1966

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Recommended Citation

Tassicker, O J.; Herceg, Z; and McLean, K, "The Electrical Resistivity of Precipitator Fly-Ash" (1966). *Wollongong University College Bulletin*. 7.
http://ro.uow.edu.au/wucbull/7

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THE BEHAVIOUR OF PRECIPITATOR DUST IN ELECTROSTATIC FIELDS

A PRELIMINARY REPORT OF PROGRESS

Introduction

The attention of the authors was drawn many times over the last two or three years to the difficulties arising in the operation of electrostatic precipitators in New South Wales. The principal means for the removal of dust, smoke, fog and fumes is by means of electrostatic precipitation. In this State, such devices are used to clean exhaust gases from chemical industries, paper mills, cement plants, ferrous and non-ferrous industries and from the electric-power generating industry.

Of these several industries, the most widespread problems occur in collecting fly-ash from the exhaust flue-gas of electric-power generating stations. There are at least ten such major stations at present in N.S.W. Others are under construction and more are projected as power generation in the State expands. Clearly then, the special problems connected with the precipitation of fly-ash are of major importance, being the largest single industrial application of precipitators.

Public attention to the problem of atmospheric air pollution has become focussed through the introduction of 'Clean-Air' legislation in N.S.W. Throughout industry, there is a corresponding awareness of the need to maintain and improve upon collection efficiencies in precipitators.

There have been several indications that fly-ash precipitation in southern N.S.W. has special difficulties as compared with other parts of the world. Many tests performed by the Electricity Commission of N.S.W.[1] on actual plant and pilot plant have indicated a definite pattern of deteriorating efficiency when moving from the Northern to the Southern coal-fields.

Evidently then there is some property of coals from the Southern fields which renders it more difficult to precipitate. The E.C.N.S.W.[1] Projects Division considered that the resistivity of the fly-ash on the Southern fields may have been very high, though their tests were not conclusive. Following discussions with staff from the E.C.N.S.W.[1] it was agreed that staff from the Electrical Department of the Wollongong University College would endeavour to obtain consistent measurements on fly-ash from Tallawarra and Vales Point.

This preliminary report then describes work done so far on the measurement of fly-ash resistivity and some notes on the equipment used. An indication is given of promising theories to be pursued with regard to the atomic origin of these resistivities.

Particle Resistivity and Precipitator Performance.[2]

Particle deposits on the collection surfaces of electrostatic precipitators must possess at least a degree of conductivity, or operation is impossible. Negatively charged particles arriving on the outer layer of dust must have the possiblity of being discharged. Ionic currents must be conducted through the layer of dust to the collecting electrode.

Long field experience and the work of many investigators indicates that with resistivities up to about $2 \times 10^{+10}$ ohm-cm, no special difficulties are encountered. Above this value of resistivity, back corona becomes apparent. When resistivities in excess of 10^{+11} ohm cm occur, rapid deterioration of precipitator performance may be expected[3].

It must be understood that in an actual plant, the atmosphere surrounding the dust layer is hot, humid and contains several gases. The particles are thus conditioned and laboratory experiments conducted in the absence of such agents must recognise this limitation.

Nature of Fly-Ash

Fly-ash particles, produced by the combustion of pulverised coal are of irregular shape, but tend to be hollow spheres. The mass-median diameter of such particles is of the order of 15 micron.

Chemically, the composition is mainly silica and alumina with smaller quantities of iron, calcium and magnesium.

A typical sample might contain :-

SiO_2	72%
Al_2O_3	22%
Fe_2O_3	3%

Since these compounds have been sintered at high temperature in the furnace, they rarely occur in isolation, but in mineral forms more or less difficult to identify.

Factors affecting Resistivity

When considering the conductivity of such particles, several processes must be simultaneously operative.

Conduction may take place over the surface of a particle (surface resistivity) or through the body of the particle (volume resistivity).

The presence of moisture and adsorbed[4] gases on the surface of a particle may have a major effect on the surface conductivity.

The electric field strength within the particle layer influences the conductivity in accordance with the Schottky and other effects.

The absolute temperature of the specimen determines the energy of free electrons and has a major effect on the resistivity.

Dust compacted under mechanical pressure is likely to behave differently from that which adheres loosely to a surface.

Any experimental and theoretical investigation must distinguish between all the effects mentioned above.

Test Apparatus

The test equipment shown in Fig.4 consists principally of a classical dielectric test rig with guard ring, screened leads, high tension d.c. supply, temperature regulated oven and micro-ammeter.

A principle difficulty in using the jig is to ensure regular compaction pressures, as at elevated temperatures, fly-ash flows as readily as a fluid. Since tests are carried out at 300°C, the jig must be mechanically and electrically stable. This necessitates the use of mica, polytetrafluorethylene, beryllinne oxide and other such insulating materials which retain their properties at high temperatures.

Currents of the order of 10^{-9} amps must be measured without inserting excessive impedance in the circuit. All sources of noise must be removed. Refer to Figures 5 and 6.

Particle layer thicknesses down to 2 or 3 mm. must be accurately measured at elevated temperatures.

Since the resistivity of such a semi-conductor is markedly temperature dependent, jig temperatures must be measured to 1°C.

The measurements, though apparently following classical lines, present difficulties several orders of magnitude greater than those encountered in measuring the resistivity of, say, insulating tapes and films.

Current and Voltage Relationships

In Fig.3 is shown a typical set of curves displaying the non-linear relationship between current and voltage. All these measurements have been taken at a nearly fixed temperature of 196°C.
As indicated in the next section, the resistivity is markedly dependent upon temperature, and even the difference in the second curve of 1.4°C is significant.

It should be noted from these curves, that at a constant current density, the voltage drop is closely proportional to the thickness of the layer. Consider for example, a current of 60×10^{-9} amp :

Thickness	Voltage Drop
.150"	4000
.079"	1900

Then $\frac{.150}{.079} = 1.9$ and $\frac{4000}{1900} = 2.1$

This shows a correspondence within the probable errors of the experiment.

Early in the experimental work, it was believed that for a fixed current density, the voltage drop across a layer was not proportional to the thickness due to some surface effects. More careful work, keeping a closer control on compaction and temperature showed these early conclusions to be mistaken.

In the next section, the great importance of the linear relationship between depth and voltage for a given current density is demonstrated.

Conductivity and Temperature

Since it becomes convenient to work with conductivities rather than resistivities, we define :

$$\text{Conductivity} = \sigma = \frac{I.}{V} \cdot \frac{\ell}{a}$$

where $I =$ current, amps.

$V =$ potential difference, volts

$\ell =$ depth particle layer, cm.

$a =$ area current path, cm^2

All the results shown in Fig. 3 are then converted to conductivities.

When considering the fundamental behaviour of the conductivity as a function of temperature, the absolute temperature T^{0} Kelvin is important.

In Fig. (1) and Fig. (2) is shown the relationship between the conductivity σ and the reciprocal of the absolute temperature $\left(\frac{1000}{T}\right)$. A study of these curves shows that above 135°C, the relationship when plotted on semi-log paper is quite linear. Samples of fly-ash taken from the Northern and Southern coal fields both follow this straight-line relationship remarkably closely.

An exponential-type law is evident.

Curve fitting on the available data identified the straight line region as

$$\sigma = A\ \epsilon^{-\frac{E}{T}}$$

where A and E are constants.

This suggests that the samples are behaving exactly in accordance with known semi-conductor laws[5].

In this case,

E = activation energy.

At the lower end of both curves, linearity is departed from and in terms of semi-conductor behaviour, may be ascribed to impurities in the particles.

Then it should be noted that the slopes of the two curves for the two specimens of ash are almost the same. In terms of normal semi-conductor theory, this suggests that the same material makes up the bulk of the particles. Quite possibly other factors, such as particle shape and size-frequency distribution may be important.

Comparison of the Tallawarra and Vales Point Dispersoids

In the first instance, the most outstanding conclusion to be reached concerning the Vales Point and Tallawarra 'B' fly-ash is that the former has a resistivity some 30 times lower than that of the latter for the same voltage gradient.

Temperature	Resistivity ohm-cm		$\frac{\rho \text{ (Tallawarra 'B')}}{\rho \text{ (Vales Point)}}$
	Vales Point	Tallawarra 'B'	
135	$5 \times 10^{+12}$	$1.82 \times 10^{+14}$	36.4
220	$1.11 \times 10^{+11}$	$2.95 \times 10^{+12}$	26.6

The precipitator operating temperature is about 135°C. At this temperature, the resistivity of the Vales Point sample is over the value usually considered to be critical ($2 \times 10^{+10}$ ohm cm.).
The Tallawarra 'B' specimen is well above the critical range.

Though these measurements have all been made on dry dust in the absence of conditioning agents, it seems clear that on the basis of the high resistivities, difficulties in precipitation were likely to occur at Tallawarra.

Future Tests and Activities

As a result of the preliminary investigations already made, a further programme of experimental work, theoretical analysis and field testing is proposed as follows :-

(a) Analysis of the fundamental conduction processes in terms of semi-conductor behaviour,

(b) Isolation of the surface and volume resistivity effects within particle layers,

(c) Construction of an improved design of dielectric test jig which will be suitable for field measurements and overcome compaction difficulties,

(d) Determination of resistivities when conditioned by flue gases in the field,

(e) Microscopic sizing of the fly-ash particles by means of the Coulter or Barkco Counter,

(f) X-Ray Diffraction pattern analysis of the fly-ash particles.

Much of this work is either in hand or completed. Details of these new results will shortly be issued in a more substantial report.

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1/11/1965.

References

1. Meetings with the Electricity Commission of N.S.W. Projects Division, viz :

16/12/1964 Messrs. I. Dennis, K. Watson, Z. Herceg, K. McLean O. Tassicker.

21/12/1964 Messrs. I. Dennis, K. Watson; O. Tassicker, Z. Herceg.

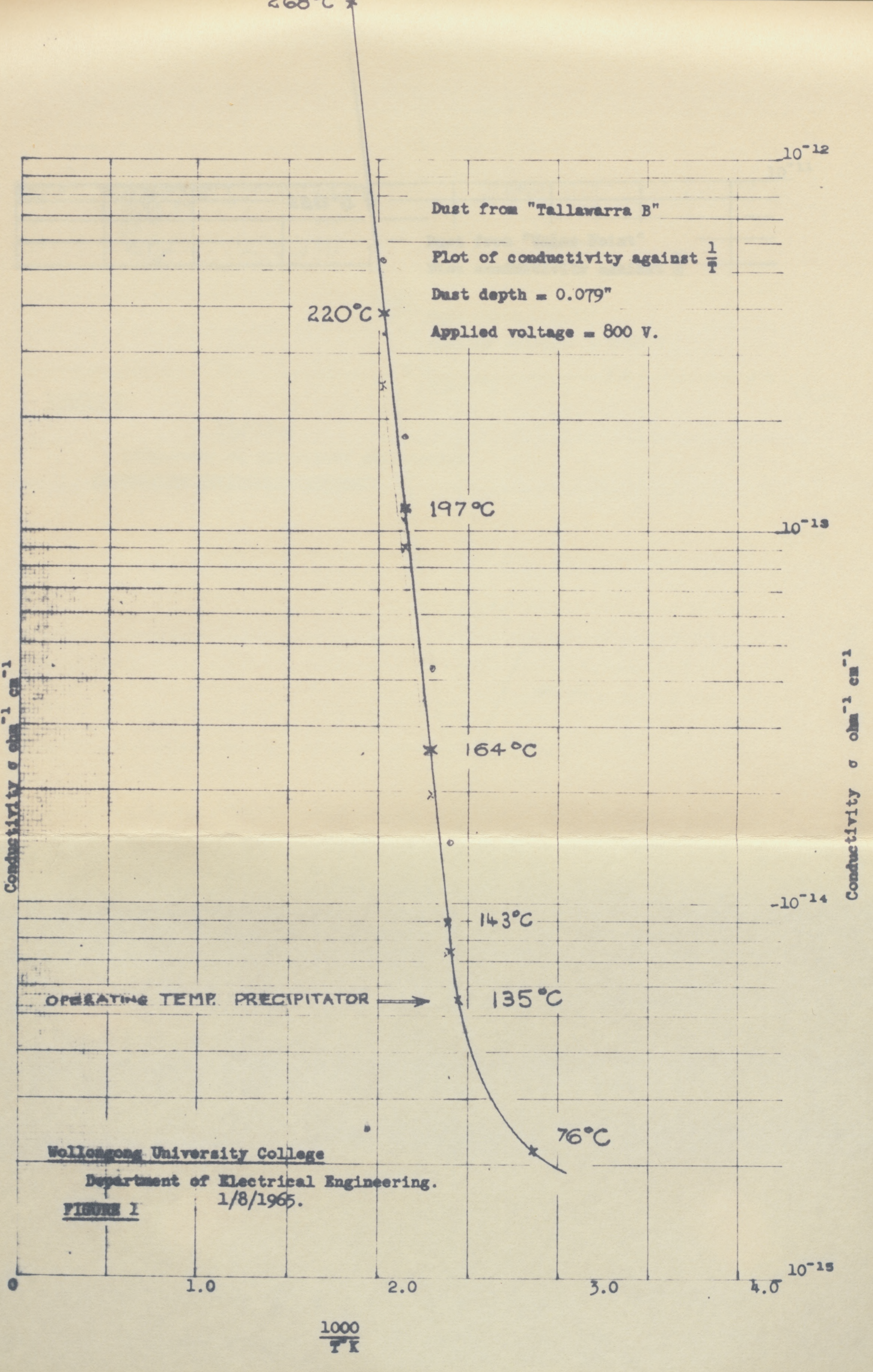
10/ 3/1965 Messrs. I. Dennis, K. Watson, N. Lamb, K. Blecher, O. Tassicker.

2. H. J. White, - "Chemical and Physical Particle. Conductivity Factors in Electrical Precipitation". Chem. Eng. Progress 52, 244 (1956).

3. G. W. Penney - "Electrostatic Precipitation of High-Resistivity Dust". A.I.E.E. Tech. Paper 51-201 (1951).

4. R. O. Daniels, Jr. "A Study of the Effects of Adsorbed Films Upon the Surface Electrical Conductivity of Powders". PH.D. Thesis, Univ. Utah. 1952.

5. E. M. Conwell - "Properties of Germanium and Silicon" Proc. I.R.E. Nov. 1952, pp 1327 - 1337



Dust from "Tallawarra B"

Plot of conductivity against $\frac{1}{T}$

Dust depth = 0.079"

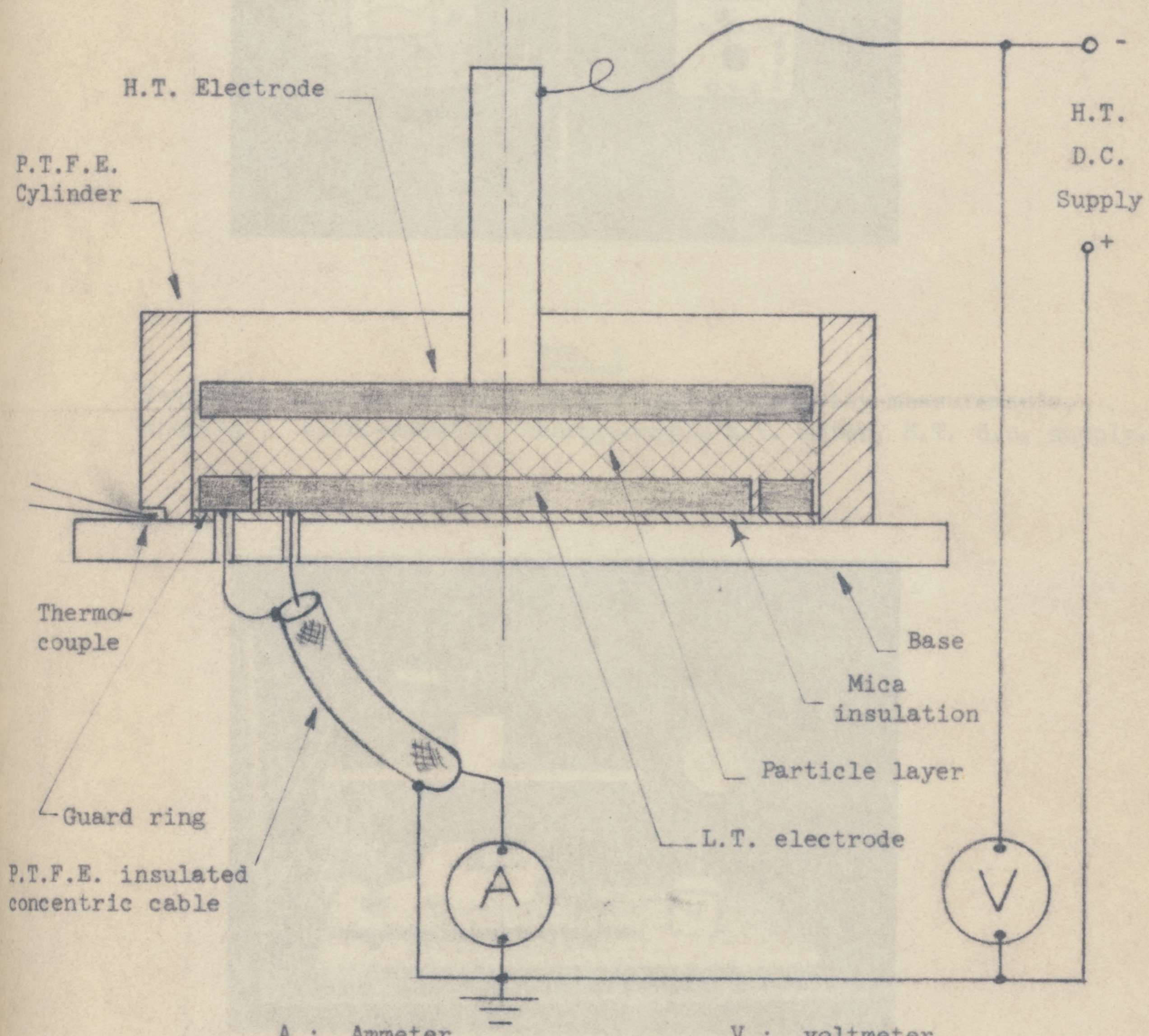
Applied voltage = 800 V.

Wollongong University College

Department of Electrical Engineering.
1/8/1965.

FIGURE I

Dielectric Test Jig for the measurement of particle resistivity at elevated temperatures.



A : Ammeter
1×10^{-10} amp F.S.D.
3×10^{-10} amp F.S.D.
10×10^{-10} amp F.S.D.
1 M Ω input impedance

V : voltmeter
0 - 300 V F.S.D.
0 - 1,000 V F.S.D.
0 - 30,000 V F.S.D.

SCALE full size FIGURE 4. DIELECTRIC TEST JIG

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FIG. 5

Measuring Instruments used in particle resistivity measurements, showing : Micro-ammeter, thermo-couple M.V. meter, H.T. d.c. supply.

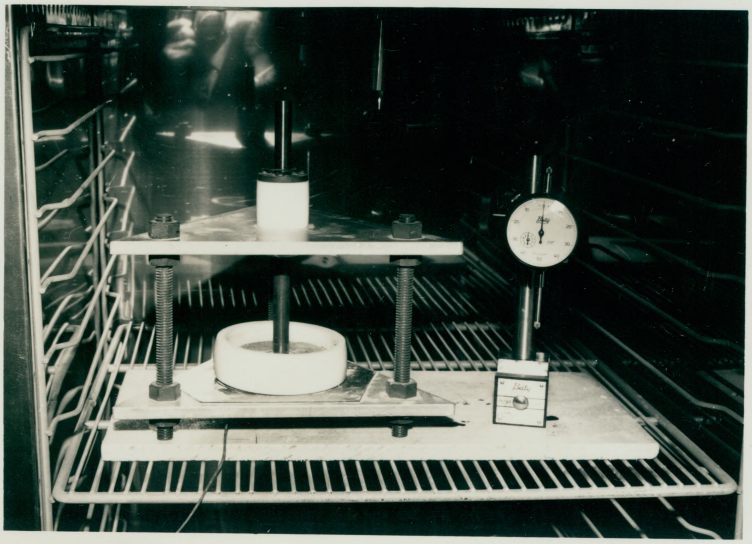

FIG. 6

Dielectric Test Jig inside oven.