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THE BUILDUP OF ELECTROSTATIC CHARGES BY FALLING POWDERS. A PRELIMINARY REPORT

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PICATINNY ARSENAL
DOVER, NEW JERSEY

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A PRELIMINARY REPORT

by

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May 1969

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ABSTRACT

Many automatic loading machines permit explosives to fall freely through orifices. Since, however, numerous unexplained detonations have occurred in the course of this operation, measurements have been initiated to determine whether the falling powders can build up an electrostatic charge sufficient to initiate explosions. A simple system has been designed to determine to what extent the charge buildup depends on the nature of the falling powder, its size, its flow rate, or the orifice size, the orifice material, the orifice geometry, or other factors such as the effects of various pretreatments on the powder, e.g., drying, ballmilling, the relative humidity of the surrounding air, etc. Preliminary measurements indicate very clearly that voltages of the order of 7-9 kilovolts are developed and that the total energy available in the built-up charge is roughly 10^{-3} joules. This voltage and energy is sufficient to detonate common primary explosives. Furthermore, the rate of charge buildup can be explained by a very simple theory which assumes that the falling stream acts as a constant current generator. However, it is not known why the falling powder would act in this manner, and consequently the physical process responsible for the charge buildup is still not understood. It therefore is suggested that a program be initiated to investigate basic electrostatic processes in both explosives and inert materials.

INTRODUCTION

Unexplained explosions have occurred in loading plants which employ automatic loaders for the handling and dispensing of lead azide. These incidents have been thoroughly investigated without, however, arriving at clear-cut explanations for the detonations. It is well known that primary explosives are extremely sensitive to impact, friction, and electrostatic discharges, and it is reasonable to assume that any one or a combination of these may have caused the explosions.

The relative importance of impact, friction, and electrostatic discharge in causing initiation is not known. However, although electrostatic initiation is a prime suspect, almost no information is available on the generation of electrostatic charges in loading equipment. This preliminary investigation was undertaken by the Explosives Laboratory, Picatinny Arsenal, in order to determine whether this is an important consideration.

The approach used was to investigate whether an appreciable electrostatic potential could be developed by freely falling powders. The apparatus used simulates automatic loaders such as the Jones loader, combined with a continuously operated "water-wheel" dispenser.

EXPERIMENTAL PROCEDURE

Apparatus

The apparatus used to measure charge buildup by falling powders consisted basically of a metal hopper with an adjustable orifice located above a metal receiver, but separated from it by insulating rods. The hopper and receiver were connected to an electrostatic voltmeter to measure the voltage which usually developed when the powder was allowed to fall freely (Fig 1). The hopper was a galvanized iron cylinder of 6½ inch diameter and 4½ inch height, soldered to a funnel inclined at an angle of 60° and containing a Lucite stopcock which controlled the flow rate. It was fastened to a Lucite plate supported by four Lucite rods of 1 inch diameter. The receiver was a one-gallon can with a funnel inclined at an angle of 60° soldered to the cover. The maximum free fall was 22 inches, which is the distance from the orifice to the bottom of the receiver. Attachments could be inserted between the hopper and receiver to determine how the various flow patterns affected the charge buildup. Polystyrene, brass, and aluminum orifices were used. The orifice openings had diameters of .070 inch, .112 inch, .158 inch, .194 inch, and .250 inch which provided flow area ratios of 0.08, 0.2, 0.4, 0.6 and 1.0, respectively.

The hopper and receiver were connected by means of a minimal length of RG 58A/U coaxial cable to an electrostatic voltmeter (Fig 1). To minimize the effect of external fields, the apparatus was completely enclosed in a Faraday cage consisting of a Lucite box with a bronze-screen inner liner (Fig 2).

An electrostatic voltmeter (Sensitive Research Instrument Corporation) with a 0-6 kv range and a capacitance of 13.1 picofarad (pf) was used to record charge buildup. The total capacitance of the apparatus was 138 pf, of which 92 pf was due to the coaxial cable. Capacitance was determined with an impedance bridge (Boonton Electronics Corporation, Capacitance Bridge Model No. 74-CS8 and Fluke Model 710B).

Several modifications were available and could be added to the apparatus to determine if the charge buildup is altered by flowing the powder over itself or over one or more metal surfaces. One of these was a flat copper chute whose angle to the base could be varied. A second one consisted of a copper cone of 2 inch diameter, inclined at an angle of 45°, and provided with an orifice of 0.25 inch. This cone was mounted in such a manner as to permit changing the angle between the falling powders and the cone side. Three cones actually could be installed in this manner, and powder could be flowed through all three in succession.

Also, a condensor was attached to the hopper to determine if the charge-buildup rate depended on the presence of an initial charge.

In order to analyze the voltage-versus-time curves, it is essential to know if the powder flows through the various orifices at a constant rate. This was measured by weighing the powder passing through different orifices as a function of time. Typical results are shown in Figure 3. It was found that the flow rates were constant and reproducible. However, two distinct flow rates were obtained when the .194-inch-diameter orifice was used. Each of these rates corresponded to a different flow pattern, which was established when the flow was initiated, and subsequently maintained itself for the duration of the measurement. The data points for each mode definitely are reproducible. It is suggested, but not proven, that these two modes correspond to laminar and turbulent flow and can be obtained only with certain size orifices.

Sample Materials and Preparation

Inert powders were used for the initial measurements because they did not create any safety problems. The substances selected were intended to cover a range of electrical characteristics believed to be typical of explosive powders.

The materials studied were aluminum oxide, sand (Berkshire and Ottawa), sodium carbonate (anhydrous), carborundum, pentaerythritol, sodium chloride, and microballoons (i.e., hollow glass spheres). The powders were sieved to obtain uniform particle size, and subjected to the treatments described below.

Aluminum oxide was the material studied most thoroughly because it could be obtained with uniform particle size distribution. Most of the tests used the portion passing through a 100 mesh, but retained on a 200 mesh sieve. This provided particles in the 74 to 194 micron range.

To determine if pretreatment affected the charge buildup, several particle-conditioning experiments were tried. These included: (1) drying, (2) flowing the powder down metal chutes and through cone configurations, and (3) ballmilling the powder prior to use.

The drying pretreatment consisted of heating the powder in air at 110°C for periods of up to seven hours. As described above, during the flowing-pretreatment phase the powder was allowed to fall over various configurations of the chute and cones. In one configuration, the angles between the chute and the cones were selected so that the material would flow over itself, which, it was hoped, would determine if the friction generated by the granules flowing past and over one another would cause charge transfer and enhance the charge buildup. Also, in this way it was possible to vary the period of time for which flowing powder was in contact with stationary powder.

Ballmilling the powder prior to the charge-buildup measurements was intended to indicate whether or not the condition of the powder surface was important. First, this process exposes freshly broken surfaces; second, it strains the powder to some extent. It is known that piezoelectric crystals, such as quartz and some explosives, develop surface charges when strained. Ballmilling was performed in a rotating porcelain container using ¾-inch ceramic balls. Usually the powder was milled for one hour, quickly transferred to the apparatus, and charge-buildup measurements started immediately.

RESULTS

The electrostatic charge buildup produced by various falling powders was measured using the apparatus and materials described above. The effects of particle size and type, orifice size and material, pretreatment, and relative humidity were observed and tabulated.

The sign of the charge buildup developed by some representative powders when falling through a polystyrene orifice is given for each material in Table 1. The notation "gnd" refers to the point at which the ground lead was attached to the system.

The polarity of the charge formed was determined by using a 1200-volt potential of known polarity. Alternatively, a capacitor containing a charge of known polarity was applied to the terminals of the voltmeter during or after each measurement.

The voltages developed by 74-194-micron size aluminum oxide flowing through a polystyrene orifice of .112 inch diameter are shown in Figure 4. The curves show steady voltage increases as a function of time. The shapes of the curves resemble those for the voltage developed across a capacitor when charged at a constant rate.

Figure 5 shows a typical spread of data points for consecutive runs on the same sample. This was the usual pattern or trend obtained for consecutive runs on the same sample if the temperature and humidity remained constant through the recording period. It should be noted that consecutive runs were quite reproducible with respect to both total elapsed time and data point spread.

The drying of the aluminum oxide at 110°C for periods of up to seven hours did not noticeably affect the charge-transfer properties of the material.

An attempt was made to determine whether the buildup rate was related to the friction generated by the granules flowing past and over one another, which in turn might cause some charge transfer. This inter-particle friction probably is different from the particle-orifice friction. Numerous physical and electrical configurations were tried. In some of the experimental arrangements the granules flowed through a series of copper cones, in others the material flowed down an incline covered with a bed of the same material. Also, the material was allowed to fall between plates, points, and wedges of various configurations, both charged and uncharged, and at ground potential and above ground. The charge-formation properties were not affected, however, by any of these varying flow conditions and configurations.

Of the various treatments tried, only ballmilling the material with ceramic balls for one hour seemed to have an appreciable effect on the rate of charge formation. Figure 5 shows the buildup rates for untreated and for ballmilled powder. All ballmilled samples produced potentials above the 6 kv limit of the meter. Runs were terminated when the meter limit was reached. In all runs conducted with ballmilled material the voltage generated exceeded 6 kv in less than 8 minutes for a 582-gram sample.

The effects produced by using different orifice materials are shown in Figure 6. These are voltage-time curves for successive runs with ballmilled aluminum oxide flowing through both brass and polystyrene orifices. The lower buildup rate obtained with a brass orifice is evident: 4 to 5 kilovolts were generated in 4 minutes during consecutive runs using a polystyrene orifice; but in the same period only 1 kilovolt was obtained with a brass orifice. Subsequently the polystyrene orifice was restored and another run was conducted; but the voltage buildup was not only about 2 kilovolts. The experiment was repeated with a ballmilled sample run first through a polystyrene orifice, and then consecutively twice through a brass orifice (Fig 7). The voltage buildup was 5.5 kilovolts with the polystyrene orifice, but it was markedly reduced to 3.5 kilovolts after 4 minutes with the brass orifice. During the next run with the brass orifice the voltage was reduced further to about 0.2 kilovolt. Similar results were obtained with an aluminum orifice. However, the second run produced less charge than that obtained with a brass orifice.

Another important variable is relative humidity. Although it could not be altered at will for detailed study relative humidity is clearly important, since it can affect both the rate of buildup and the total charge. The considerations relating to the falling powder experimental apparatus and the loading machines are the same: Any charge actually accumulated depends on both the formation rate and the leakage rate. The latter usually, but not always, involves two leakage paths: first, surface paths, and second, the surrounding air. The surface paths are moisture dependent, especially if dissoluble salts are present. It is well known that the conductivity of air increases with its moisture content. Although, as mentioned above, the relative humidity could not be controlled it was always recorded. In this manner, it was found that it was impossible to obtain any measurable charge formation when the humidity reached 50%. Also, the leakage resistance of the apparatu. was a constant 5×10^{14} Ω at below 30% humidity but was reduced considerably when the humidity was higher.

The effect of cleaning the apparatus prior to the experimental run is illustrated in Figure 8. Consecutive runs were made on the same sample prior and subsequent to cleaning the apparatus with a so-called foxtail brush. Runs 26-1 through 28-1 show values normally obtained for typical runs, while tests 29-1 and 30-1 show the enhanced behavior due to gentle dusting of the apparatus with the cleaning brush. Subsequent brushings with a piece of cloth, clothing, or even the bare hand seemed to enhance the buildup capability of the material. This feature may be the cause for some of the variations in the data.

DISCUSSION

Qualitative measurements were made on the electrostatic charging of selected powders, so that the apparatus and the techniques that produced the most reproducible results could be used in later research.

In the quantitative tests that were conducted to determine whether the flow rates were constant as a function of orifice diameter, the results also indicated that the charging curves resembled those for the voltage developed across a capacitor when charged at a constant rate. Also, the indications were that each curve would reach a saturation value.

The trends obtained with the different materials used showed that the charge increase was directly proportional to the decrease in particle diameter. However, measurements could not be made with some very fine powders, since they would sometimes fail to flow through the orifice, and also displayed a tendency to form clots, a phenomenon not clearly understood.

In the tests conducted, the effect of relative humidity on all particle sizes was quite evident.

Ballmilling the aluminum-oxide powder prior to its flowing through the apparatus had the greatest effect of all the methods tested for enhancing the charge buildup. The ballmilling, conducted with ceramic balls for one hour, did not affect the particle size of the aluminum oxide. Actually, ballmilling particles in the 74- to 149-micron range produced less than 2% by weight of particles of less than 74 microns. Figure 5 clearly shows the effect of the ballmilling on the charge formation. A possible cause for this effect may be the formation of new surfaces and the increase in the number of points of contact for transfer of charges. This enhanced effect is further illustrated in Figure 6, for the tests of which a smaller sample size was used. Here again, one notices that the charge buildup in consecutive runs of the same material is reduced.

It is of interest to note that changing the orifice material from plastic (polystyrene) to metal (brass) causes a marked reduction in the buildup voltage. The potential increases somewhat if the sample is rerun through the plastic orifice. Figure 7 also shows this effect of the metal orifice on the pretreated aluminum oxide. Again, successive runs tend to reduce the charge transfer.

In respect to the charge accumulation, the questions arise as to how the charge buildup occurs, what determines the polarity of the charge, and what is actually being measured.

Two types of interaction occur as the powder falls freely through the apparatus. That there is a particle-orifice interaction or friction was clearly demonstrated by changing the orifice material. The lack of a particle-particle interaction, on the other hand, was demonstrated by flowing the powder over itself in one or more chutes located between the orifice and the receiver.

The polarity of the built-up charges, as shown in Table 1, may be dependent on the dielectric constants of the powders. The positive values are usually associated with materials having the higher dielectric constant.

A variable which initially was not considered was shown to have a pronounced effect upon the characteristics buildup. As described above, while investigating why certain measurements could not be repeated, it was discovered that brushing the insulating parts of the apparatus with a brush, wiping it with a dry rag, or even rubbing it with one's hand materially influenced the charge-buildup properties. This observation indicates that probably, indeed almost certainly, charges on insulators near the falling powder influence the charge buildup.

If a charge is present on the insulating members of the apparatus, fine particles which carry a charge can, during the measurement, be electrostatically attached to the charged surfaces. Thus, a charge may appear on the hopper or receiver. If, during successive runs, the insulator is cleaned, one can regenerate charged surfaces, and very large charges can accumulate. However, this assumption of a fine-powder mechanism is, at this time, almost entirely conjectural, and unsubstantiated by experiment.

Incidentally, and this may be important from the point of view of plant operation, it has been found that if the proper humidity conditions prevail (40% relative humidity or less), these surfaces can retain that charge for several days. A method has been found to clean the apparatus without imparting any change to the surfaces, i.e., by washing it first with water, then with alcohol, and permitting it to air-dry.

Some calculations were made to determine the number of charges carried or transferred per particle. On the assumption that, in the case of aluminum oxide, these are spherical particles with an average diameter of 112 microns, there would be approximately 1.36×10^6 particles per gram Al_2O_3 where $\rho Al_2O_3 = 3.95\ g/cm^3$. From experiments it has been found that one can obtain a 6-kv rise with 100 grams of material passing through an orifice of .158 inch diameter. Using these values, and taking the capacitance of the system as 138 pf, it can be calculated that there are approximately 3.8×10^4 unit charges transferred per particle.

Recently, J. Polson and H. A. Hanna of the Iowa Army Ammunition Plant have constructed an apparatus to demonstrate that changing electrostatic and electromagnetic fields can easily initiate freshly broken lead azide. This behavior is attributed to the fresh crystal surfaces formed during crushing or grinding operations, particularly if the azide is confined subject to the pressure of an electrical probe. The two investigators have calculated that the energy required for initiation under these conditions is less than 4×10^{-10} joules. This is several orders of magnitude less energy than that developed in the experiments described in this report.

An apparatus similar to that constructed by Polson and Hanna was fabricated in this Laboratory, and by means of it it has been demonstrated that their original observations are correct. However, it still remains to be proven that detonations occurring in their apparatus are due to the simultaneous presence of a fresh surface, an applied pressure, and a changing electrostatic or electromagnetic field in a confined medium. If, on the other hand, a peculiar combination of conditions such as described above is required for an initiation, there arises the question why mishaps do not occur whenever these conditions prevail. It is quite conceivable that the minimum energies required for initiation of primary explosives are lower than previously supposed or, alternatively, that the energy required is minimized by other factors.

The fact that falling lead azide can generate an electrostatic charge has been demonstrated by Mahler (Ref 8). He devised a simple isolated system similar to the Jones Loader where a small sample of lead azide (½ gram) was permitted to fall freely through a 1/32 inch opening into a tilted insulated funnel which in turn permitted the lead azide to fall into an insulated metal container. The lead azide was then manually poured back into the dispenser. With an electrostatic voltmeter across the dispenser and funnel, this procedure was repeated with the same sample until a saturation voltage was reached. Positive potentials of 780 and 860 volts were recorded. Further studies of a similar nature were continued by Polson and Hanna (Ref 7) and they obtained potentials of the same order.

The efforts described here were designed to determine the factors which effect the initiation of explosives, with the ultimate objective of improved safety in handling. Consequently, at this time, and even though the available information is extremely scant, it might be useful for some investigators in this area to speculate on the possible causes of these mishaps.

a. If in the loading apparatus there are moving parts which can be momentarily insulated from one another either by floating freely or by the interposition of a nonconducting lubricant, then it is possible for a potential to be generated between the moving members.

b. Freely flowing powder materials may generate an electrostatic potential between members of the loading apparatus.

c. Cleaning operations involving the machine, tables and shield may be a source of potential danger unless all members are adequately grounded to permit any charge to leak or bleed off. It has been shown that a charge generated on insulating members can persist for several days under favorable ambient conditions. Consequently, it is specifically suggested that all plastic explosion shields be covered by wire screening (suitably fastened to prevent flyoff in case of a detonation.)

d. The starting and stopping of electrical machinery in the vicinity of a loading operation should be carefully scrutinized. Relatively high transient electrical and magnetic fields may be generated by electrical start-ups and shutdowns.

It is conceivable, although not proven, that some of the mishaps involving loading machines may have resulted from starting, stopping, or cleaning operations.

A simple theory has been formulated to account for the voltage-vs-time behavior observed in the freely falling powders (see Appendix). This theory can be tested by plotting specific functions of the data. Such plots are shown in Figures 9 and 10 (Fig 9, Charge-rate plot for V_∞ equal to 6.5 and 6.96 kv; Fig 10, Charge-production rate for V_∞ equal to 4.3 and 2.85 kv), with V_∞ calculated from a best plot fit to be 2.85 and 4.3 kv for runs 55 and 149, respectively. The initial data points for these two runs are given in Figures 5 and 7, respectively. In the runs tested, the values ranged from 2 to 8 kv. It is extremely important to remember that this theory, in its present form, does not explain the mechanism of charge buildup or predict the polarities observed. These must be determined by future experiments.

Experiments were performed to determine the effects caused by brushing, rubbing, or cleaning the insulating sections of the apparatus. After a run was completed, the particles which had been attracted to the Lucite were brushed off. The same batch was then rerun and the voltage recorded. Examples of the voltages developed after cleaning are shown in Figure 8. There is a significant increase. These few preliminary measurements indicate clearly that charges formed on the insulating surface influence both the rate of charge buildup and the total accumulated charge. Obviously, this observation has safety implications and requires additional investigation.

CONCLUSIONS

1. Falling powders can generate electrostatic charges having total stored energies greater than 2×10^{-3} joules and creating potentials in the kilovolt range. (Their energies and potentials are known to be sufficient to initiate some primary explosives.)

2. Both the rate of charge formation and the total charge generated depend on various factors such as size and type of powder, orifice size and material, pretreatment of the powder by ballmilling and drying, and the relative humidity of the surrounding air. The formation rate is somewhat reduced when metal orifices are used and/or the relative humidity is increased to approximately 50%.

3. It has been clearly shown that additional factors, such as the presence of electrostatic charges in and on the experimental apparatus, may determine both the buildup rate and the total charge generated. These other factors, and consequently the whole mechanism or physical basis of electrostatic charge formation by falling powders, are not completely understood as yet, and should be made the subject of a long-range basic investigation.

4. Studies should be conducted also on the use of Lucite or related materials to determine their role in the charge-buildup characteristics of a system utilizing these materials. The present data suggests that Lucite has a disadvantage if used in an explosive-loading operation, since it has the tendency to acquire and retain electric charges on its surfaces. That study should include means of eliminating or minimizing the charge-buildup characteristics.

ACKNOWLEDGEMENT

The assistance of Mrs. Louise Millington in conducting many of the tests is gratefully acknowledged.

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TABLE 1

Sign of charge developed by powder falling through a polystyrene orifice

Material	Hopper	Receiver
Al_2O_3	–	+ gnd
Sand	+	– gnd
Na_2CO_3 (Anh)	–	+ gnd
Carborundum	– gnd	+
Pentaerythritol	–	+ gnd
Microballoons*	–	+ gnd
NaCl	–	+ gnd

*Microballoons are hollow glass spheres.

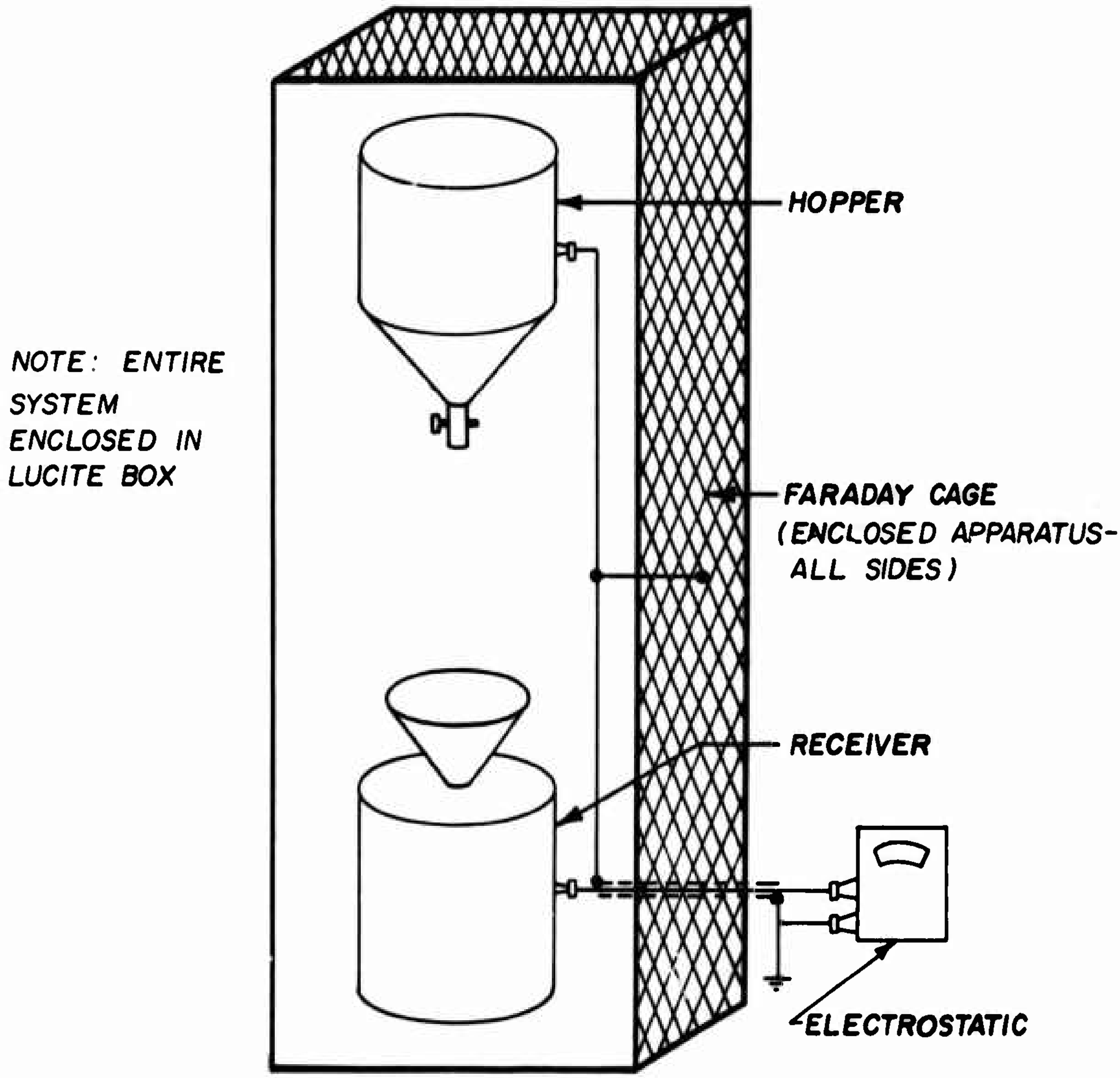


Fig 1 Typical elec:rical configuration

Fig 2   Photograph of test apparatus

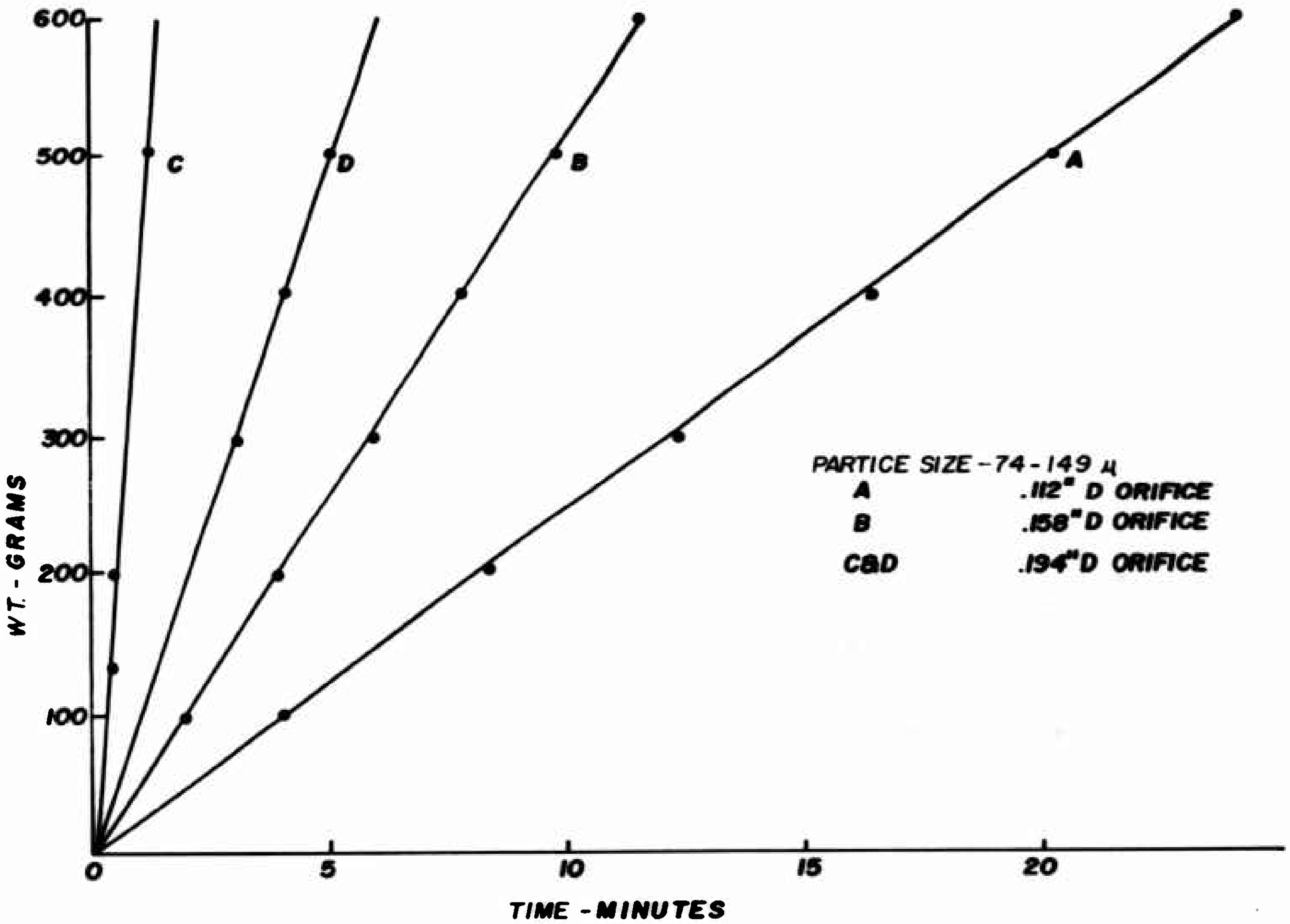


Fig 3 Flow rates of Al_2O_3 as a function of orifice diameter

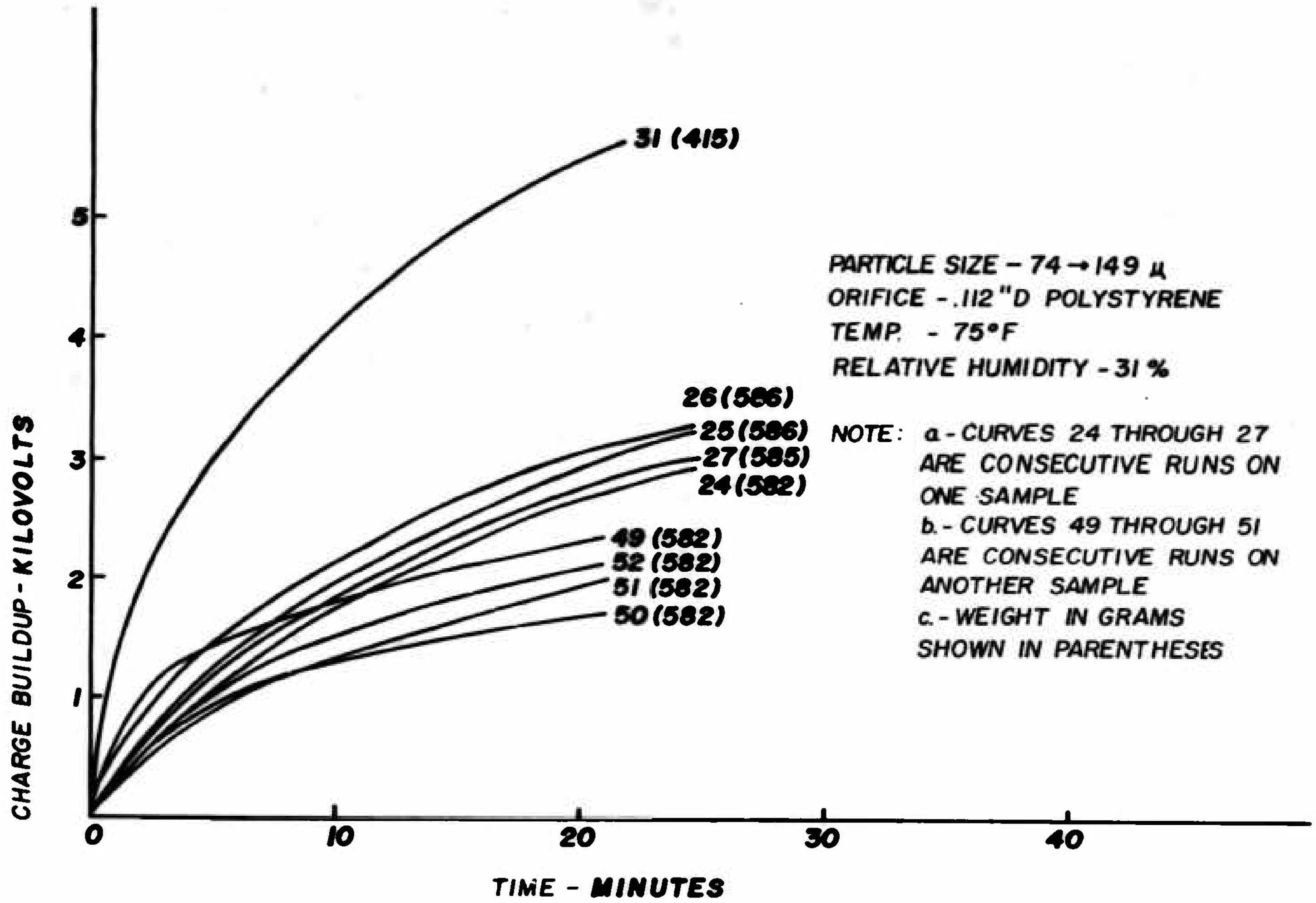


Fig 4 Typical curves showing rate of charge buildup for Al_2O_3

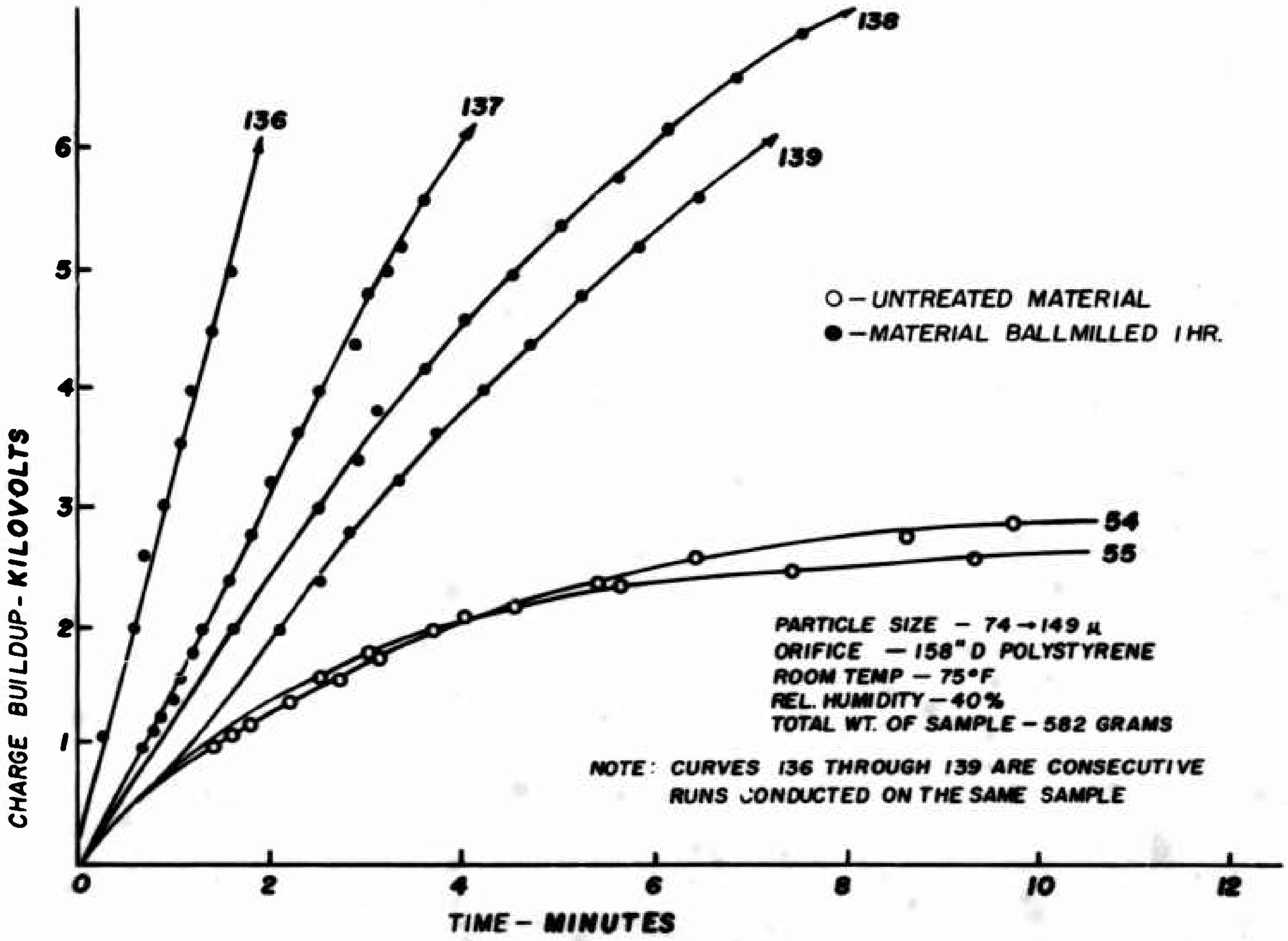


Fig 5 Effect of ballmilling on the rate of charge buildup for Al_2O_3

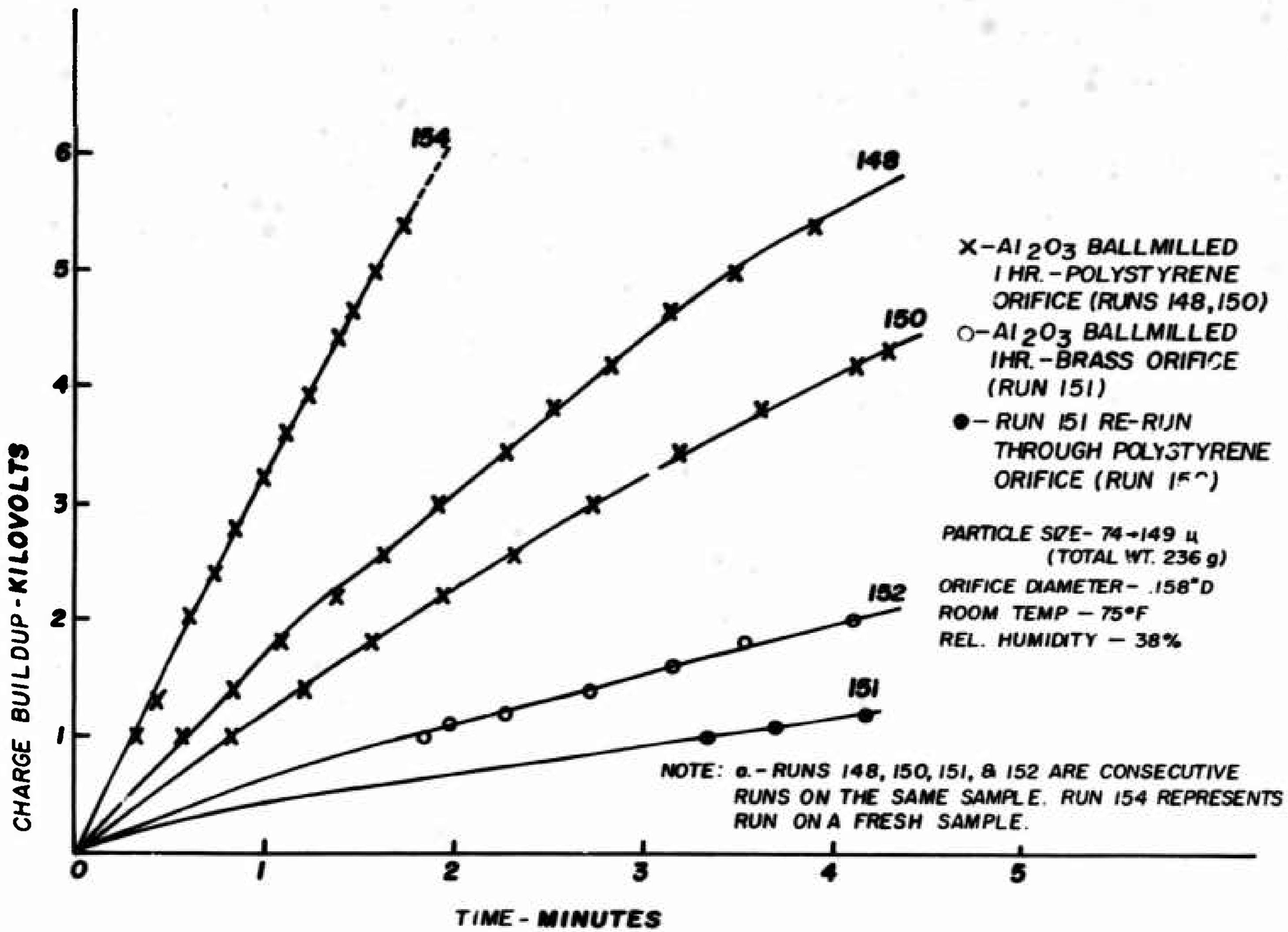


Fig 6 Effect of orifice material on the rate of charge buildup for ballmilled Al_2O_3

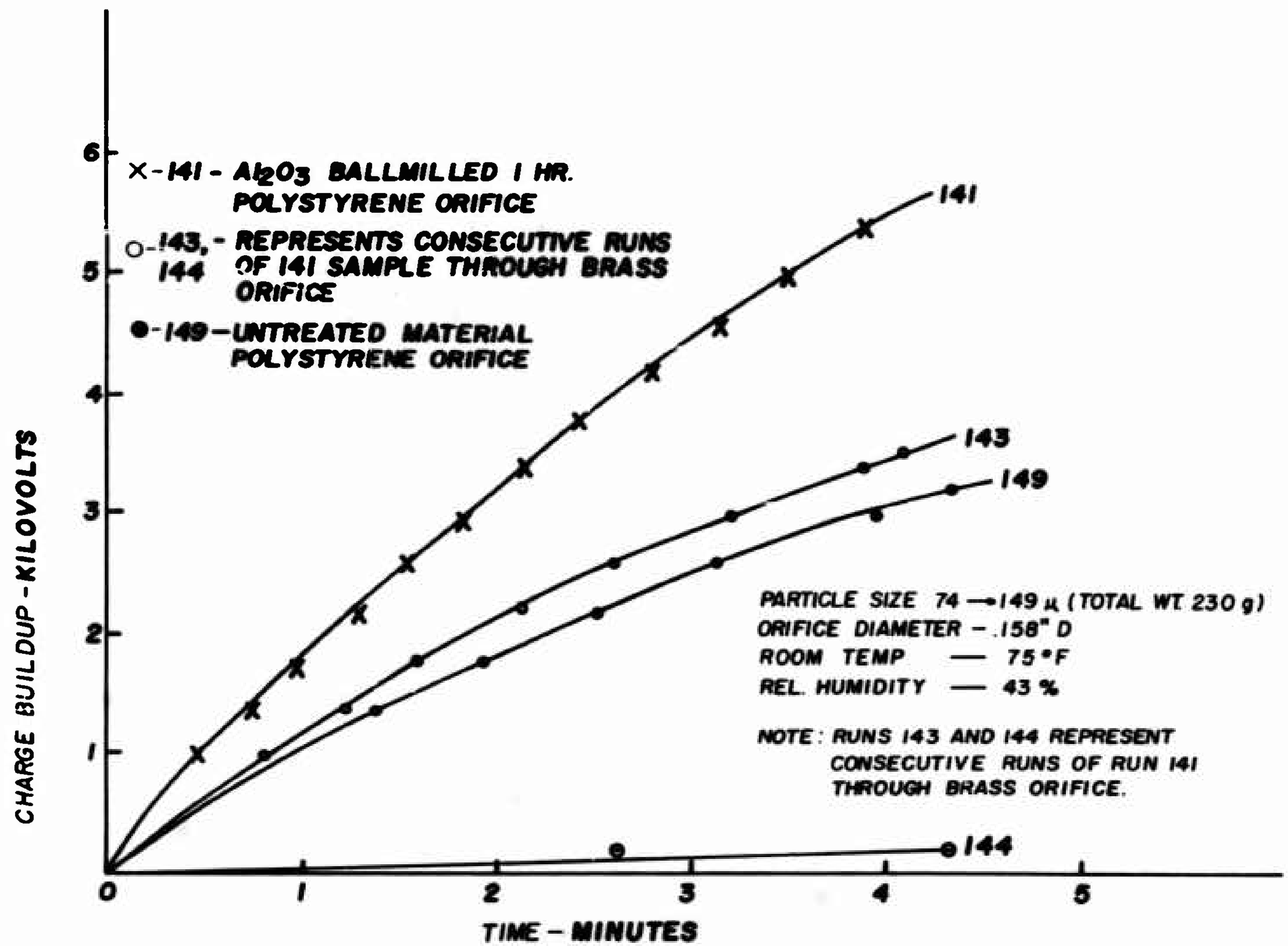


Fig 7 Effect of orifice material on rate of charge buildup for ballmilled Al_2O_3 (Repeat of Fig 5)

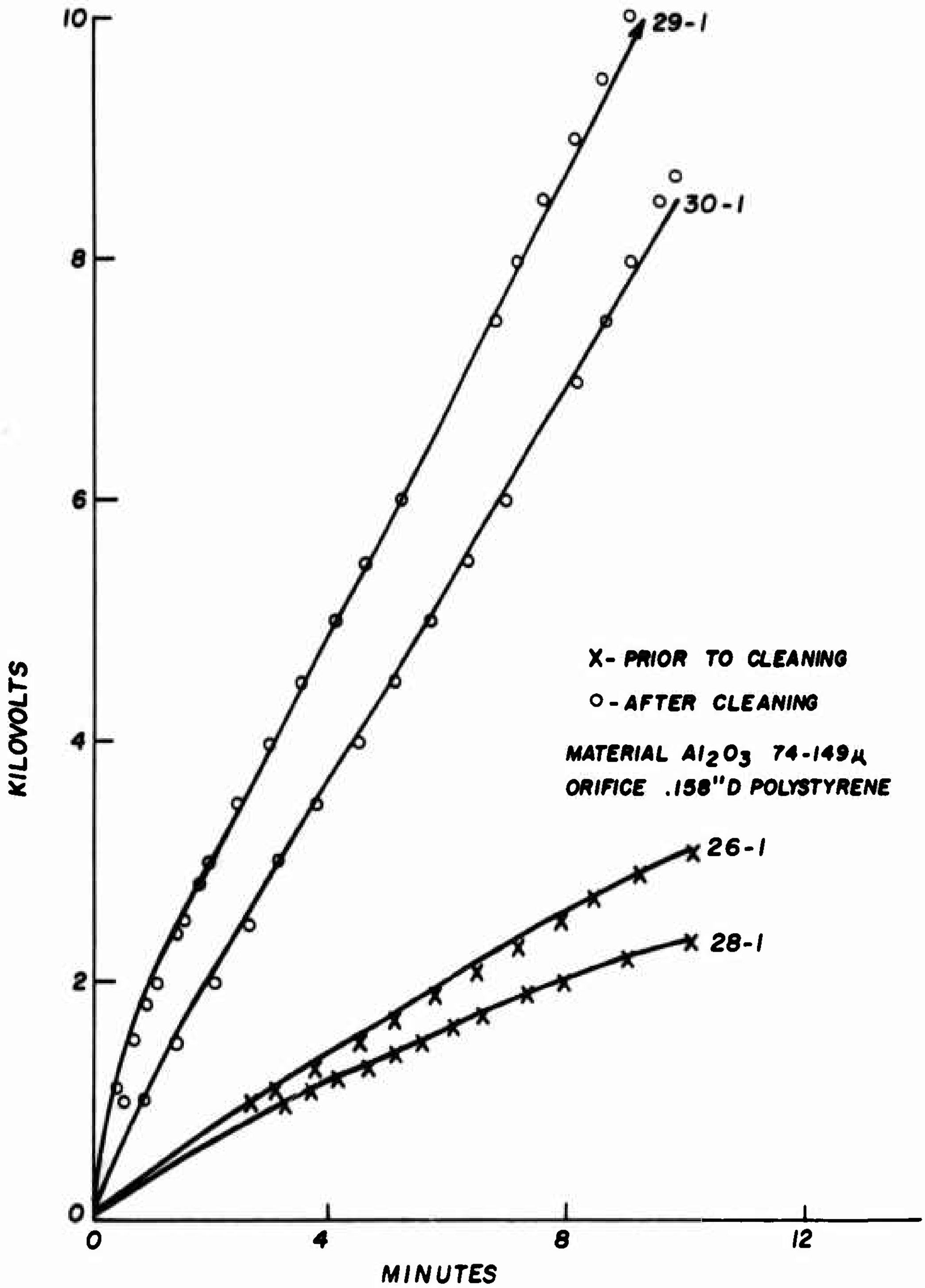


Fig 8 Curves show the effective charge buildup as a result of friction cleaning of apparatus

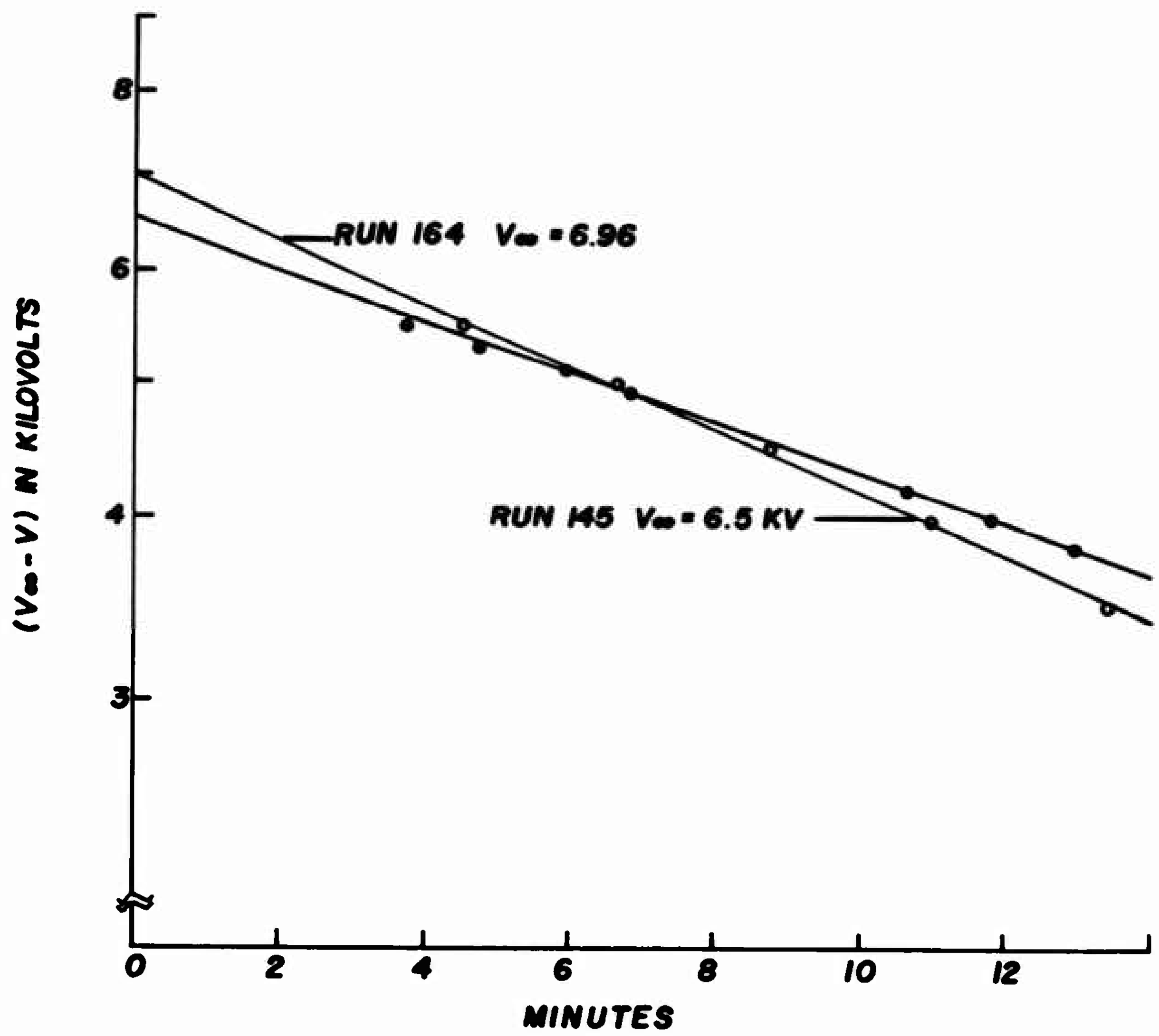


Fig 9 Charge rate plot for V_∞ equal to 6.5 and 6.96 kv

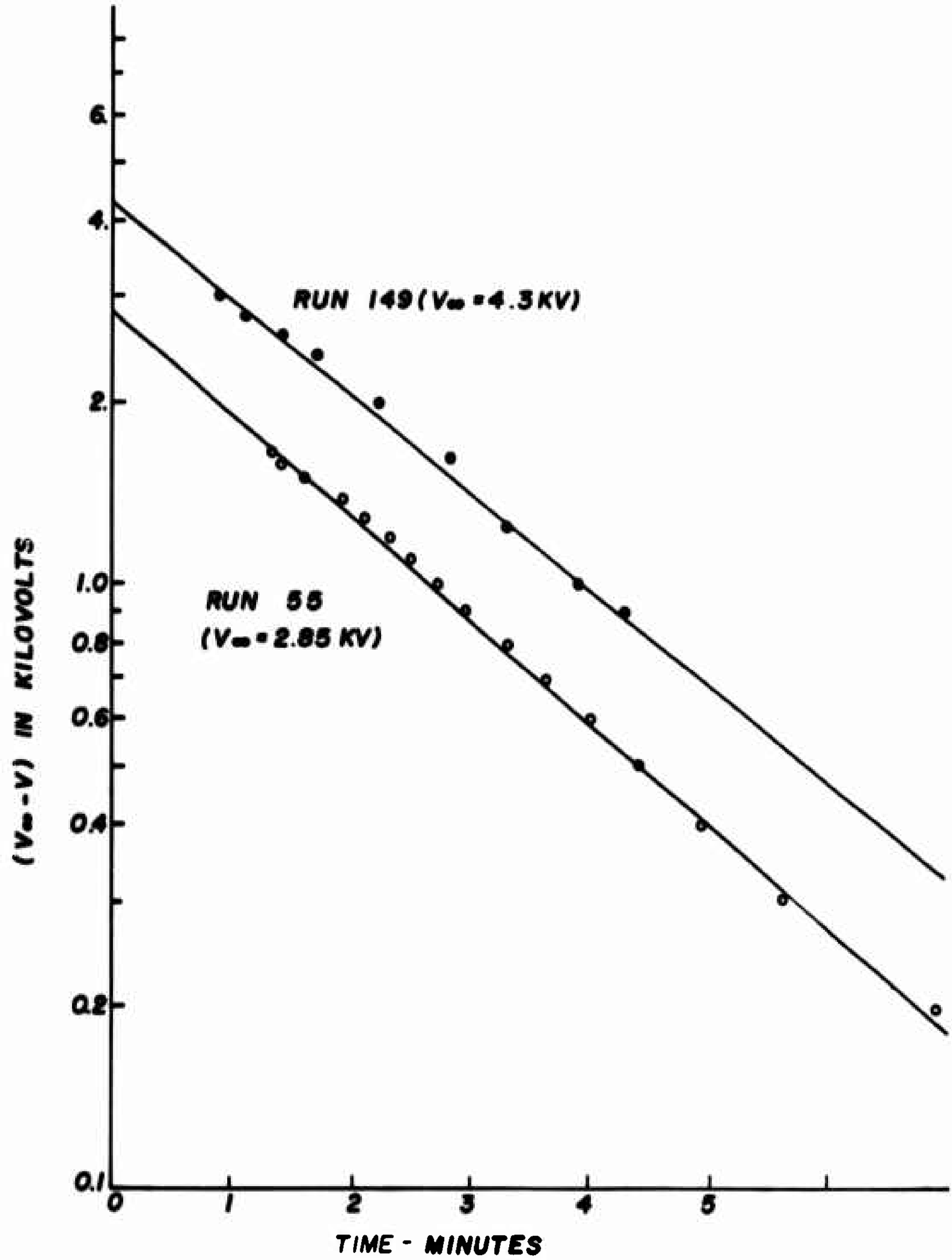
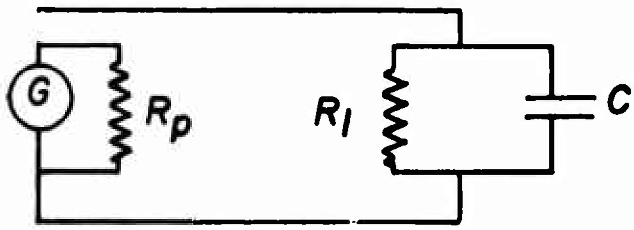


Fig 10 Charge production rate for V_∞ equal to 4.3 and 2.85 kv

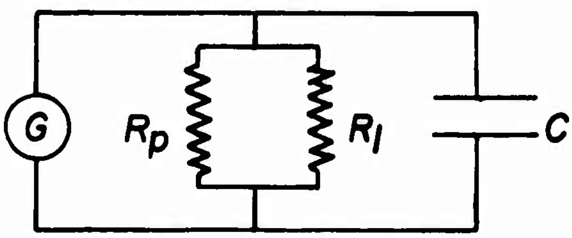
APPENDIX

Electrostatic Charge Buildup by Falling Powders

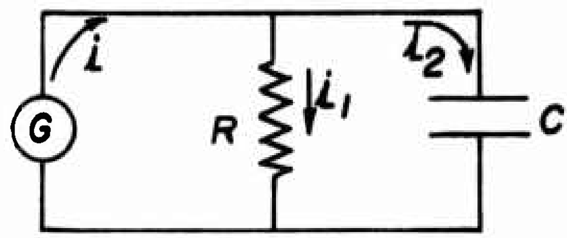
Postulate that a steady stream of powder, consisting of particles of a normal, non-conducting insulator, if falling from one equipotential conducting surface to another. Assume that this stream of powder does two things: First, it carries a constant amount of charge Δq from one surface to the other per unit time Δt. Second, assume that it has a constant resistance R_p which is finite when the stream is flowing and infinite when it is not. Also, let C be the capacity and R_l the leakage resistance between the two equipotentials. In circuit theory terminology, the falling charge is a constant charge generator G shunted by a resistant R_p, and the entire system is represented by the diagram.



This is equivalent to



or



where $R = 1/R_p + 1/R_l$.

Since the generator produces a charge Δq in the time Δt, it can be regarded as a constant current generator producing a current $i = \Delta q/\Delta t$. Then i = current through resistance R + current into capacity C, or

$$i = i_1 + i_2$$

The potential across R is simply Ri_1, which must be equal to the potential across the condenser C; call this V(t), where t is the time, or

$$i_1 R = V(t), \text{ and } i_1 = V(t)/R$$

At any time t the potential across C is

$$V(t) = \frac{1}{C}\int_0^t i_2 dt \text{ or } \frac{d}{dt}V(t) = \frac{1}{C} i_2$$

and $i_2 = C\frac{dV(t)}{dt}$

Thus $i = i_1 + i_2 = \frac{1}{R} V(t) + C\frac{dV(t)}{dt}$

$$i = \frac{1}{R} V + C\frac{dV}{dt}$$

$$\left(i - \frac{V}{R}\right) = C\frac{dV}{dt}$$

or

$$\frac{1}{C} dt = \frac{dV}{\left(i - \frac{V}{R}\right)}$$

Since i is a constant, this may be integrated directly.

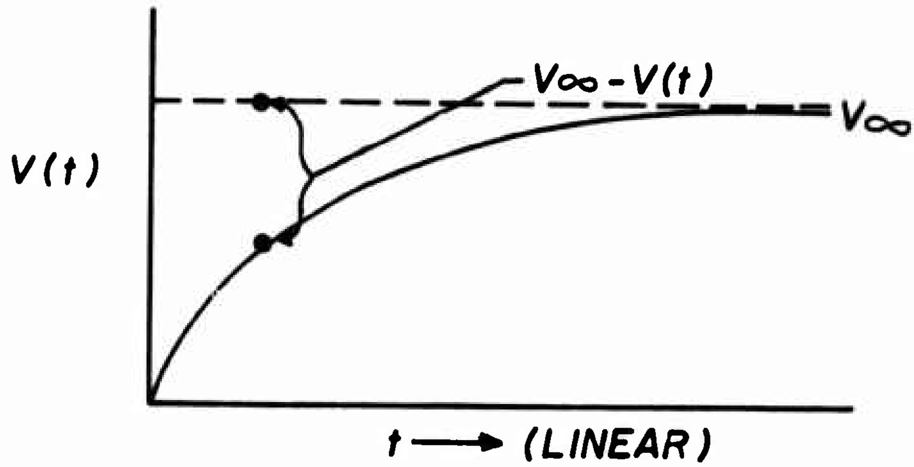
Putting V(t) = 0 at t = 0, the solution is

$$V(t) = iR\,(1 - e^{-t/RC})$$

for t large, i.e., t > > RC, $e^{-t/RC}$ becomes zero, and

$$V(t) = V_\infty\,(1 - e^{-t/RC}) \qquad (1)$$

where $V_\infty = iR$



Equation 1 can be written

$$\ln\left(1-\frac{V(t)}{V_\infty}\right) = -\frac{1}{RC}\,t \qquad (2)$$

Thus a plot of $\ln\left(1 - \frac{V(t)}{V_\infty}\right)$ against t will have slope $-1/RC$. Since C can be measured, R can be computed from the slope and thus i, the charge production rate, can be computed from V_∞ or iR.

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13. ABSTRACT

Many automatic loading machines permit explosives to fall freely through orifices. Since, however, numerous unexplained detonations have occurred in the course of this operation, measurements have been initiated to determine whether the falling powders can build up an electrostatic charge sufficient to initiate explosions. A simple system has been designed to determine to what extent the charge buildup depends on the nature of the falling powder, its size, its flow rate, or the orifice size, the orifice material, the orifice geometry, or other factors such as the effects of various pretreatments on the powder, e.g., drying, ball-milling, the relative humidity of the surrounding air, etc. Preliminary measurements indicate very clearly that voltages of the order of 7-9 kilovolts are developed and that the total energy available in the built-up charge is roughly 10^{-3} joules. This voltage and energy is sufficient to detonate common primary explosives. Furthermore, the rate of charge buildup can be explained by a very simple theory which assumes that the falling stream acts as a constant current generator. However, it is not known why the falling powder would act in this manner, and consequently the physical process responsible for the charge buildup is still not understood. It therefore is suggested that a program be initiated to investigate basic electrostatic processes in both explosives and inert materials.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Explosive loading Automatic loading machine Primary explosive Electrostatic charge Ballmilling Explosions Impact sensitivity Friction sensitivity Freely falling powder Charge buildup Aluminum oxide Metal orifice Relative humidity						

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