AN ALTERNATIVE APPROACH FOR CHARGE DECAY MEASUREMENT TO ASSESS THE SUITABILITY OF MATERIALS

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Abstract

A method of charge decay testing is proposed in which a localized electric field is applied by a fieldmeter to an area of the material to be tested. The variation of electric field is recorded as charge migrates across the surface. Arrangements are described for this method of testing and studies reported comparing results with corona and tribocharge decay measurements. Interesting differences are shown between the methods of testing.

Induction charge decay testing is not proposed as a replacement for corona or tribocharge decay testing. It offers the opportunity for simpler instrumentation and measurement of faster charge decay times.

Keywords: Charge decay testing; Assessment of materials; Measuring instrumentation

1. INTRODUCTION

The measurement of charge dissipation, or charge decay, in conjunction with measurement of capacitance loading provides the appropriate way to assess the electrostatic suitability of materials [1]. 'Suitability' being judged in terms of the avoidance of significant surface voltage on a surface resulting from interaction with other surfaces or sources of charge. This method of assessment is more appropriate than traditional measurement of resistivity. Resistivity shows the fastest route by which charge can migrate over, or through, a material. Charge dissipation reveals the slowest route - and hence reveals the opportunity for charge to be retained and so maintain significant surface voltages following tribocharging actions.

A number of methods have been developed that aim to measure charge decay. Many of these are actually not suitable for assessing the suitability of materials and few either involve observation of the decay of tribocharge or have been shown to give results that match tribocharge decay [2,3]. The use of a high voltage corona discharge to deposit a localized patch of charge on the material to be tested and then a fieldmeter to observe how quickly the surface voltage created decreases has been shown to be a versatile and practical way to assess materials [4]. This method is described in Standards documentation [5].

While corona charge provides a method of measurement that can be easily be used on a wide variety of materials (including powders and liquids) the instrumentation involves appreciable mechanical complexity. To make measurements of decay times desirable for the effective limitation of static risks (well below 1s) it is necessary to mount the corona discharge electrodes on a plate that shields the fieldmeter from the corona voltages and yet can be moved away quickly so the fieldmeter can observe the surface voltage created and its decay. Instrumentation that has been developed achieves removal of this shielding plate in about 20ms and using a fast response field mill fieldmeter enables decay times to measured down to below 50ms [4,6].

The present paper is concerned with an alternative method of measuring charge decay that does not involve the use of a high voltage corona and can be implemented within much simpler instrumentation. The method of measurement is described together with the results of preliminary studies on a number of materials. Comparative tests are also described based on corona charge decay and tribo charge decay measurements.

2. INDUCTION CHARGE DECAY MEASUREMENT

The basic arrangement for the new method for charge decay measurement is illustrated in Figures 1. The fieldmeter is positioned close to the surface to be assessed. The surface is supported with an open backing and is initially at earth potential. A step voltage is applied to the fieldmeter. The localized electric field created by the voltage difference between the fieldmeter and the surface causes charge to migrate across, and perhaps through, the sample surface. The basic form of the fieldmeter response is illustrated in Figure 2. There is an initial fast step in the fieldmeter response followed by a slower rise towards the level that would apply if the sample surface were a fully conducting earthed surface. The size of the initial fast step in the fieldmeter response is partly due to the field created at the sensing aperture in relation to its structural earthed surroundings and partly to the dielectric constant and any very fast charge migration features in the sample surface – such as, for example, conductive threads in specialized fabrics. The form of the slower change of fieldmeter output after the initial step reflects the rate and character of the charge migration across and through the sample surface. It is this feature that is relevant to assessment of the suitability of materials and is the feature to be examined.

The main prospective advantages of this approach in comparison to corona charge decay measurement are:

a) the avoidance of the need for the mechanical arrangements for fast removal of the fieldmeter shielding plate carrying the corona discharge points

b) avoidance of the need for as high voltages as needed for creating suitable corona discharge charging

c) opportunity, with a fast response fieldmeter, of measuring much shorter charge decay times than is feasible in corona charge decay

d) avoidance of any influence of residual air ionisation.

The main prospective limitations are:

- the need for the fieldmeter signal processing circuits to be stepped in voltage with transfer of observations back to any ground level data analysis, storage and display facilities
- the lower electric fields likely to be available for measurement with certain materials requiring higher signal to noise performance from the fieldmeter. In particular this will limit the opportunity to study charge decay on samples with an earthed backing and with close patterns of embedded conductive threads – which are desirable capabilities [5].

The above approach may appear to have similarities to IEC1149-3 [7] but is significantly different. The most important differences are a) that the induction charge decay method induces charge and makes observations for the same side of the surface to be tested, and b) that the main function of IEC1149-3 is to assess the shielding capabilities of materials. (An alternative approach for assessing shielding performance has been developed and described [8]).

An approach based on signal decay after exposure to a limited period of induction charging is not an appropriate as a general method for assessing the suitability of materials [9]. The reason is, of course, because features where charge migration is very slow may not become fully charged, so they are not fairly assessed.

3.EXPERIMENTAL ARRANGEMENTS FOR TESTING

3.1 Arrangements for induction charge decay testing

The performance of the induction charge decay approach described was examined using the set up illustrated in Figure 3. A JCI 140 Static Monitor [10] was used as a fieldmeter. The signal output on the sensitivity range used for induction charging studies was 1.0V output for an electric field of 23kV m^{-1} at its sensing aperture. For the tribocharging a sensitivity a tenth of that was used. The fieldmeter response time was -3dB at 100Hz.

The fieldmeter was mounted on insulation down from the top of an earthed shielding enclosure 200mm diameter at its lower end. The base of this shielding enclosure rested on the surface of the sample to be tested. The gap between the sensing aperture of the fieldmeter and the plane of the sample surface was 20mm. Beneath the sample was 150mm diameter open aperture earthed support surface for supporting and earthing the boundary of the sample.

The fieldmeter was linked to a Picoscope 3224 digital oscilloscope that was linked to an Apple MacBook laptop computer. Observations were displayed and recorded using Picoscope 6 software running within a partitioned Windows XP operating system.

The MacBook was run on its batteries (for electrical isolation) and the Picoscope was powered via its USB link to the MacBook. The Picoscope and computer were supported on a metal tray that was stood off from the bench surface to keep its capacitance to ground low.

The fieldmeter and the support tray for the Picoscope and computer could be quickly stepped up in voltage from earth by switching connection from earth to the output of a Monroe Model 214 high voltage supply unit that provided voltages of either polarity to be applied in steps of 1V, 10V, 100V and/or 1000V up to ±3kV. For the induction charge decay studies a voltage of 600V was used and with the particular fieldmeter geometry used this gave an electric field about 35kV m^{-1} at the fieldmeter sensing aperture with an earthed metal sample surface.

No control was available for the temperature and humidity of the test environment. To minimise risk of change in material characteristics in comparative tests between induction, corona and tribo charge decay measurements these tests were made soon after each other with some interlacing to examine consistency in performance. Care was also taken to minimize handling of test areas and to avoid breathing on to sample surfaces.

For each period of induction charge decay testing the step voltage applied was kept stable at a defined value. Observations were recorded of the fieldmeter response in the absence of any test sample and when a metal conducting surface was used. These observations provided the reference signal levels. With some samples it was practical to pursue testing of until they reached an asymptotic level, as illustrated in Figure 2. Where this was not practical measurements with the fully conducting surface provided the end point reference for pursuing decay time calculations.

3.2 Arrangements for corona charge decay testing

Corona charge decay measurements were made using a JCI 155v5 Charge Decay Test Unit [3,6]. Samples were supported in a JCI 176 Charge Measuring Sample Support. This provided the facility to measure the corona charge transferred to the test surface and from this the capacitance loading could be calculated [3,11]. Observations were analysed and displayed using JCI-Graph software [3].

3.3 Arrangements for tribocharge decay testing

Tribocharge decay tests were carried out with the same basic arrangement as used for the induction decay tests with one side of the shield lifted so the central region of the fabric could be touched or lightly impacted with a woolen sock tightly wrapped around the handle of a thin wooden spoon that was then quickly withdrawn. The arrangement was similar to that used in earlier studies [3].

3.4 Sample materials

Three sample materials were tested: a cotton handkerchief, an area of cling film and an area of blue artificial fabric. Each sample was tautly supported to minimize the risk of movement of the sample surface during a test due to electrostatic attraction to the fieldmeter.

The ambient humidity over the period of testing was quite high – 65 to 75% and not necessarily constant during any one day. This limited the range of testing opportunities and consistency of results with the materials readily available.

Attempts were made to test a sample of a cleanroom garment fabric with a 5mm stripe pattern of included conducive threads. While corona charge decay tests indicated decay times that would have been useful, the high capacitance loading provided by the conductive threads meant that the voltage for the start of decay was too close to the maximum of that for a metal surface for sensible measurements. This illustrates one feature limiting application of induction charge decay measurements.

4. TEST RESULTS

Induction charge decay observations were analysed by transferring the Picoscope data, recorded as .csv files, into an Excel spreadsheet with observations displayed as a graph of fieldmeter output voltage versus time. Examples of induction and corona charge decay graphs for cling film are shown in Figures 3 and 4. The voltage and the time for the start of the induction charge decay were taken as that at the beginning of the smooth part of the rising signal, after the initial fast rise – as indicated in Figure 2. The end point voltage was taken as that provided by observations with a flat metal sample surface. The 1/e and the 10% voltage decay levels were then calculated as fractions of this difference and these values and associated times found in the spreadsheet list of fieldmeter voltages. The values obtained for the 3 samples tested are shown in Tables 1, 2 and 3.

Tribocharging observations were analysed in basically the same way as the induction charge decay observations. It was only practical to make tribocharging measurements with the blue fabric because decay times with the cling film and cotton surfaces were too fast compared to the time for charging, removal of the charging surface and resetting the position of the shield mounting the fieldmeter. Results for the blue fabric are shown in Table 1.

Corona charge decay observations were analysed using the software JCI-Graph to obtain decay times to 1/e and to 10%. Examples of decay curves for cling film are shown in Figure 4.

5. DISCUSSION ON RESULTS

The results for the three materials tested in Tables 1, 2 and 3 show there are differences in charge decay times between the three methods of test. In particular:

- Induction charge decay measurements with the blue fabric seem broadly comparable to tribocharge decay results but both are definitey longer than decay times measured by corona charge decay.
- With cling film induction charge decay times are definitely shorter than decay times measured by corona charge decay – particularly to the 10% end point level.
- With the cotton fabric decay times seem more comparable between induction charge decay and corona charge decay.
- Each set of measurements was fairly self-consistent. Variations between days may well have been due to charge of humidity and/or different areas of sample tested.

Direct comparison between the three methods of charge decay testing is not simple. The delay between the end of charging and the time at which the voltage is taken for the start of the decay is a bit different between the three methods. This may affect calculation of decay times because the rate of decay usually slows up progressively during the progress of charge decay. With induction charging the decay starts within a ms or so of application of the charging voltage. With corona charge decay there is the delay of about 20ms between the end of corona charging and the peak signal observed. (This is due to the time needed for the plate carrying the corona discharge points and shielding the fieldmeter to move fully out of the field of view). With tribocharge decay there was about a ½s delay between the end of charging and observation of the peak voltage, associated with the time needed to remove the charging surface and seat the fieldmeter and shield back down on the surface. In the studies with the blue fabric an attempt was made to examine if this delay would significantly affect results calculated for the corona charge decay tests. For the analysis in JCI-Graph a delay of 0.5s was introduced between the end of charging and the selection of the decay timing start. The results are shown in the right hand pair of columns in Table 1. While these show a delay in the start of decay timing gives longer decay times it is clear that corona decay times remain definitely shorter than induction and tribocharge decay results for the blue fabric.

Differences between the three methods of testing might arise if there is some difference in the species of charge migrating with the different methods of charging, if there is difference in the microscopic distributions of charge at the surface or if there is any influence from the area charged and the area of the sample. The response time of the fieldmeter did not have any influence in the present studies because this time is short compared to all the other times involved – as shown by the fast initial rise of signal in the induction and corona charge decay tests.

It would be useful to pursue comparison between charge decay performance from induction, tribo and corona charging with a wider variety of materials. This could be relevant to the development of Standards. The approaches of scuff and ball dropping charging may be useful for achieving quick response and good quality measurements in tribocharging studies [3,12].

6. COMMENTS ON PRACTICAL APPLICATION

The method of induction charge decay described provides a simpler way to assess the characteristics of materials than tribo or corona charge decay. It is however not as generally applicable as the corona charge decay method. One basic limitation is that the level of the ‘zero’ signal to be used in assessing decay curves is not as simply defined. For a plane sample surface (for example a stretched area of fabric) the ‘zero’ can be well defined by measurements using a plane conducting sample surface. This defines the level to which the fieldmeter readings will eventually rise during ‘decay’. With non-plane surfaces it is not as easy to establish this end point ‘zero’ unless one can feel sure that the decay has reached an asymptotic top level. With corona and tribo charge decay the zero is defined by the zero of the fieldmeter, which can be determined just before each test and checked independently.

When studying light flexible materials it is necessary to ensure these are held taut to reduce the influence of movement of the sample surface under electrostatic attraction. Any movement of the sample surface as the electric field between the sample and the fieldmeter decreases could affect the effective ‘zero’ level. Such problems do not arise in tribo or corona charge decay measurements where there is a larger separation distance between the sample surface and the fieldmeter - so electrostatic forces are much smaller and the ‘zero’ is well defined by a zero initial charge condition.

As much lower voltages are used in induction charge decay measurements than in corona charge decay the fieldmeter signals will be much smaller. This means that decay time measurements to a 10% end point level require a fieldmeter with particularly good signal to noise ratio and the use of an appropriate technique for accurate time measurement in the presence of signal noise (for instance stutter timing [13]).

7. CONCLUSIONS

The method of induction charge decay testing described has been shown to produce fairly consistent results in repeat tests with each of the three materials tested. Comparison of results with the limited range of materials tested with induction, corona and tribo charge decay measurements indicate:

- Induction charge decay results with a blue fabric artificial fibre fabric are comparable to tribocharge decay results, but are longer than measurement from corona charge decay.
- Induction charge decay times with cling film are definitely shorter than decay times from corona charge decay.
- Results with the cotton fabric show similar decay times between induction charge decay and corona charge decay.

Induction charge decay is not proposed as a replacement for corona or tribocharge decay testing. The definitive test remains tribocharge decay measurement, but this is often not practical or convenient and involves more difficult experimental test arrangements. Induction charge decay measurement does offer the opportunity for simpler instrumentation, opportunity to measure faster charge decay times and avoids any influence of air ionization.

It is concluded that the induction charge decay method of testing materials described warrants fuller investigation – in particular regarding apparent differences in charge decay behaviour between induction, tribo and corona charge decay measurements. If confirmed, these differences are relevant to the definition of Standard methods of test for assessing the suitability of materials.

References:

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Table 1: Artificial fibre blue fabric

Test reference	Induction charge decay		Tribocharge decay		Corona charge decay			
					from peak		with 0.5s delay	
	1/e	10%	1/e	10%	1/e	10%	1/e	10%
40346 (22/03/14)					7.8	58	10.4	
20140322-001	24	98						
20140322-004			34	165				
20140322-005			36.5	152				
20140322-006			40.5	150				
40347 (22/03/14)					13.9	-	18.5	
40348 (22/03/14)					11.2	-	13.34	
20140322-0007	43	111						
40361 (28/03/14)					33.6	179	46	182
40362 (28/03/14)					26.6	120	37	146
20140328-0001			71	300				
20140328-0002			74	301				
20140328-0003	96	264						
20140328-0004	94	210						
40363 (28/03/14)					22.6	95	24	

Table 2: Cling film

Test reference	Induction charge decay		Tribocharge decay		Corona charge decay	
	1/e	10%	1/e	10%	1/e	10%
40339 (17/03/14)					0.062	0.233
40340 (17/03/14)					0.061	0.215
40349 (22/03/14)					0.085	
40350 (22/03/14)					0.056	
40351 (22/03/14)					0.051	
40354 (25/03/14)					0.054	0.262
20140325-0002	0.031	0.067				
40356 (25/03/14)					0.055	0.252
20140325-0003	0.024	0.060				

Table 3: Cotton handkerchief

Test reference	Induction charge decay (s)		Tribocharge decay (s)		Corona charge decay (s)	
	1/e	10%	1/e	10%	1/e	10%
20140326-0001	0.022	0.055				
20140326-0002	0.021	0.053				
20140326-0003	0.020	0.052				
40359 (26/03/14)					0.014	0.047
40360 (26/03/14)					0.014	0.047
20140326-0004	0.020	0.053				
20140326-0005	0.020	0.051				

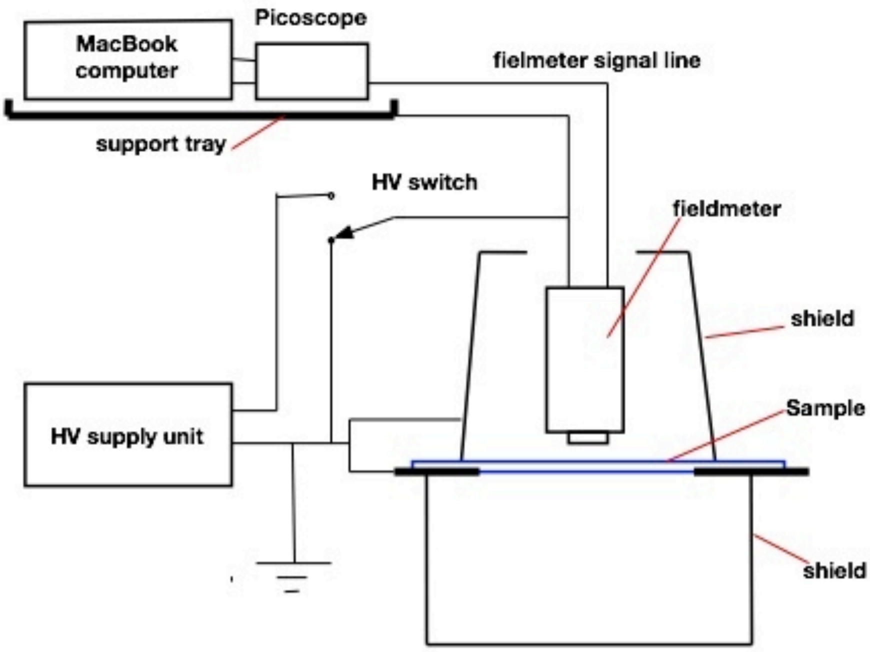


Figure 1: Arrangement for induction charge decay testing

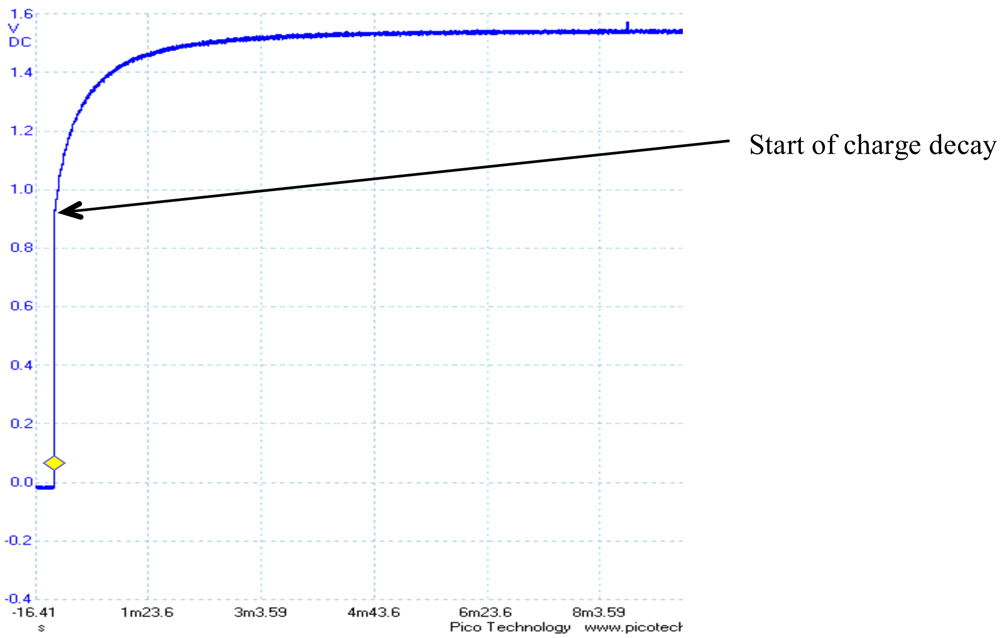


Figure 2: Response of fieldmeter to step function application of voltage. (Picoscope record of 600V induction charging test on taut surface of blue fabric 20140322-0001)

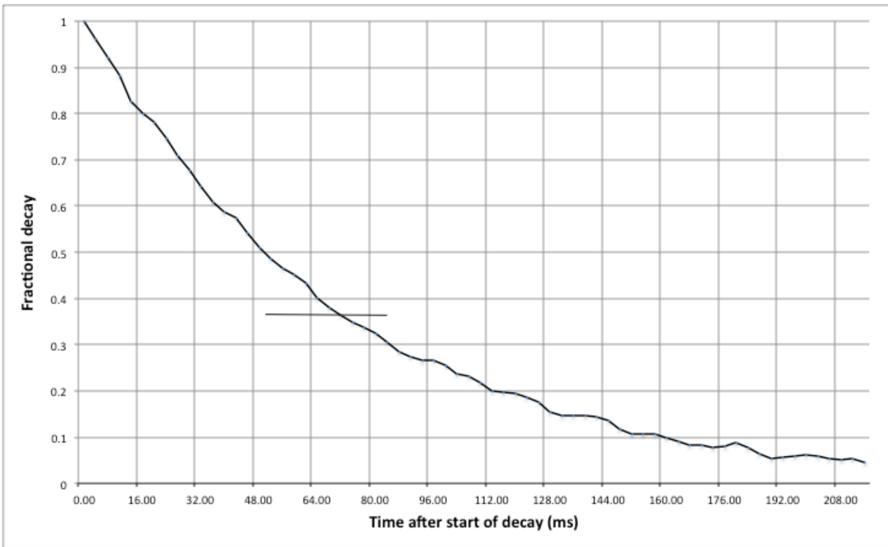
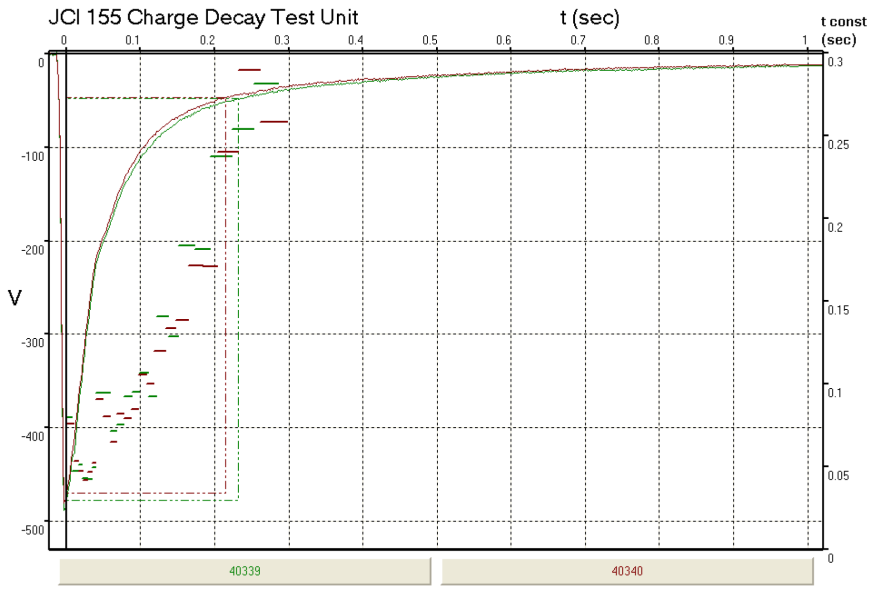


Figure 3: Analysis of decaying portion of induction charge decay with cling film. Time to 1/e about 70ms.



1 : C:\Documents and Settings\John Chubb\06032310\06032310\2014-03-17\00040339.jc5
Cling film
Serial: 06032310, run: 00040339
Date: 17.03.2014 at 20:02:33
Corona (Voltage): -6000
Corona (Time): 0.019 s
Surface (Temp. °C): 20
Surface (% R.H.): 62.55
Pretest (Voltage): 0.3
Peak at -477.4 volts
1/e reached after 0.063 sec
10% reached after 0.233 sec
Received charge = -7.09 nC
Capacitance loading = 6.38

2 : C:\Documents and Settings\John Chubb\06032310\06032310\2014-03-17\00040340.jc5
Cling film
Serial: 06032310, run: 00040340
Date: 17.03.2014 at 20:03:56
Corona (Voltage): -6000
Corona (Time): 0.019 s
Surface (Temp. °C): 20
Surface (% R.H.): 62.18
Pretest (Voltage): -0.91
Peak at -469.5 volts
1/e reached after 0.061 sec
10% reached after 0.215 sec
Received charge = -7.11 nC
Capacitance loading = 6.52

Figure 4: Corona charge decay measurements with cling film and analysis