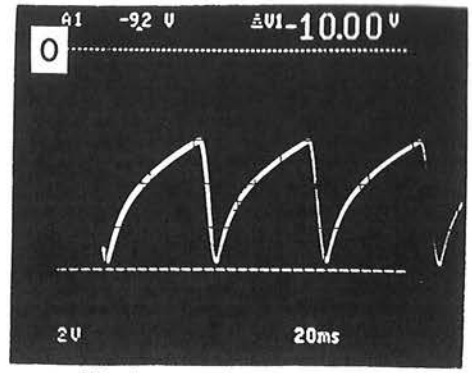


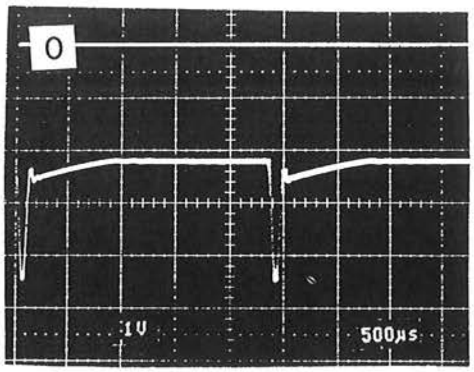
Figure 10 Maximum measuring depth versus particle concentration



DC voltage



oscillating voltage



pulsed voltage

K_V = 10.000 V/V

Figure 11 Voltage waveshapes adopted for corona tests

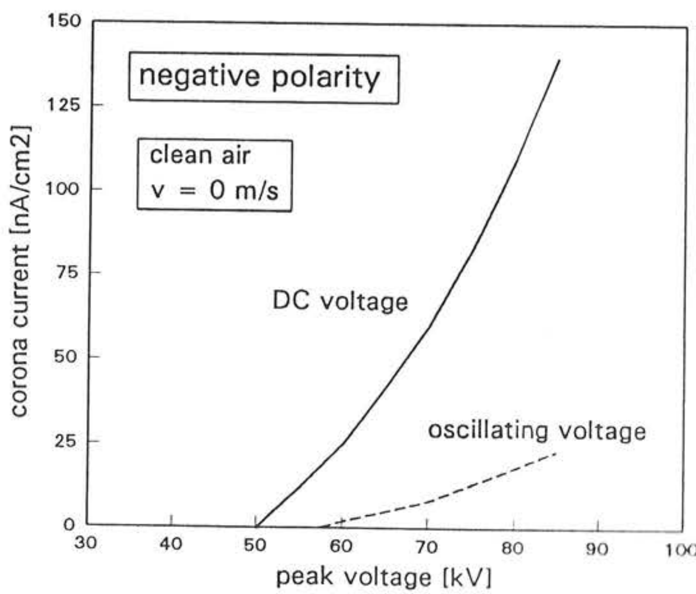


Figure 12 Example of measured voltage-current characteristics

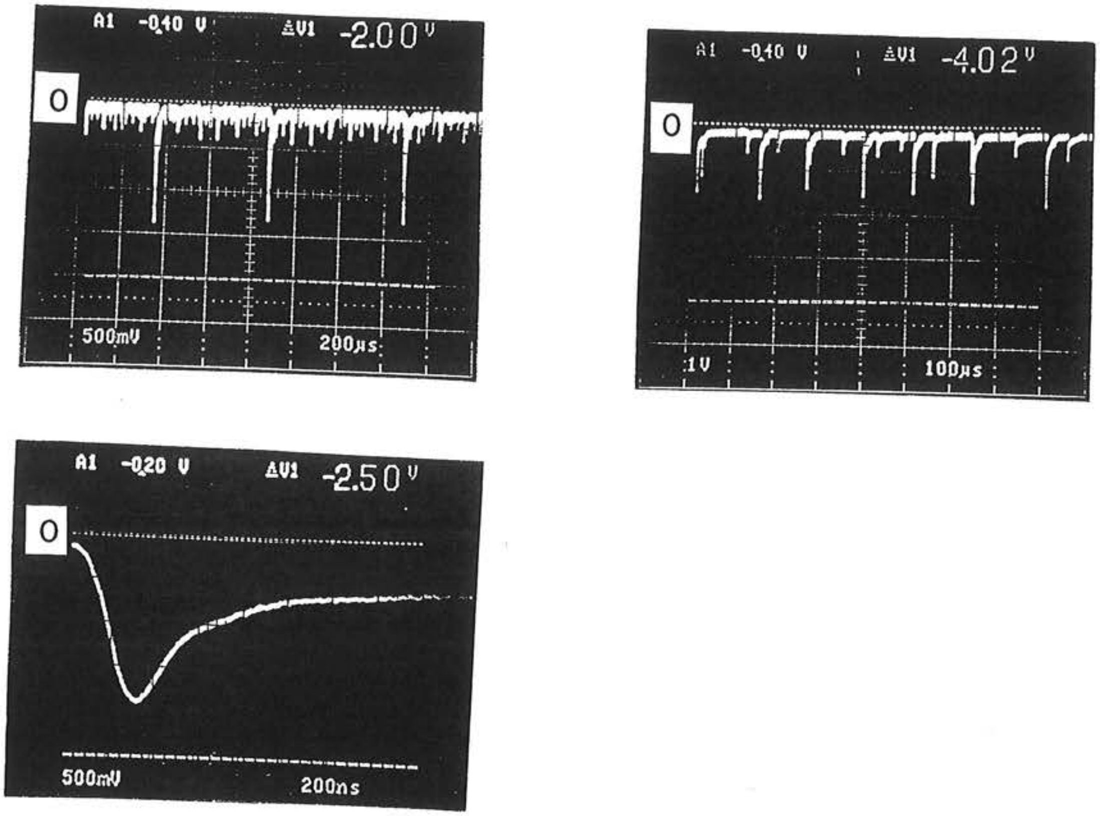
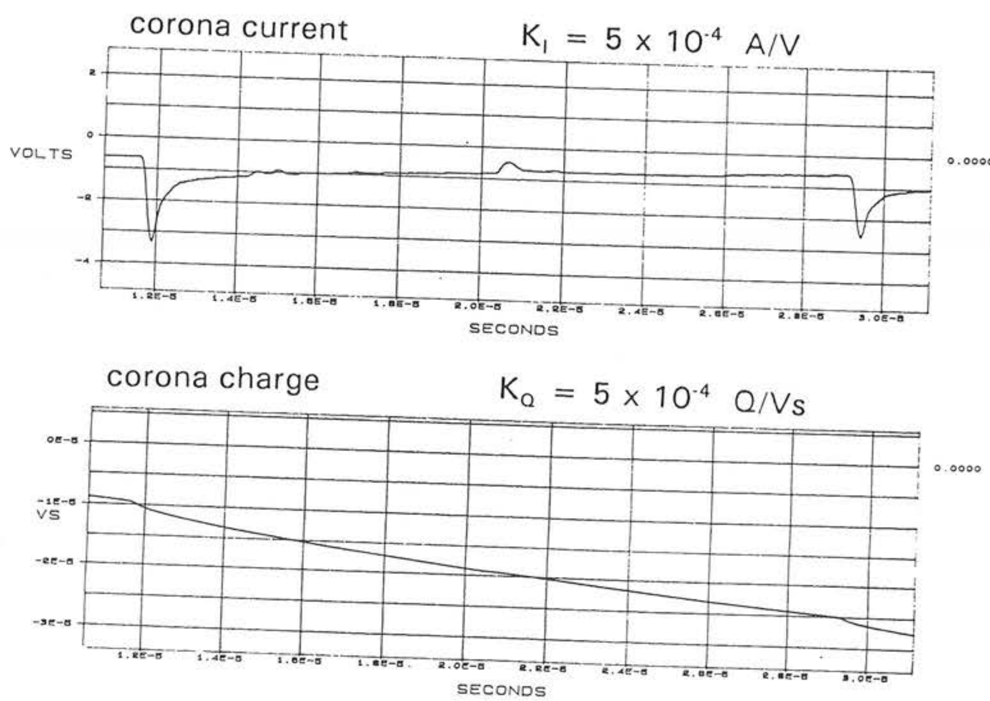


Figure 13 Examples of analogical corona current measurements



DC voltage

$V_p = -80$ kV

Figure 14 Example of digital corona current and charge measurements