MEASUREMENT OF DUST RESISTIVITY AND THE EFFECT OF FILTER OPERATING PARAMETERS ON ITS VALUE

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ABSTRACT

Methods of measuring the electrical resistivity of a dust layer have been outlined and the porous electrodes cell was adopted in this work to determine the influence on resistivity of a number of parameters. Whereas the dust layer thickness and the applied voltage have been found to have no influence, resistivity has been found to be dependent on the other factors investigated which included particle size, packing density, temperature and air relative humidity. Glass beads and limestone powders of different mean particle sizes were used in the study. The temperature was varied from 20 - 100 °C and the air moisture condition ranged from relatively dry to near saturation point. The data obtained here may lead to a better understanding of the newly introduced electrically enhanced fabric filter whose performance has been indicated by other workers to be influenced by the resistivity of the collected dust layer.

INTRODUCTION

The electrical resistance of a layer of particles can be determined by applying a high DC voltage and measuring the leakage current through the layer. This current consists of the component that flows through the particles and that which flows over the particles surface, hence the wide use of literature of the words intrinsic or volume conductivity and surface conductivity. The resistivity ρ is calculated from the measured current I, voltage U, electrode surface area A and the distance between the electrodesd as,

$$\rho = \frac{U}{I}\frac{A}{d} = R\frac{A}{d} \qquad (1)$$

Several factors affect the resistance of a layer of particles. These include [1-14, 17, 21, 22]. Particle data: Particle size and particle size distribution, chemical composition, etc.; Surrounding gas data: Temperature, humidity, composition, etc.; Packing data: Porosity of the dust layer; and Electrical data: Applied electrical field and current density. Since the resistivity value obtained will depend on the conditions of measurement, it is, therefore, appropriate in its measurement to duplicate as much as possible the actual operating conditions. The measurement procedure normally consists of collecting the dust sample, determination of the geometrical size of the sa sample, applying of a potential difference across the sample and measuring the resulting current while keeping constant the influencing factors.

A variety of apparatus (also called cells) for measuring the resistivity of particulate solids in the gas cleaning industry have been developed over the years, with investigations being mostly related to electrostatic precipitators, primarily because their collection efficiencies are directly affected by the resistivity of the collected layer of dust [12, 21, 22]. Since the particles form a continuous layer on the precipitator plates, all the ion current must pass through the layer to reach the ground plates. This creates an electric field in the layer which can become large enough to cause a local electrical breakdown called "back corona". Back corona is prevalent when the resistivity of the layer is high, typically above 10^{11} Ωcm. With back corona, charging of the particles becomes difficult which leads to a reduction in the collection ability of the unit. Conversely, at resistivities below about 10^{6} Ωcm, the particles hold on the plates so loosely that reentrainment becomes severe. Four main types of measuring methods will be briefly described.

Point-plane method

The underlying concept in this method is to simulate the electrostatic precipitator action by collecting a layer of particles on the plate electrode of a point-plane system (Fig. 1(a)). The probe is inserted directly into the dust-laden gas stream and allowed to come into thermal equilibrium. A high voltage is applied across the point-plane electrode system such that a corona is formed in the vicinity of the point. The dust particles are charged by the ions and free electrons from this corona in a manner analogous to that occurring in an electrostatic precipitator.

Two methods of taking measurements on the sample may be used. Either the corona current is measured by the use of a wire electrode (normally [1] a 0.2 mm diameter wire placed 1 mm above the collecting electrode and fully covered by dust) connected to an electrometer or by means of an auxiliary high voltage disc electrode [9] which can be lowered onto the dust layer to measure the leakage current through the layer.

Concentric cylinder cell

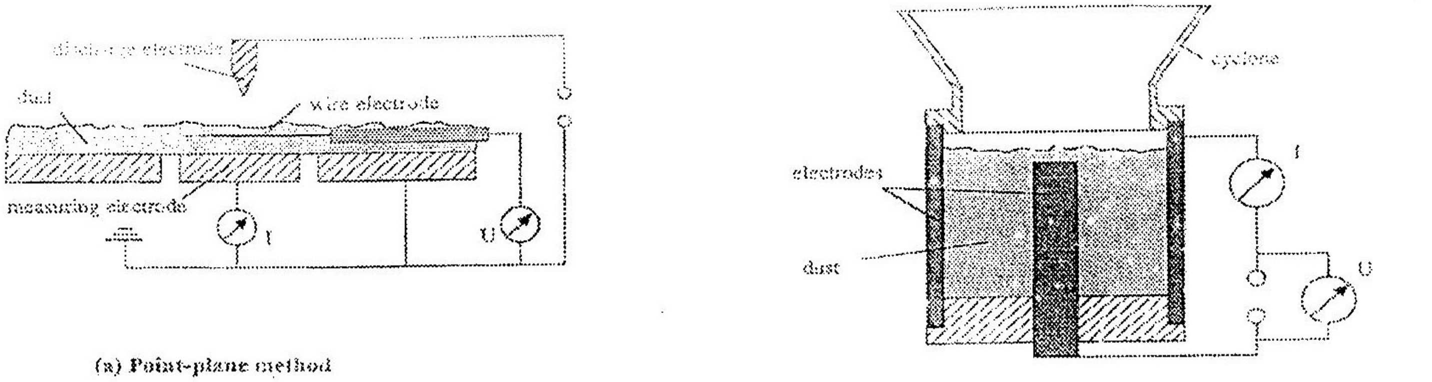
This cell is made of two concentric electrodes insulated from one another. Resistance measurement differs from the point-plane method in that the particle layer must be placed in the cell by mechanical means. This can be though hand filling or as shown in Fig. 1(b), for example, by the use of a small diameter cyclone which collects the dust from the gas stream. Resistivity, pis then calculated from the measured resistance R as [5]

$$\rho = R\frac{2\pi L}{\ln(\frac{d_1}{d_2})} \tag{2}$$

where L is the length of the electrodes, d_1 and d_2 are the diameters of the outer and inner electrodes, respectively.

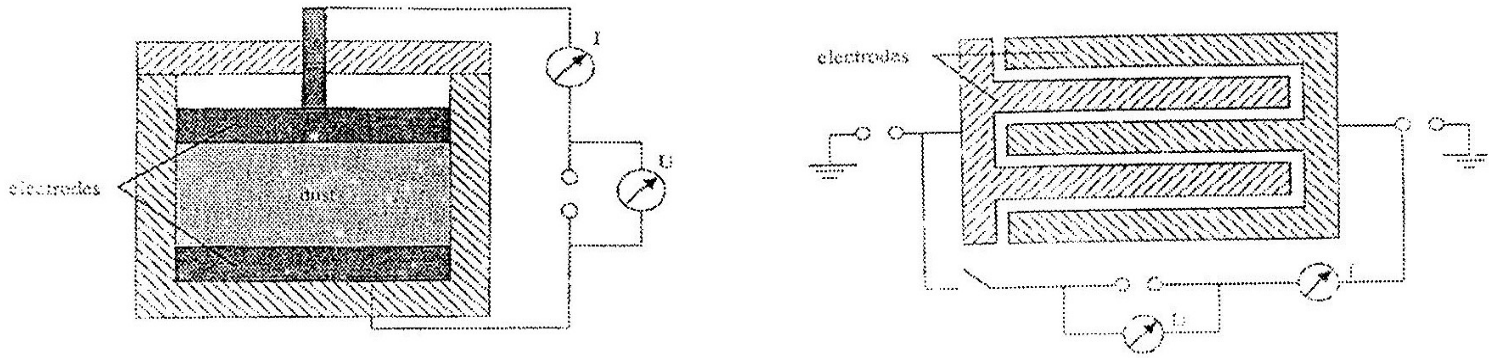
Disc electrodes cell

The cell, made of a highly insulating material, consists of two porous metal electrodes (Fig. 1(c) laid opposite to each other across a bed of particles. By applying a high DC voltage across the bed and measuring the current flowing through it, the resistivity can be calculated from (1). To avoid changes in the bed packing structure a constant force is maintained on the top electrode.



(a) Point-plane method

(b) Concentric cylinder cell



(c) Disc electrodes cell

(d) Finger-type electrodes cell

Fig. 1 Methods of measuring electrical resistivity of a layer of dust

Finger-type electrodes cell

With this apparatus (Fig. 1(d) the dust is deposited on a plane surface of comb-like fingers. The deposition occurs by electrostatic precipitation when it is placed in a dustladen gas stream from corona electrodes placed above and below the collecting surface. When sufficient dust has been deposited, the resistance is determined by applying a voltage between the finger electrodes and then measuring the current. The resistivity is then obtained by multiplying the measured resistance with a pre-determined apparatus factor which is dependent on the geometry of the fingers [4,5].

Each of the methods outlined above has its advantages and disadvantages. The point-plane method has the advantage that the conditions are reasonably close to those prevailing in an actual electrostatic precipitator in terms of cake build-up and electric field strengths and current densities. Its major drawbacks are, as pointed out above, its inapplicability for high resistivities, the instability of the dust layer for low resistivities, and the vulnerability of the wire electrode to mechanical shocks.

The finger-type-electrodes apparatus is also, due to its principle of cake formation, suitable for investigations on electrostatic precipitators. The vulnerability of the weakly held cake between the fingers to mechanical shocks is its major drawback and its application is only limited to high resistivity dusts [5]. The advantage of the cylindrical cell and the disc electrodes cell is their inability to represent what actually takes place in a real filter. The former suffers an additional disadvantage resulting from the inability of the cyclone to collect micron and submicron particles efficiently. On the other hand these apparatus make it possible for fundamental investigations o 1 the influence of structural, physical as well as chemical changes of the dust on its electrical resistivity to be carried out with good reproducibility. The present study is a part of a development work on a new type of filter, the electrically-enhanced fabric filter, discussed elsewhere [4], and it is aimed at determining the influence of a variety of factors on the resistivity of a layer of dust.

EXPERIMENTAL

A disc electrode cell and an air heating and humidifying apparatus were constructed and used in this study. The cell, shown in Fig. 2, is an all PTFE device [16,20] except for the porous sintered stainless steel electrodes (90 mm diam., 4mm thickness) which allow an axial flow of the pre-conditioned air through the packed bed. The air conditioning apparatus consists of an electrically heated tube and a water flash bottle immersed in a water bath. Additionally, the cell is itself covered with a heating mat. A stepwise rise in the water bath temperature regulated the relative humidity of the air while a silica gel bed was used in the place of the water bath when dry air was needed. The temperature and relative humidity of air were measured simultaneously by a probe inserted in the cell.

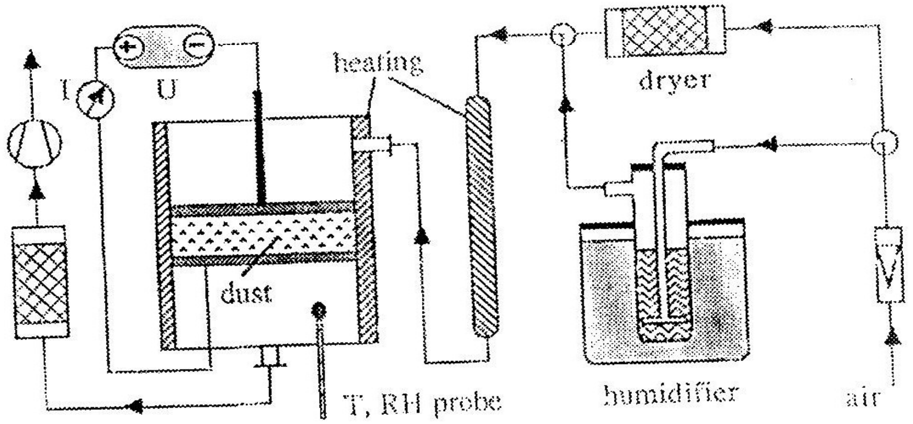


Fig. 2 Schematic of the experimental apparatus

After the cell had attained a thermal equilibrium, the electrodes were connected to a DC voltage source and the resulting current measured with a high sensitivity electrometer (Keithley 610C - measures as low as 10^{-13} A). Most dusts and fumes handled in industrial filter applications originate from smelters, furnaces, dryers, calcines, etc. and are bound to be composed of other chemical components such as oxides, silicates, etc. and not water vapour alone. With minor adjustments it is expected that the same arrangement can be used for measurements which may involve chemical conditioning of the dust.

Tests were done using glass beads samples of sizes 150 µm, 0.82, 1, and 2 mm and with limestone powder samples of mean sizes 2.2, 4.2, 11 and 24 µm. The later have been denoted by F1, F2, F3 and F4, respectively.

RESULTS AND DISCUSSION

Influence of bed thickness

Fig. 3 shows the resistivity of beds of glass beads of mean size 150 µm for various bed thicknesses. These results indicate that the thickness of a packed bed of particles has no influence on its resistivity. It is, however, worth pointing out here that for yet thinner beds errors can result from wall effects and inaccuracies in placing the electrodes properly or for yet thicker beds a layer non-uniform packing density may result.

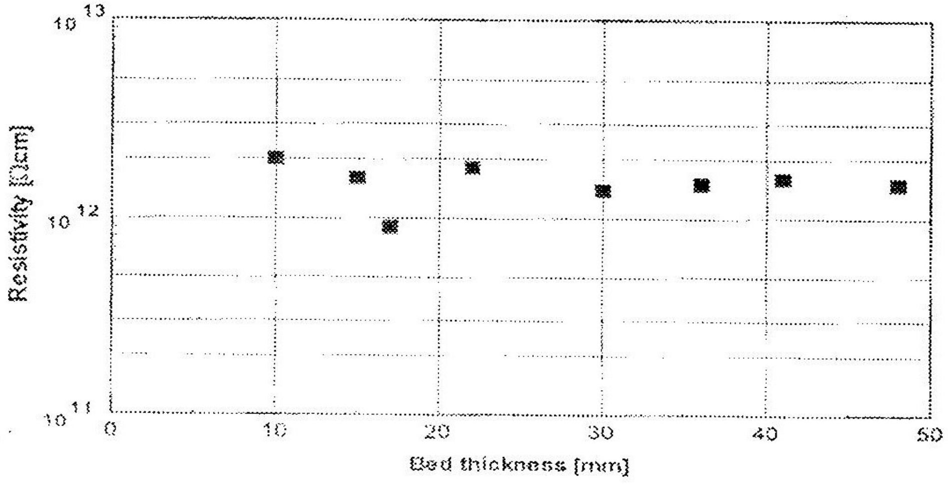


Fig. 3 Influence of bed thickness on resistivity

Influence of test voltage

Resistivity values of beds of three different particles sizes of glass beads in dry air are shown in Fig. 4 for various test voltages up to 3.5 kV. It can be observed that, except for low voltages (<1 kV), resistivity is not affected by the applied voltage. It is known, however, that for high resistivity dusts high electrical fields can lead to an electrical breakdown of the bed. Such occurrences can be avoided by limiting field strengths in the bed to about 1.5 kV/cm[11]. The effect of the particle size on the resistivity of the packing is easily observed here. Beds of small er particles have lower resistivities in comparison to those of bigger particles which reflects the more compact structure of the small particle beds.

Results for an 18 mm thick bed of the limestone power F2 presented in the same figure show that resistivity dropped sharply at first but thereafter remained more or less constant up to a voltage of 2500 V. At this point a high shoot-up in the current appeared and measurements were not possible any more. It is probable that a spark-over occurred in the bed because the field strength was well above the limiting value of 1.5kV/cm. Tests with thicker beds at higher voltages were not possible because the air pump available could not deliver sufficient air to overcome the resulting high pressure drop across the bed.

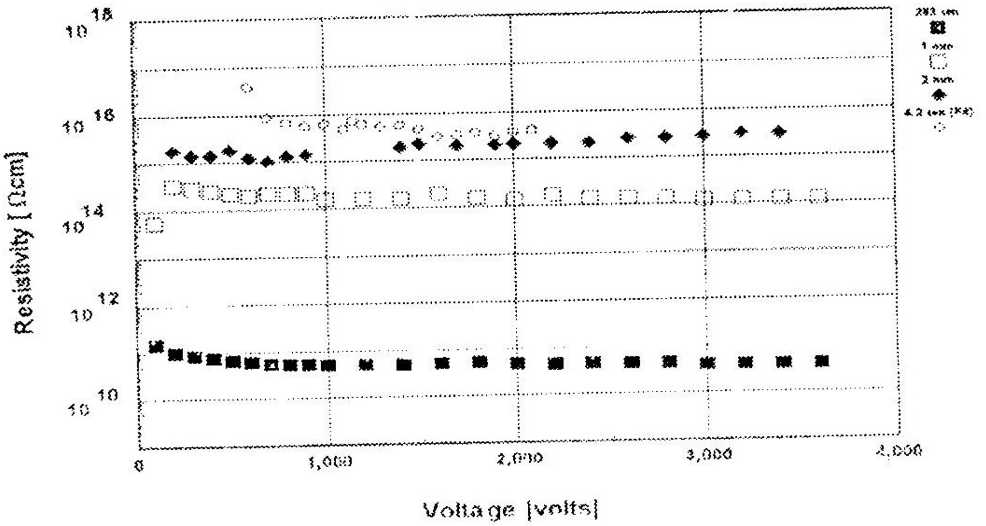


Fig. 4 Influence of voltage on resistivity Glass beads and 4.2 µm lime stone]

Influence of temperature

Fig. 5 shows the variation of resistivity with temperature for two glass beads particle sizes in dry air (RH <5%). In both cases resistivity rises with temperature to a maximum and then falls almost linearly in the semilogarithmic diagram. The increase of resistivity with temperature is a result of the decrease in the surface resistance due to the desorption of water molecules initially adsorbed on the particle surfaces. Although experiments were carried out in relatively dry atmospheres it shows that there could still be some adsorbed water molecules present. The overall resistivity is dependent, amongst several factors, the type of the adsorbed molecules, temperature and particle size. Above a certain temperature resistivity is dominated by the volume (intrinsic) resistance component. The volume resistivity itself depends on the composition and temperature of the particles. It has long been established |9| that the volume resistivity of dielectric materials (e.g. glass and many types of dusts) decreases with increasing temperature. This explains, therefore, the inverted-V nature of the curves.

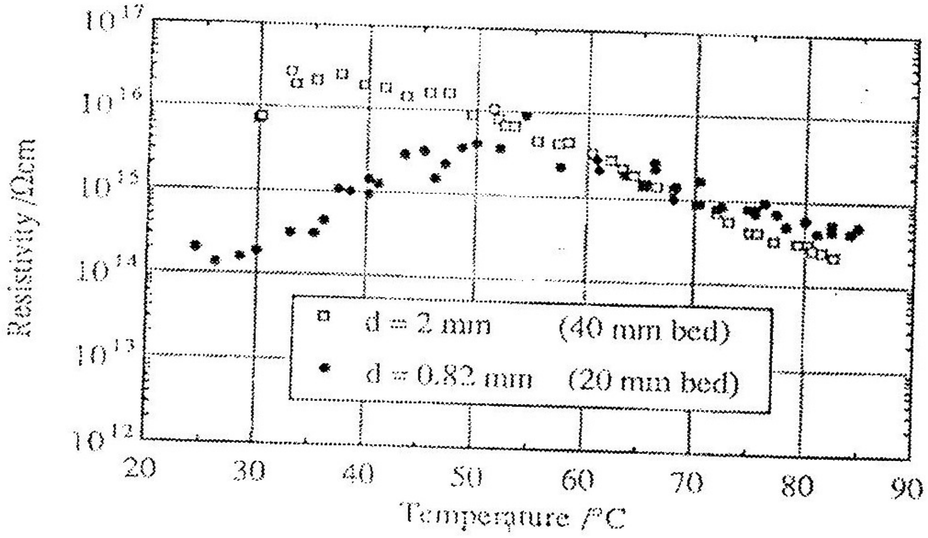


Fig. 5: Influence of temperature on resistivity (Glass beads)

The variation of resistivity with temperature for the four types of limestone powers is plotted in Fig. 6. Measurements were made on 150g dry samples (RH<4%) for bed thicknesses of 25 mm giving a bulk density of 980 kg/m^3. In all cases a test voltage of 1000 V was used. It can be seen that for temperatures beyond 30° C resistivity decreases linearly with temperature in the semi-log plot which indicates the same resistivity-temperature characteristic typical of dielectric materials as observed for the glass beads. The apparent constancy of the resistivity of powder F3 for temperatures above 50° C could not be explained. Some moisture was most likely present in power F1 and was driven-off as soon as the temperature rose above ambient conditions, hence the observed initial rise in the resistivity.

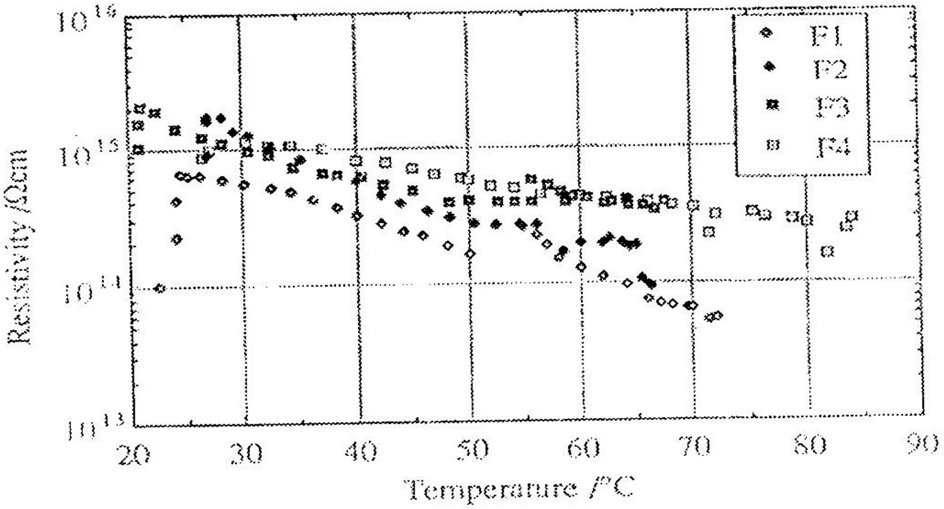


Fig. 6 Influence of temperature on resistivity (Limestone powder)

Results presented in Fig. 7 were obtained for samples of limestone power packed to different bulk densities by varying the force applied on the top electrode. It is obvious that the more compact structure of the high density beds increases their electrical conductivity.

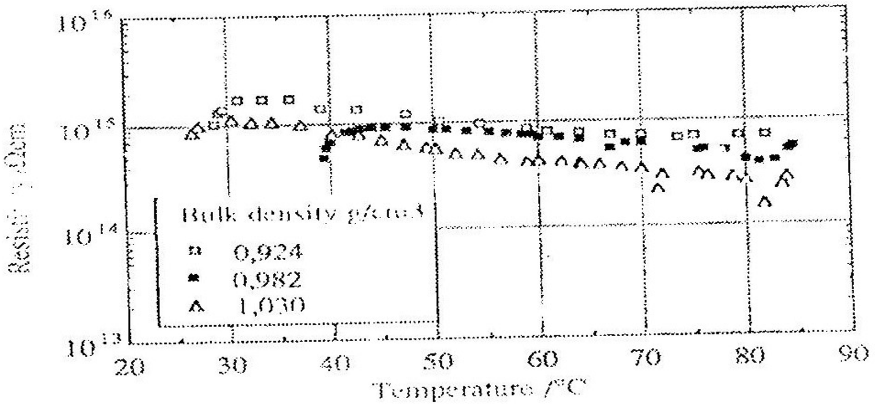


Fig. 7 Influence of packing density on resistivity (Limestone F4, dry air)

Influence of air relative humidity

Fig. 8 shows the influence of air relative humidity on resistivity for glass beads of two mean particle sizes. These tests were started with a relatively dry air which was then changed gradually and resistance measured in a sequence of increasing relative humidities while maintaining the temperature constant at 30° C. In a dry atmosphere a bed of the smaller particles (0.82 mm) has a resistivity of around 2.10^{14} Ωcm whereas that of the 2 mm glass beads is more than 10 times higher. As pointed out above, the high compactness of the bed of the smaller particles, which means more particle-to-particle contact points (number of contact points is an inverse function of particle diameter [19] and the higher specific surface area of the particles makes it to be more conductive than that of the bigger particles. It is also observed that the increase in relative humidity lowers the bed resistivity. Principally the resistance of a completely dry bed of particles (without any conductive molecules adsorbed on the particle surface) depends only on the particle-to-particle contact resistance and the resistivity of the particles themselves.

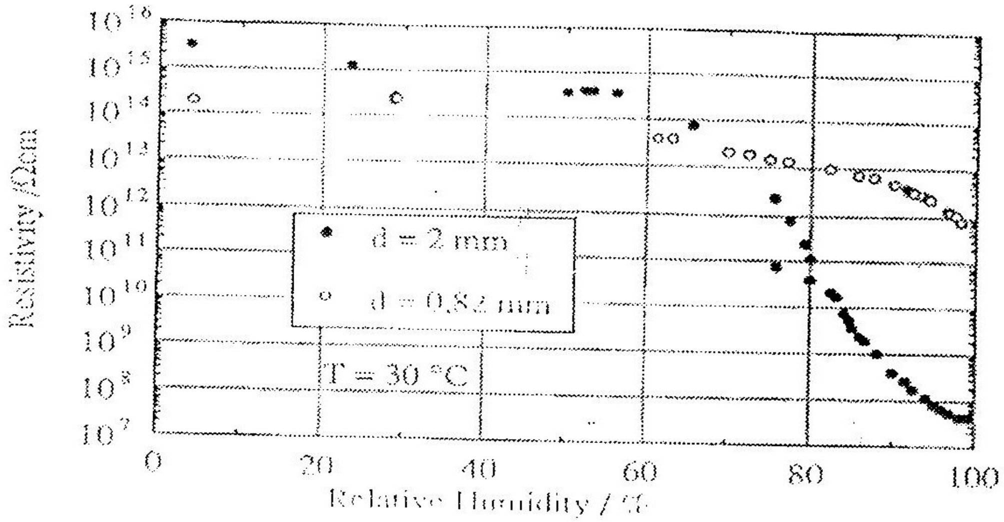


Fig 8: Influence of relative humidity on resistivity for different particle sizes (glass beads)

Introduction of water vapour into the bed leads first to condensation at the contact points which lowers the contact resistance. Further addition of water vapour results in the formation of a water film on the particle surfaces. this film then predominates charge conduction if no ionic dissociation of the particle constituents takes place. This appears to be the case for beds of the smaller particles in our tests as the lowest resistivity value of around 10^{12} Ωcm measured at 100% relative humidity is about the same as that of neutral water. The lower values measured for the bigger particles are probably, therefore, due to the presence of some conductive impurities in the bed.

Fig. 9 shows resistivity plotted as a function of temperature with the air relative humidity as the parameter for limestone F4 samples with packing densities of 0.98 - 1.21 g/cm^3. The resistivity of dry powers falls continuously with rising temperature and it is lowered by the introduction of moisture, the decrease being highest at low temperatures. The inverted-V, ρ - T characteristic is also observed in this case and could be explained from the fact that as the temperature rises, more and more of the water adhered to the surfaces is driven off exist in vapour form in the interstices which raises the overall resistivity. However, at even higher temperatures, the intrinsic resistivity becomes predominant causing, as the case is for all dielectric materials, the total resistivity to fall with increasing temperature.

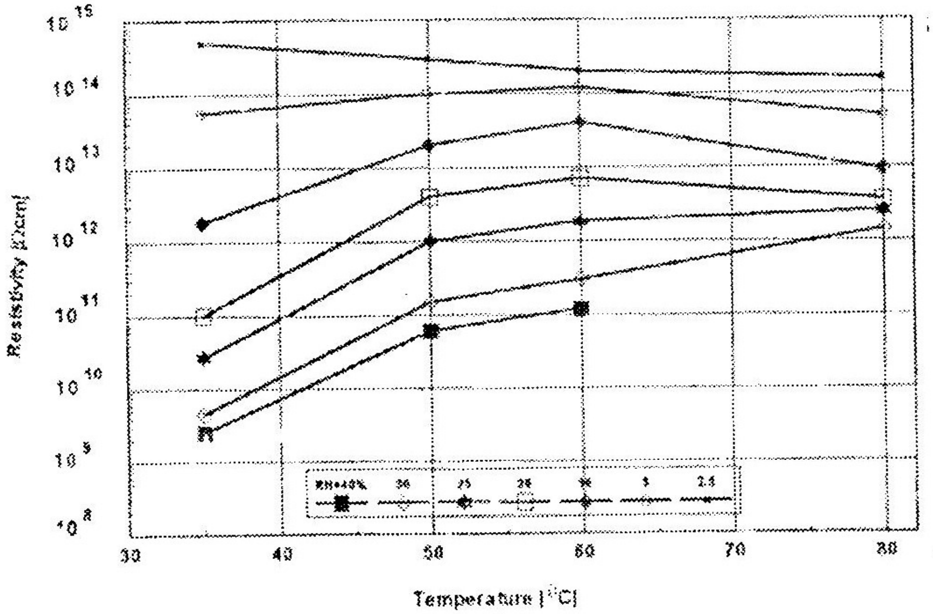


Fig. 9 Resistivity as a function of temperature and relative humidity

CONCLUSION

The point-plane and the finger-type electrodes methods are suitable for imitating the action in electrostatic precipitators but are both prone to problems caused by back corona and mechanical instability of the dust layer. On the other hand the porous electrodes method, which hardly represent what happens in a real filter, is very suitable for fundamental studies relating resistivity to the structure and chemical composition of the dust layer.

Resistivity has been found to decrease with increasing air relative humidity and to first rise to a maximum before falling continuously with increasing temperature. Layers formed from the smaller particles as well as those with high packing densities have lower resistivities. Apart from the extreme (too low or too high) values, bed thickness and voltage have no influence on resistivity.

By measuring the dust resistivity at regular intervals of time the apparatus used in this work may be used as a simple method of monitoring the performance of electrostatic precipitators thereby saving both the electrical power consumed and the amount of pollution caused to the environment.

In electrically enhanced fabric filters particles are charged before reaching the collecting fabric and the pressure drop measured on the formed dust layer has been found to be lower than that of a similar layer formed without the presence of charging, which is advantageous in terms of lowering the operating costs of a filter. This improvement has been noted to depend on the resistivity of the collected dust [4,5] and it is expected, therefore, that the present results may lead to a better understanding, prediction and improvement of the performance levels of this new type of filter.

NOMENCLATURE

A	Area of electrode	m^2
d	Diameter	m
I	Current	A
L	Distance between electrodes	m
r	Radius	m
R	Resistance	Ω

U	Voltage	volts
p	Resistivity	Ω.m

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