Short communication

Analysis of long corona charge decay times

John Chubba,*, Harold Walmsley

a Infostatic Ltd, 2 Monica Drive, Pittville, Cheltenham, GL50 4NQ, UK
b Harold Walmsley Electrostatics Ltd, 31 Fairways, Frodsham, Nr Warrington, WA6 7RJ, UK

1. Introduction

Assessment of the electrostatic suitability of materials by observation of corona charge decay is most directly made in terms of the decay time to 1/e or to 10% of the initial peak surface voltage achieved at the end of the charging action [1]. For materials with decay times up to 1000 s or so this is fine, but with many materials (notably pharmaceutical powders and electrostatic paint powders) decay times may be up towards a million seconds. It is not usually convenient to pursue observations over such times. The present paper is concerned with the opportunity to predict decay times to 1/e or to 10% from observations that only extended far enough to achieve these decays. The approach involves simple numerical processing of the rate of increase in the local charge decay time constant with time and the intercept of this at some selected time. This analysis is useful for assessing and comparing materials that have decay times over say 10^3 s.

Studies on materials with long charge decay times (notably pharmaceutical powders) have shown that the local charge decay time constant comes to increase linearly with time during the progress of charge decay. This is an empirical result. This linear increase provides the basis for calculating the time to 1/e and/or to 10% from much shorter periods of observation than the times to achieve these decays. The approach involves simple numerical processing of the rate of increase in the local charge decay time constant with time and the intercept of this at some selected time. This analysis is useful for assessing and comparing materials that have decay times over say 10^3 s.

The 'local decay time constant' values are derived by dividing the voltage decay curve into a number of short time segments and comparing materials that have decay times over say 10^3 s.

What has been clear from studies on a wide variety of materials over many years is that the variation of the local decay time constant with time has a definite form: after an initial settling down period the local decay time constant increases linearly with time. This is an empirical result – and no theoretical backing is offered at this time. On the basis of this behaviour it was recognized that if it is observed that the local decay time constant increases linearly with time then it should be possible to predict decay times to 1/e or to 10% from observations that only extended far enough to provide a period of a good quality linear variation. This paper is concerned with assessment of this prospect.

Corona charge decay curves, as observed in studies using JCI 155v5 charge decay test instruments, have been compared to a number of theoretical forms [4–6] and to particular experimental studies [7]. No match in the form of these decay curves is observed. The present analysis is proposed as appropriate where it is found that if it is observed that the local decay time constant increases linearly with time then it should be possible to predict decay times to 1/e or to 10% from observations that only extended far enough to provide a period of a good quality linear variation. This paper is concerned with assessment of this prospect.

2. Theoretical analysis

After an initial settling down period the local decay time constant \( \tau \) comes to increase linearly with time, \( t \), from an initial time constant value \( \tau_0 \) where the straight line relationship starts as: \( \tau = \tau_0 + t \frac{d\tau}{dt} \) (1)
The governing equation can be written in terms of the surface voltage $F$ as:

$$\frac{d\ln(F)}{dt} = \frac{1}{C_0} \left( s_0 + kt \right)$$

(2)

where $k = \frac{d}{dt}$ and $s_0$ is the initial value of the time constant. This approaches the standard exponential decay equation as $k$ tends to 0.

Eq. (2) has the solution (readily verified by taking logs and differentiating):

$$\frac{\phi}{\phi_0} = \left( 1 + \frac{kt}{s_0} \right)^{-1/k}$$

(3)

As $k$ tends to zero, Eq. (2) tends, as it should, to the standard exponential form for constant $s_0$.

Rearranging Eq. (3) gives:

$$t = \left( \frac{s_0}{k} \right) \left[ \left( \frac{\phi}{\phi_0} \right)^{1/k} - 1 \right]$$

(4)

Where $\phi_0/\phi = 2.718$ (e) for decay to 1/e and $\phi_0/\phi = 10$ for decay to 10% (note: the ratio is the initial voltage over the final). Numerical values for these decay times are to be obtained from best straight lines fits to experimental data to give $s_0$ and $k$. The value of $s_0$ is obtained from the decay time constant value at the point where the variation of local decay time constant becomes linear and the value of $k$ from the slope of the best fit straight line.

### 3. Comparison of theory to experimental observations

As was noted above (and is illustrated in Fig. 1) that the linear increase in local decay time constant only starts after an initial settling down period. The above analysis is restricted to the time after this and the time to this point is added on to the calculated decay time to give the total predicted time to 1/e and/or to 10%.

A number of charge decay records have been analysed where there has been opportunity to compare predictions with actual decay time measurements. An example of straight line fitting is shown in Fig. 2. Values for $s_0$ and $k$ are derived from this fitting. The results with the results of three predictions shown in Table 1 show that decay times can be predicted with some confidence even though the accuracy is not high – within about 5% for the examples shown. Further studies are needed to establish the accuracy of prediction when the period of observation is only a modest fraction of the decay time value to be estimated. The accuracy of prediction will be dominated by the accuracy of fitting of the straight line to the variation of local decay time constant after the initial settling down period. This will depend on the quality of the voltage decay curve observations and extension of the period of fitting. Accuracy could be estimated from analysis of the fitting errors. In conducting practical studies this might be used as a way to decide how long it is necessary to proceed with individual charge decay tests.

The initial ‘settling down period’ may well be associated in practical materials and surfaces with faster migration of charge via some secondary component. This is often shown in voltage decay curves that initially fall quite quickly and then ‘plateau out’. In such cases it seems reasonable to expect that the fraction of the long decay time component might be estimated from the intercept of the plateau voltage compared to the initial peak voltage.

### 4. Conclusion

An approach has been described that provides a way to predict charge decay times to 1/e and/or 10% from periods of testing that are appreciably shorter than these times. The approach involves simple numerical processing of the rate of increase in the local charge decay time constant with time and the intercept of this at some selected time. This is of considerable value in the testing and assessment of materials where charge decay times may be up in the range $10^4$–$10^5$ s.

### References