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BULLETIN No. 18

WOLLONGONG UNIVERSITY COLLEGE
THE UNIVERSITY OF NEW SOUTH WALES

PROGRESS REPORT 1967 - 1968

Electrostatic Precipitation of High Resistivity Fly-Ash

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DIVISION OF ENGINEERING AND METALLURGY

JULY, 1968

WOLLONGONG UNIVERSITY COLLEGE

RESEARCH PROGRAMME

INTO

ELECTROSTATIC PRECIPITATION OF FLY ASH

JULY, 1968.

CONTENTS

($ Indicates primary source of financial support.)

1. Project No. 1. ($ ECNSW).

"DEVELOPMENT OF DIELECTRIC DISPERSOID JIG"

now known commercially as

EEL ELECTROSTATIC PRECIPITATOR ANALYSER 223

1.1 This project, as far as the University is concerned, has now drawn to a very satisfactory conclusion. A sophisticated measuring instrument of laboratory precision, but intended for use under the worst possible industrial environments has been brought to commercial production. On behalf of the three inventors, Unisearch Pty. Ltd., applied for patents and negotiated with a number of internationally recognised companies for the right to manufacture and market the device. The successful company was EEL International Pty. Ltd. of Bayswater, Victoria, to whom the world rights were assigned. Unisearch was fortunate to be able to conclude an agreement with a company so experienced in the manufacture of scientific instruments. During the following six months when the research version of the equipment was translated into a commercially practicable unit, EEL International collaborated closely with staff from the University College and with other bodies including the Electricity Commission of New South Wales.

1.2 The commercial prototype of the Model 223 Electrostatic Precipitator Analyser is shown in the photograph of Fig. 1.1. To the

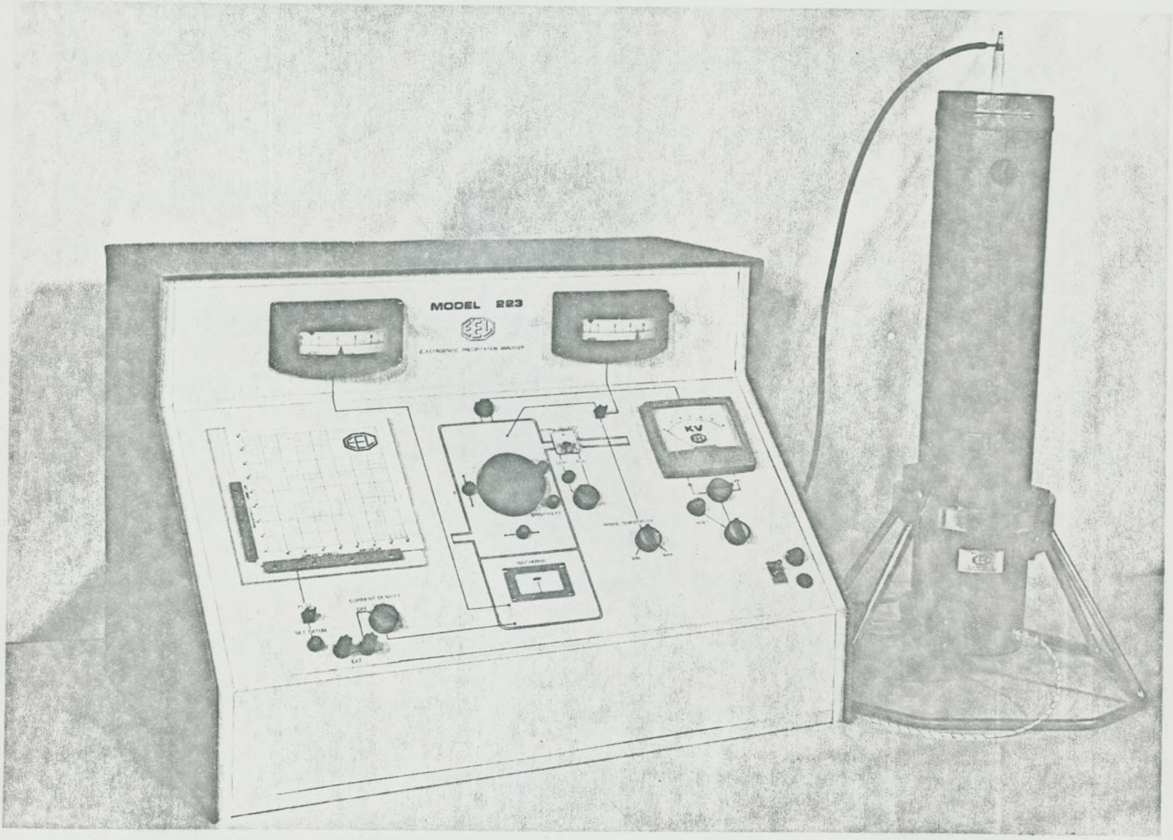

Fig.1.1 EEL Electrostatic Precipitator Analyser 223. This is the first commercial production model. Electro-mechanical assembly on the right. Control cubicle containing all instrumentation on the left.

right is shown the electro-mechanical part of the system, while to the left is the console which contains all the instrumentation. The vertical cylinder on the right, supported by a light framework of welded aluminium legs, contains an upper and a lower chamber both of stainless steel. The upper chamber consists of a precision coaxial electrode precipitator. The complete electrical ionisation characteristics of the flue gas, from corona initiation to sparkover, may be measured at any desired temperature in this chamber. Dust carried in the flue gas is extracted with an efficiency exceeding 99%. Thus a completely representative sample of the solid dispersoid is deposited on the walls of the upper chamber. Measurements of collection efficiency and particle migration velocity may be carried out. Thus the optimum gas temperature of the main plant may be readily determined. The effect of trace additives, such as ammonia, to improve the gas ionisation characteristics may be immediately observed.

1.3 By controlled vibration, the dust is dislodged from the walls of the upper precipitator chamber. Falling into the lower chamber, the same vibration compacts the dust into the guarded cylindrical electrode system. Here, still in contact with its gaseous environment, the electrical resistivity of the specimen may be measured. Various current densities may be applied and compared with those in the main plant precipitator. Very high or very low values of resistivity will point to the problem of the formation of back-ionisation in the main plant. Those temperatures necessary to avoid back ionisation difficulties may be easily determined.

1.4 The upper and lower chambers are sealed everywhere with high temperature O rings so that the system may be operated at positive pressure or vacuum.

1.5 The console at the left contains all heater controls, high voltage D.C. power supply (smoothed and full wave rectified), and all measuring instruments. The panel is clearly engraved so that the equipment may be used by sub-professional staff. The resistivity is displayed on a semi-automatic X-Y plotter. The corona current voltage characteristic is displayed as an X-Y trace on a cathode ray oscilloscope screen. EEL International, who developed the control console, have incorporated a number of ingenious features so as to render the equipment portable, rugged and accurate.

1.6 The whole equipment is thus seen to be correctly described as an Electrostatic Precipitation Analyser. It is able to measure the complete electrical characteristics of the gas and dispersoid. It embodies a small pilot precipitator which may obviate the necessity for arduous expensive tests on large pilot plants in certain cases.

1.7 The special assistance of officers of the Electricity Commission of New South Wales, particularly Mr. J. Blecher and Mr. K. Watson, is gratefully acknowledged. The Commissioner met the costs of development in the research stage. Colleagues in the CSIRO, Australian Coal Industries Research Laboratories and the Shortland Laboratories of the B.H.P. have all rendered valued advice. Finally, the enterprise of EEL International has transformed a research device into an engineered package.

It is hoped that all those who design or operate electrostatic precipitators may find their task easier with this new instrument.

2. Project No. 2. ($ NCRAC)

"CONDUCTION MECHANISMS IN HIGH RESISTIVITY LAYERS".

2.1 General

It has been generally accepted that the poor performance of electrostatic precipitators in New South Wales and Queensland is associated with the exceptionally high resistivity of the fly-ash obtained from the coal in these areas. As a first step in understanding the reason for this, this project is directed towards studying the conduction mechanism through small particles compacted between two parallel plates.

2.2 The Model

A model has been devised in which the particles are represented as spheres of equal diameter packed together to form a simple cubic array. Current conduction from one particle to another must flow through the restricted area of contact of any two adjacent particles. The model assumes that the characteristics of these junctions will dominate and determine the overall characteristic of the compacted layer of particles.

2.3 Experimental

In order to study the effects of point contacts, a point-to-plane experiment has been devised. This comprises an arrangement where three metal points of 200 micron diameter are placed

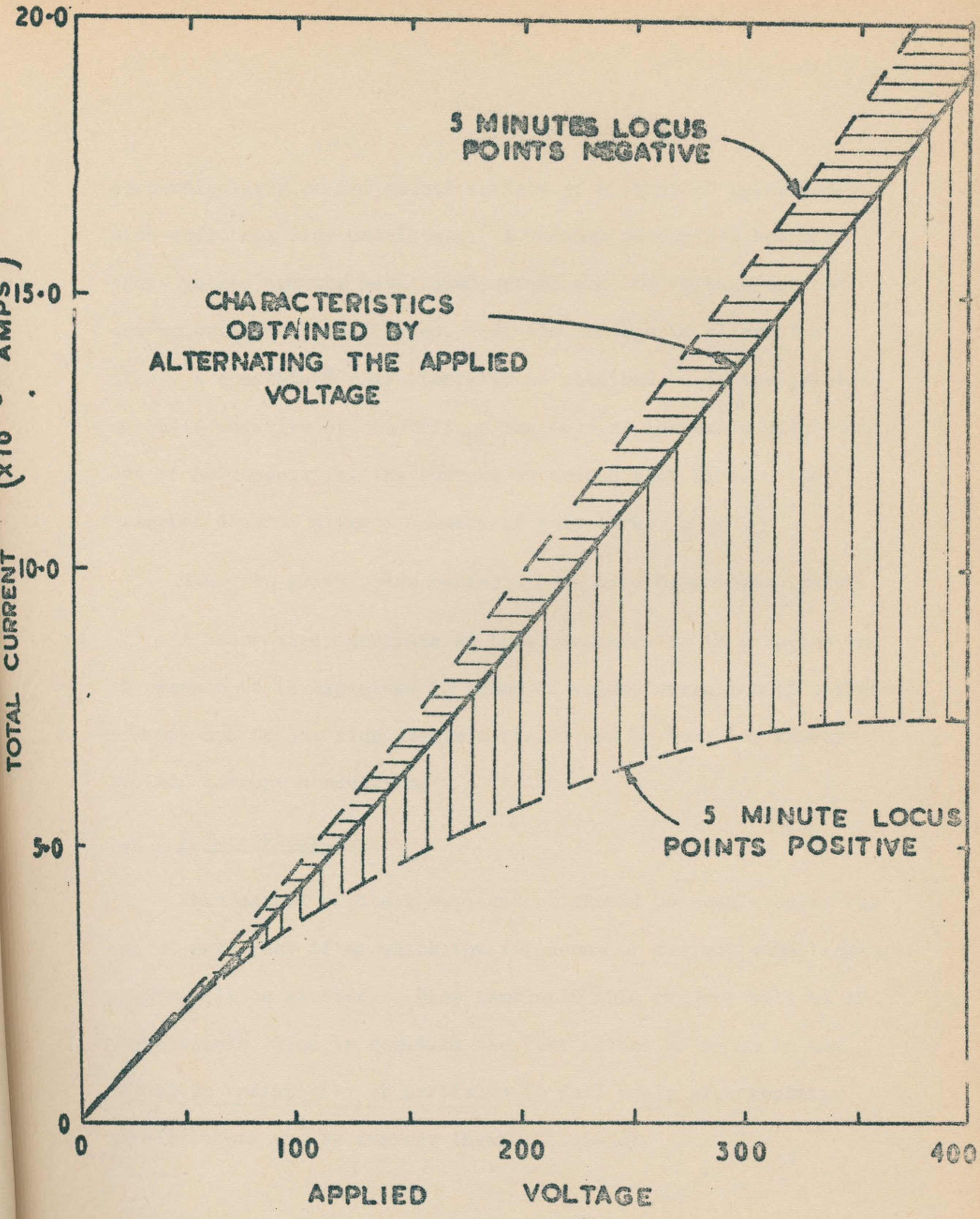

FIG. 2 METAL POINT TO GLASS PLANE CHARACTERISTICS

perpendicularly on one smooth surface of a sheet of pyrex glass with the other side metallised. A voltage is applied between these points and the metallisedsurface and the voltage/current characteristics investigated. If the voltage is alternated slowly a consistant characteristic is obtained. If the points are held negative at one voltage the current increases with time and if held positive, the current decreases with time. The attached diagram gives a summary of this work. (Fig. 2)

Glass to glass point contacts have also been investigated.

A theoretical analysis of this phenomena is in progress and at present it is explained in terms of volume variation of carrier density due to the high electric fields and by "carrier number" limited current conduction.

2.4 Future Programme

This aspect of the investigation should be completed by the end of next year after which the influence of surface conditioning agents will be studied. When completed this project will be of considerable value in deciding the best method of reducing the effective resistivity of particles in full scale electrostatic precipitators and so improve their efficiency.

3.0 Project No. 3. ($ NCRAC)

"ELECTRICAL CHARACTERISTICS IN CONTAMINATED CORONA SYSTEMS"

3.1 In this period, the work was concentrated on developing an experimental set-up suitable for systematic measurements aiming

(a) to identify processes in contaminated corona systems, and

(b) to determine quantitatively the influence of individual parameters, particularly the temperature, humidity, thickness of the contaminating layer, its porosity and resistivity (which is also a function of temperature and humidity).

3.2 Measuring techniques

3.2.1 The corona jig was designed (it was built and donated by Australian Iron and Steel) to enable measurements in point-to-plane or wire-to-plane configuration.

A standard point-to-plane geometry (0.5 mm hemispherically capped wire, 4 cm gap) is presently used for better definition of physical processes. In this configuration, the 20 x 20 cm plate electrode is insulated from ground and it has a centrally placed probe of 2 cm^2. The high-voltage power supply provides a continuously adjustable d.c. voltage up to 30 kV.

Contamination is simulated by sheets of paper or other insulating materials (including non-porous plastics) covering the plate electrode. These sheets produce conditions similar to those in precipitators contaminated with the deposited dust, without having to deal with an uncontrollable mechanical instability of dust layers. Layer thicknesses between 70 μm and 1 mm were used in experiments.

The corona jig is placed in an environmental chamber having a temperature range of 150°C and a reasonable humidity control (for temperature below 100°C).

3.2.2 The plate-electrode and probe current waveforms were measured with a Tektronix 564 CRO, using 3A6 plug-in amplifier and 1121 preamplifier. The overall rise time for this system, including connections to the electrode, did not exceed 10^{-8} sec.. To measure the d.c. level of pulses, a more sensitive, but slower, differential plug-in amplifier 2A63 was used, and the results were correlated with the average value measured with Philips GM 6020 or HP 419A d.c. voltmeter, and true runs (a.c. only) measured with HP 3400A voltmeter.

3.2.3 The d.c. current-voltage characteristics were plotted by using storage and X-Y facilities of the Tektronix 564, and a large time constant ($\sim$ 1 sec) in the measuring system.

3.2.4 The surface or inter-layer potential of the contaminator was measured with a Keithley 610B electrometer and 10^{12} -ohm probe. Output of the electrometer was used to plot this potential as a function of the applied (corona) voltage.

3.3 Results

3.3.1 The current-waveform measurements for negative corona showed that the shape of individual Trichel pulses does not depend on the plate-electrode contamination (less than 1 mm for 4-cm gap). This is consistent with the displacement-current interpretation of these pulses.

An insulating layer reduces the average current and repetition frequency of Trichel pulses, providing that back corona does not occur.

Ionization in pores of the insulating layer, or back corona, can be detected (even before a visible glow appears on the surface) by the presence of random pulses much larger than normal Trichel pulses. In this case the repetition frequency of Trichel pulses increases. At higher applied voltages the Trichel-pulse corona is interrupted by intervals of continuous discharge. Finally, in the completely continuous mode, sparkover is imminent.

Positive corona, being a continuous discharge, does not offer such a display of waveforms, although large random pulses in this case also characterize the presence of back corona.

3.3.2 Diagrams in Fig. 3-1 and 3-2 show typical results obtained by plotting the corona current and surface potential as functions of the applied voltage.

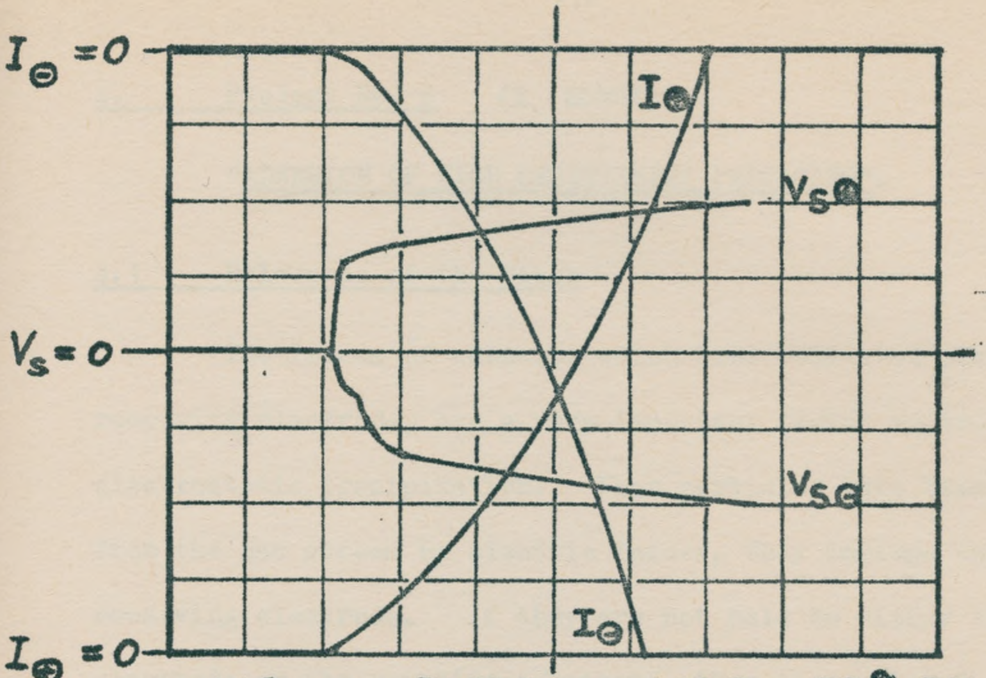

FIGURE 3.1

~140 μM PAPER. 23° C. 50% RH
HORIZONTAL : 4 KV/CM.
VERTICAL : CURRENT 72·5 μA/CM.
PAPER SURFACE POTENTIAL 500 V/CM.

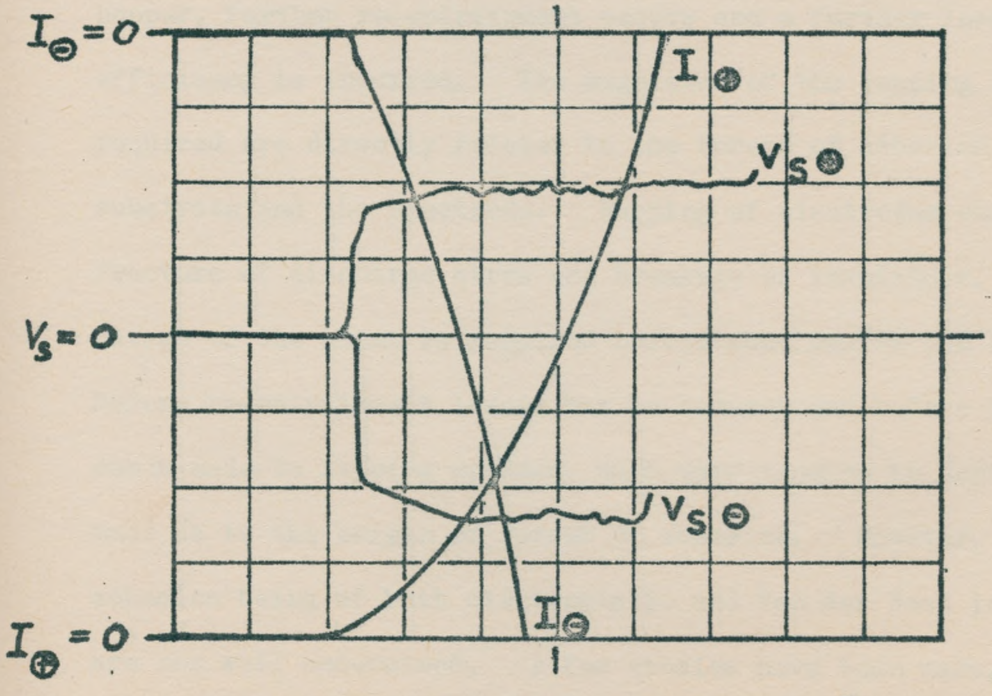

FIGURE 3.2

~140 μM PAPER. 22° C. 18% RH.

4. Project No. 4 ($ ECNSW).

"ADHESION OF HIGH RESISTIVITY PARTICLES".

4.1 Relevance of the Study

The forces of adhesion which bind collected particles to the receiving electrode, are a very important factor in the process of electrostatic precipitation. When particles have been extracted from the gas stream by electric forces, they impinge upon the receiving electrode. If they are not held to either the receiving electrode or the existing substrate, then they rebound and are re-entrained in the moving gas stream. Such re-entrainment represents a serious loss of efficiency in precipitators. During rapping of the receiving electrodes in order to dislodge agglomerates into the hopper, further re-entrainment occurs and a further loss of efficiency is incurred. The magnitude of the rapping impulses required are directly related to the forces of adhesion between the substrate and the electrode. Rapping of electrodes causes frequent fracture of discharge wires and breakage of insulators. A long outage of the plant is required before such faults can be repaired. Before re-entrainment losses can be reduced and before improvements can be made to rapping methods, much more studies in depth must be made as to the origin of forces of adhesion. However, the forces of adhesion being of both electrostatic and Van der Waal in origin are not well understood. A few studies have been made, but they have been scattered and inconclusive.

At 50% relative humidity and paper resistivity of about 10^{11} ohm-cm, (Fig. 3-1), there was no back corona. At a reduced humidity of 18% and paper resistivity increasing to 10^{14} ohm-cm, back corona appeared for both polarities (Fig. 3-2).

Negative-corona system is more affected by contamination than positive. The negative-corona current in Fig. 3-2 is suppressed till the onset of back corona. After that the current increases rapidly. Sparkover occurs at about 26 kV. With point electrode positive, the system remains stable up to 30 kV. The paper-surface potential is nearly constant in both cases, indicating that back corona has the same voltage-stabilizing characteristics as the glow discharge at low pressures.

4.2 Methodology

Of the five or six methods of measuring adhesive forces between particles and the substrate, the one adopted is that of the centrifuge.

The one used at Carnegie (Klingler and Penney) and at the Battele Institute, Frankfurt (Bhoeme, Krupp et al) is the centrifuge method. Our own careful consideration of all factors involved has also lead us to the use of the centrifuge in the present studies. Other studies of adhesion forces between small particles and a substrate have been deficient as far as relating to electrostatic precipitators are concerned. The forces of adhesion must be measured in the presence of an electric field, corona currents and the normal gaseous environment of a precipitator. What we are really proposing then, is to subject the particles to a combination of inertial, electric and ionic current field. This is a very difficult objective and we do not underestimate the experimental difficulties involved.

4.3 Centrifuge for macroscopic layers of particles

A centrifuge has already been constructed which has been used for examination of macroscopic samples of fly-ash. Real difficulties were experienced in designing a suitable corona chamber. But this has now been solved and a very suitable corona chamber has now been evolved. Corona currents have been removed from the rotating receiving electrode by means of a high quality slip-ring assembly formerly developed for aircraft. The concept and principle of the programme has been thoroughly vindicated by the centrifuge already constructed. However, higher values of acceleration are needed, and both a larger diameter rotor and higher speeds are required. Furthermore the specimen must be able to be subjected to a vacuum for outgassing of the surface of the fly-ash, both before and during centrifuging. It is important to be able to determine what adhesion effects are due to surface condition of the particle.

4.4 New Centrifuge being commissioned

A completely re-designed centrifuge has now been completed and is being commissioned. The rotor is 6" dia. constructed of high tensile aluminium, and capable of 10,000 R.P.M. Previous studies have shown that the accelerations obtainable will be adequate to examine a wide range of adhesion forces.

The rotor head has been designed to operate under any gaseous environment from NTP to a high scientific vacuum. The multi-purpose oil diffusion vacuum pump has been commissioned. Specimens of fly-ash or dielectric spheroids are deposited on the rotor by electrostatic precipitation. They will be subjected to any required level of electric field. They may also be subjected to corona currents from the ionised gas. Thus in all respects, the specimen may be tested under environments exactly the same as those found in a commercial electrostatic precipitator.

The engineering problems encountered in the design of the bearing, seals and vacuum assembly have been considerable. It is believed that they have been overcome, and the support given by Dynavac High Vacuum Pty. Ltd., John Crane Pty. Ltd. and colleagues in the CSIRO is gratefully acknowledged.

4.5 Results and Future Work

The whole plant is now being commissioned and it is expected that minor problems of vacuum joints and heat dissipation in the bearings will be overcome.

Useful results will be gained from the equipment in 1968. Systematic examination of various fly-ashes will be carried out.

5. Project No. 5 ($ ECNSW, NCRAC).

5.1 "MICRO AREA BOUNDARY PROBE".

This is a new, powerful measuring tool which has been developed at Wollongong over recent months. It shows great promise of providing a whole new range of information about the negative coronas used in precipitators at the present time and about positive coronas which may be used for high temperature gases (e.g. pulverised coal fired gas turbines) in the future.

Uses to which the equipment may be put have been the subject of extensive correspondence with Professor Leonard Loebe (Emeritus Professor of Physics, University of California, authority on gaseous discharges), Dr. A. von Engel (Oxford University, authority on gaseous discharges) and Professor H. White (of Oregon, world authority on electrostatic precipitators). All these men and others have made many encouraging suggestions and have asked to be kept informed of results.

Professor H. White remarked that he was aware of the problem of the precipitation of fly-ashes fired from Eastern Australian coals.

5.2 Results from the MABP

The micro area boundary probe as we have it is now able to determine the corona current density and the electric field strength on the receiving electrode boundary. It is considered to be such significant development from that reported in February, that we have

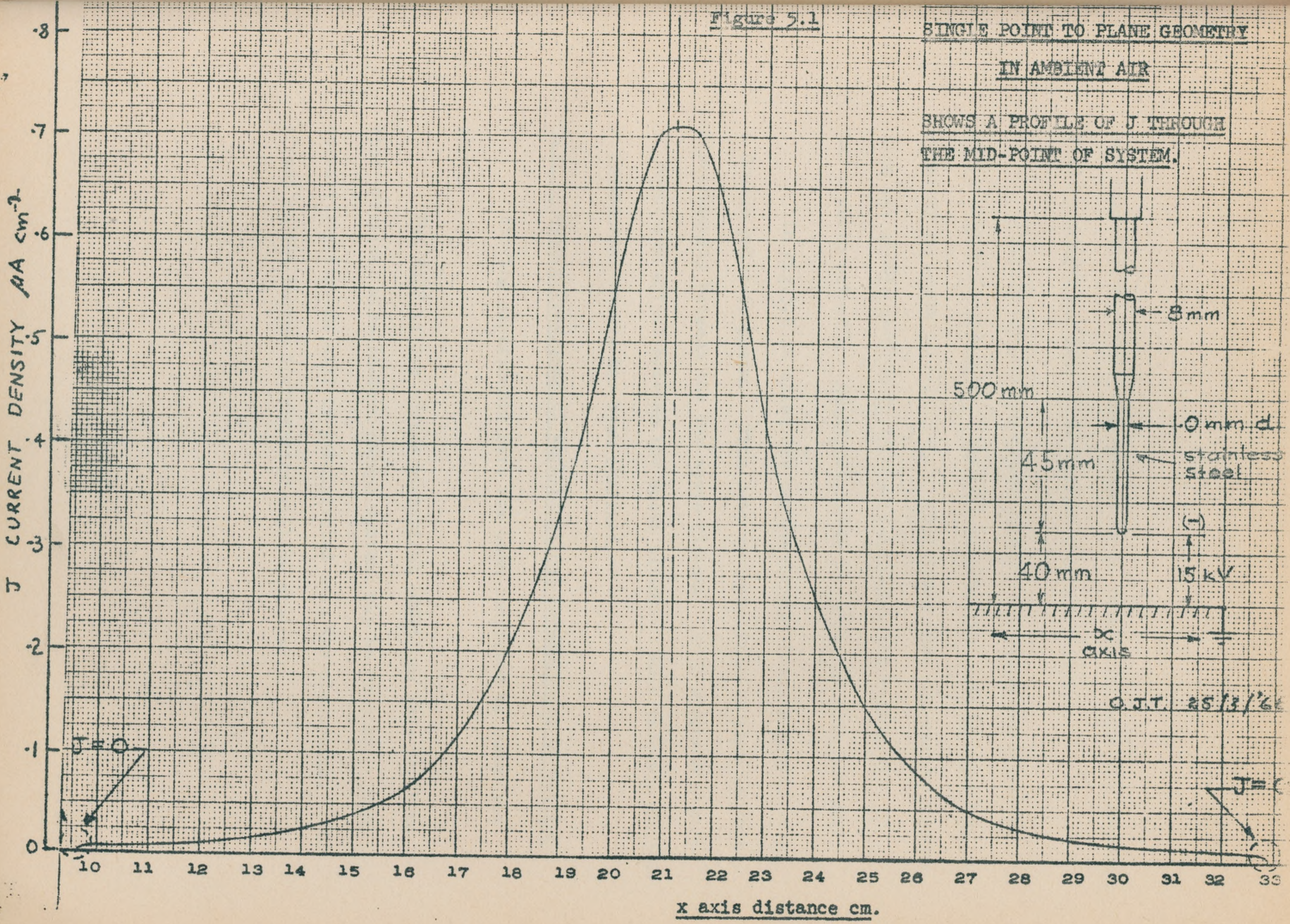

Figure 5.1

SINGLE POINT TO PLANE GEOMETRY IN AMBIENT AIR

SHOWS A PROFILE OF J THROUGH THE MID-POINT OF SYSTEM.

now been able to extend the device to be able to measure the electric field strength as well as the corona current density.

Proving results have been carried out using the point-to-plane electrode geometry. Typical results for such an electrode geometry is shown in Fig. 5.1.. This shows that the corona current does not slowly diffuse to zero at the edges, but rather that it has a sharp cut-off. Great precision is available with the MABP.

In Fig.5.2 is shown the corona current density profile for a double point-to-plane. This data is remarkable in that it shows discontinuity between the two space clouds. This suggests a sort of repulsion effect between the space clouds. Much valuable data of a fundamental nature has been obtained.

5.3 Future Programme of Work-Practical Precipitator Geometries

Proving experiments have now been completed as described above.

The MABP is now having mechanical additions made to it so that practical wire-in-duct corona systems may be studied. High resistivity fly-ash will be precipitated onto the electrodes. The effect on the corona distribution will be studied.

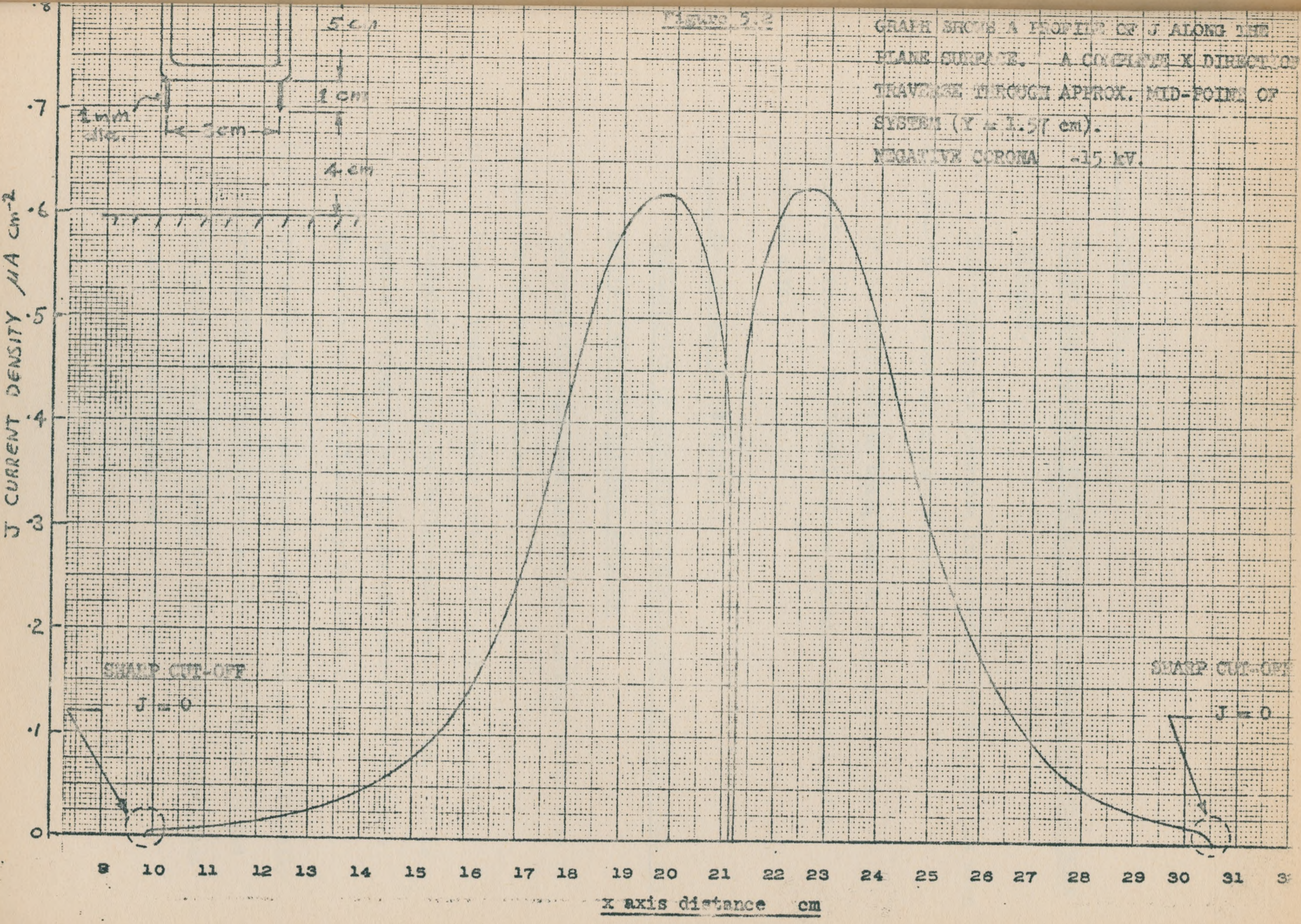

Figure 5.2

GRAPH SHOWS A PROFILE OF J ALONG THE PLANE SURFACE. A COMPLETE X DIRECTION TRAVERSE THROUGH APPROX. MID-POINT OF SYSTEM (Y = 1.57 cm).
NEGATIVE CORONA -15 kV.

6. Project No. 6

"MICRO AREA BOUNDARY PROBE APPLIED TO CONTAMINATED ELECTRODE SYSTEMS".

This project, as described in an earlier report, has now been absorbed for the time being into Project No. 5.

If the modifications being made to Project No. 5 are successful, Project No. 6 will become redundant and will not be proceeded with.

7. Project No. 7. ($ NCRAC).

"EXPLOITATION OF ELECTRIC DISPERSOID JIG", or "EEL MODEL 223 ELECTROSTATIC PRECIPITATOR ANALYSER".

The completed equipment as described in Project No. 1 is to be used for two types of test:-

(a) In-situ test on working installations of electrostatic precipitators, e.t. at Wallerawang Power Station. It is desired to find out how closely the performance of large precipitators is reflected by the Model 223.

(b) The device will be used in the laboratory using artifically created fly-ash contaminated gases. Both humidified gas and particles will be tested to find out how closely plant conditions can be simulated in the laboratory.