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Leakage Current and Charge in RTV Coated Insulators Under Pollution Conditions

D. Devendranath*, Channakeshava* and A.D. Rajkumar**

Room temperature vulcanizing (RTV) silicone rubber coating has excellent leakage current suppression characteristics. It is used extensively on porcelain and glass insulators in pollution prone areas as an anti-pollution measure. A pollution aging chamber has been fabricated and an on line 4 - channel personal computer (PC) based data acquisition system has been developed to conduct tests on RTV coated porcelain samples. A study of the dependence of the leakage current and the charge on the flow rate, conductivity and pressure of the solution forming the fog is reported. It was observed that a higher charge and a higher average leakage current were obtained at a higher flow rate and a higher conductivity. The results with coated HV insulators are consistent with those published in the literature with RTV coated fiber glass reinforced plastic (FRP) rods.

1.0 INTRODUCTION

The pollution performance of outdoor insulation systems is important for high reliability of power transmission systems. Since flashover is triggered by pollution deposits of marine, industrial, desert, and agricultural origin etc., considerable effort has been put into the development of insulators and coatings that will resist flashover in contaminated areas. Anti-pollution measures like the application of semi-conducting glazes[1], greasing and water washing of insulators, though effective, demand a stiff schedule of maintenance. One of the recent practices is to use room temperature vulcanizing (RTV) silicone rubber on high voltage ceramic/glass insulators for imparting better anti-pollution properties[2].

Silicone rubber has good dielectric properties over a wide temperature range, and offers excellent resistance to thermal degradation, corona discharge, etc. Silicone rubber acts as a good water repellent owing to its low surface energy[3]. This type of rubber coating is widely used in North American utilities and in some parts of India.

Kim and Hackam[4] have conducted tests on RTV coated fiber glass reinforced plastic (FRP) rods. They correlated the leakage current, pulse count and total charge with different flow rates of saline water and air pressure used to create the fog. Kim, Cherney and Hackam[5] applied RTV coatings to porcelain suspension and line post insulators for a comparative study of the performance of coated and uncoated insulators.

The present work is undertaken to understand the behavior of RTV coated insulators when they are subjected to varying flow rates, air pressures and fog conductivity in a pollution aging chamber. The results are compared with the published literature on FRP rods. The data obtained from these tests may be used in formulating a standard test procedure, which is still eluding workers in the field.

*Central Power Research Institute, UHV Research Laboratory, P. B. No. 9 Uppal, Hyderabad 500 039, India
**Electrical Engineering Department, Osmania University, Hyderabad 500 007, India

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2.0 EXPERIMENTAL TEST SET-UP

2.1 Test chamber

The test chamber, size $2 \times 2 \times 2.5\,m^3$, was made of stainless steel. A 400 V / 33 kV, 66 kVA, single phase 50 Hz transformer which conforms to IEC 507, 1991 specifications was used as the test source. Two IEC nozzles on each side were used as shown in Fig. 1. The RTV sample was mounted in the middle of the chamber. The test voltage applied to the samples was $7.0\,kV_{rms}$.

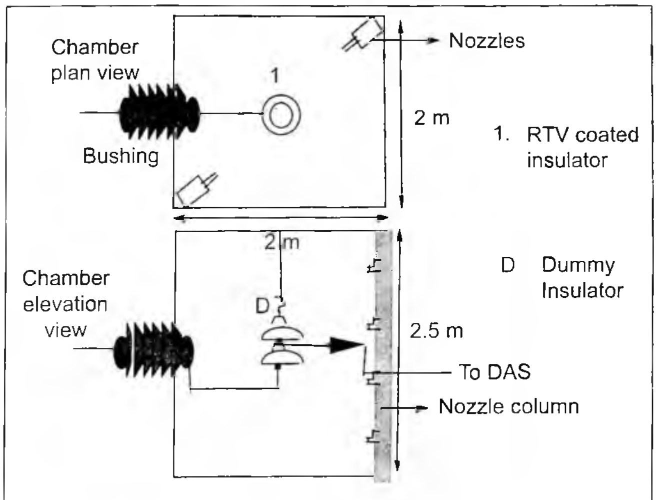

FIG. 1. TEST CHAMBER

2.2 Data acquisition system

The data acquisition system (DAS) employed a personal computer (PC) operating at 166 MHz with 16 MB memory and LABVIEW software. The DAS consists of data acquisition hardware (DAQ) and a PC based current integrator.

2.2.1 Data acquisition (DAQ) hardware

The block diagram of the DAQ hardware is shown in Fig. 2. An isolation amplifier, with a gain of 0.5, has been used to give isolation up to 1500 V. The isolated signals are passed to an eight-channel simultaneous sample/hold amplifier board. Isolation amplifiers and the sample/hold amplifier are external to the PC. A multifunction data acquisition card plugged into the I/O slot of the PC controls the simultaneous sample/hold operation. While in hold mode the multifunction card is programmed to perform multiplexing and A/D conversion of the 8 analog inputs. The A/D converter has a resolution of 12 bits and a maximum sampling rate of 1.25 MS/s.

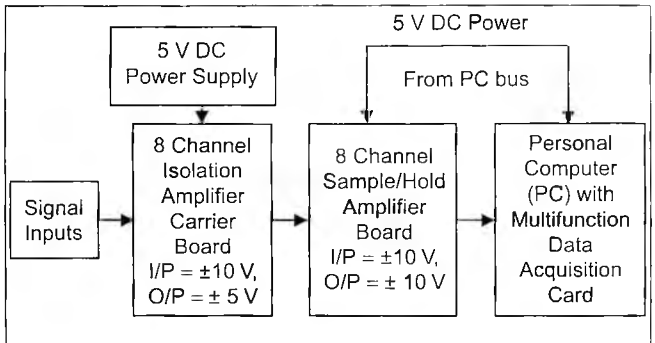

FIG. 2. DATA ACQUISITION HARDWARE

2.2.2 Leakage current integrator

The leakage current has resistive and capacitive components. The capacitive component of leakage current is almost constant. To analyze the pollution phenomena in RTV coated insulator, the resistive component of the leakage current is required. A digital capacitive current compensation technique[6] has been used. The leakage current measurement is started only after the program detects a positive going zero crossover of the voltage applied to test sample, as shown in Fig. 3a. The program causes the capacitive component of the leakage current to be nullified, thus giving the resistive leakage current as shown in Fig. 3c. This is used for further analysis. The multi-channel current integrator and peak classifier program is explained in detail elsewhere[7].

As soon as the program detects the positive going zero crossover of the sinusoidal voltage, it will start to acquire leakage current from the samples. The peak value of the resistive component is determined and counts maintained for different ranges are held in separate bins. Initialization of all bins to zero is done at the beginning of the program. The ranges defined are 0–50, 50–100, 100–200, 200–480, 480–580, 580–680, 680–780 and 780–880 mA.

The absolute value of the leakage current is added cumulatively up to the end of the integration time specified in the program as shown in Fig. 3d. The maxima of the peak values, the average value of the leakage current and the integral of the leakage current are determined and stored.

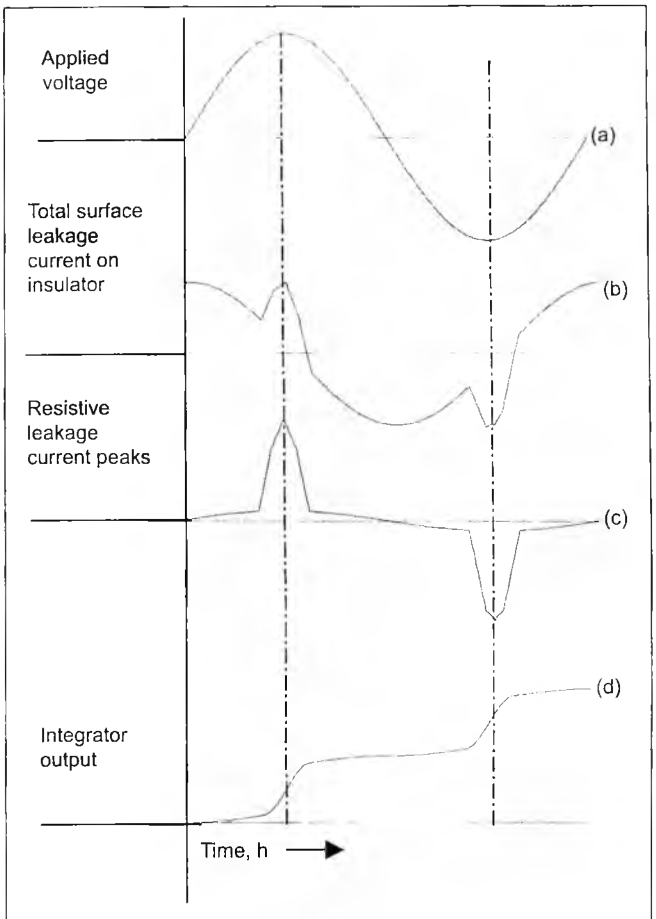

FIG. 3. THE PRINCIPLE OF THE DIGITAL CAPACITIVE CURRENT COMPENSATION TECHNIQUE[6].

3.0 SAMPLE SELECTION

Twelve units of 11 kV standard disc porcelain insulators of ANSI class 52-11, with creepage distance 380 mm, height 175 mm and diameter 290 mm have been used in the test. Each insulator has five ribs. RTV coating which has alumina trihydrate (ATH) filler was sprayed uniformly on the insulators. The coating was allowed to vulcanize in the presence of moisture in atmospheric air for 2 days. It was found that the coating thickness was 0.14 ± 0.01 mm.

3.1 Experiments

Saline solutions with conductivities of 1160 mS/m and 25 mS/m were selected for high and low conductivity test studies, respectively. Air pressure feeding the nozzles of 330 kPa and 100 kPa and flow rates of 50 ml/min, 250 ml/min and 400 ml/min were used. Tests were conducted up to $\sim$ 50 h, the minimum test time being 43 h. The variation in the test duration was due to maintenance in the test chamber. The total charge and average leakage current were determined.

4.0 RESULTS AND DISCUSSION

The leakage current and the total charge for high and low conductivity are shown in Table 1. It can be seen that for 1160 mS/m, higher pressure and higher flow rate, a higher charge and a higher average leakage current were obtained. The charge for sample 2 was less than for sample 3 due to misalignment of the nozzle and it was corrected for subsequent tests. Also, due to an experimental problem, the average leakage current could not be recorded for a few tests. For the same solution conductivity, low pressure (100 kPa), and flow rate (400 ml/min), a higher charge flowed compared to lower flow rate (50 ml/min). The same trend was also observed at lower conductivity (25 mS/m).

The general trend of the average leakage current at the end of the aging period was higher for the higher solution conductivity. For low conductivity, sample 8 and 9, the sample with higher flow rate gave more leakage current at the end of the aging period. This may be attributed to more roughening of the surface for the higher flow rate keeping the pressure constant. Also, the leakage current at the end of the aging period was observed to be higher for low pressure (100 kPa) and for low flow rate (sample 12) when compared to sample 11 with the lower flow rate (250 ml/min) using the same pressure.

4.1 Dependence of leakage current on flow rate

Figure 4, curves 1 and 2 show the average leakage current for 400 ml/min and 250 ml/min, respectively. The average leakage current was obtained while keeping the conductivity and the air pressure constant. The increase in the leakage current is attributed to the loss of hydrophobicity due to both chemical reactions on the surface[8] and a reorientation of the hydrophobic methyl groups under the water film[9]. The loss of hydrophobicity has a direct bearing on the extent of the electrical activity such as corona, arcing etc., which is believed to be the primary cause of aging of a polymer coating. This electrical activity is known to produce acids in the

TABLE 1

LEAKAGE CURRENT AND CHARGE FOR DIFFERENT TEST PARAMETERS AT THE END OF THE AGING PERIOD

Sample	Conductivity (mS/m)	Pressure (kPa)	Flow rate (ml/min)	Ageing period (h)	Total charge (C)	Average leakage current (mA)
1	1160	330	400	43.3	353.7	2.64
2	1160	330	250	50	182.4	1.17
3	1160	330	50	50	216.1	NR
4	1160	100	400	50	294.6	NR
5	1160	100	250	43.8	90.8	1.25
6	1160	100	50	50	52.8	NR
7	25	330	400	50	87.7	NR
8	25	330	250	50	82.6	0.45
9	25	330	50	50	72.9	0.44
10	25	100	400	50	69.5	NR
11	25	100	250	50	65.4	0.39
12	25	100	50	50	65.4	0.43

NR: Not recorded

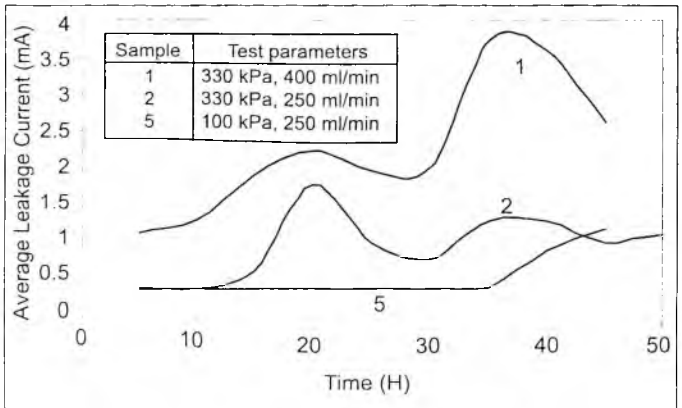

FIG. 4. AVERAGE LEAKAGE CURRENTS AT 1160 mS/m

presence of water and air, which increase the surface conductivity and attack the surface chemically[10]. The aging that results from discharges and arcing produces a more hydrophobic surface, which in turn produces more discharges[11]. The cause of electrical aging is generally related to the energy contained in the arc.

Physical examination of the sample revealed surface erosion around the insulator pin. Dry band arcing at currents as low as 1 to 5 mA is responsible for the surface erosion.

A maximum leakage current of 1.7 mA was observed for the 250 ml/min flow rate compared to 3.75 mA for the 400 ml/min flow rate, with the other parameters remaining constant. At the higher flow rate, more fog droplets impinge on the RTV surface and hence more leakage current is recorded. Kim and Hackam[4] also observed a similar result on RTV coated FRP rods.

4.2 Effect of water flow pressure

Tests were conducted at 1160 mS/m, 250 ml/min and 330 kPa and 100 kPa. For 100 kPa, the average leakage current was found to be 0.34 mA at the end of 5 h and gradually increased to 0.45 mA at 25 h. The recovery of hydrophobicity took place after 35 h with the leakage current reduced to around 0.42 mA. The current then increased to 1.2 mA at 45 h. For 330 kPa, the leakage current after 5 h was 0.35 mA and there was a slight recovery at 10 h. Because of dry band arcing the leakage current increased to 1.8 mA after 20 h and recovered to 0.85 mA at 30 h. It can be clearly seen that there appears to be competition between "loss" and "recovery" of hydrophobicity of the RTV surface, which is evident from the crests and trough of the curve before settling to a final value of leakage current as shown in curves 5 and 2 of Fig. 4. This may be due to different washing effects on the top and the protected creepage of the bottom surfaces of the RTV coated insulator.

4.3 Low conductivity solution

In Fig. 5, curves 9 and 8 show the average leakage currents at 50 ml/min and 250 ml/min, respectively at 330 kPa and 25 mS/m. A maximum leakage current of ~ 0.5 mA at 40 h was found at 250 ml/min. Similarly, the maximum leakage current was 0.42 mA after 40 h at 50 ml/min. An average leakage current of 0.35 mA was at 35 h with a low flow rate. Thus, the pattern of loss and recovery of hydrophobicity of the RTV surface was reflected in the leakage current, by showing more leakage current for higher flow rate.

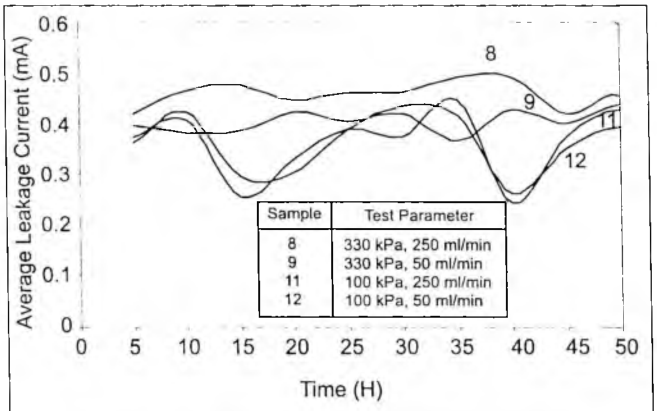

FIG. 5. AVERAGE LEAKAGE CURRENTS AT 25 mS/m

At low pressure and low flow rate, the average leakage current was 0.43 mA (curve 11), which was slightly more than the average leakage current observed (curve 12) at low pressure and intermediate flow rate (250 ml/min) and appears to be converging at the end of the test period.

4.4 Effect of conductivity

Tests were conducted using high and low conductivity solutions at 330 kPa and 250 ml/min. It is observed from Fig. 6 that a maximum leakage current of 1.8 mA at 20 h was recorded for 1160 mS/m compared to 0.42 mA for 25 mS/m. Average leakage currents of 1.17 mA and 0.45 mA were found at 50 h. The higher conductivity solution roughened the RTV surface (near the pin) resulting in more leakage current. Physical inspection of the sample showed that the higher conductivity solution had resulted in more dry band arcing near the pin as seen in Fig. 7, thus resulting in a larger loss of hydrophobicity than for the lower conductivity solution. The higher electric field near the pin of the insulator resulted in a higher current density at that point, which led to evaporation of the filamentary paths forming dry band arcing. Dry band arcing was initiated and this activity accelerated the degradation and aging of the surface, resulting in rougher surface, a loss of the low molecular weight silicone fluid and a loss of hydrophobicity[4,12,13,14]. The low conductivity solution gave rise to carbonization of the outermost under-rib as shown in Fig. 8. It

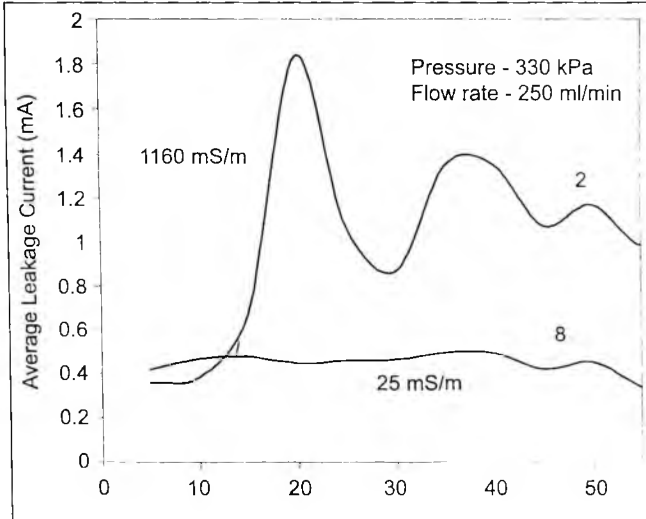

FIG. 6. AVERAGE LEAKAGE CURRENT AT 1160 AND 250 mS/m

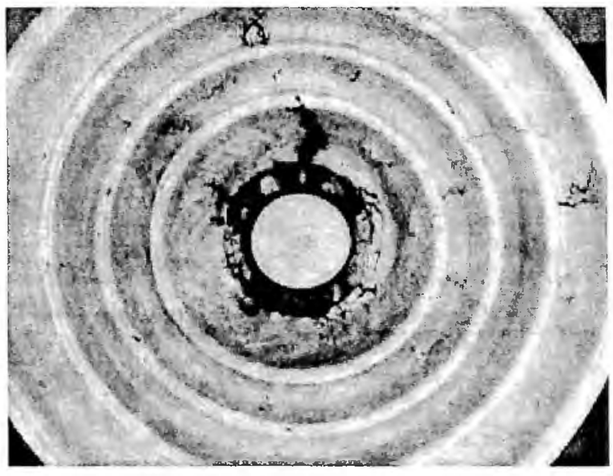

FIG. 7. SAMPLE AGED AT 1160 mS/m, SHOWING DRY BAND ARCING NEAR THE PIN

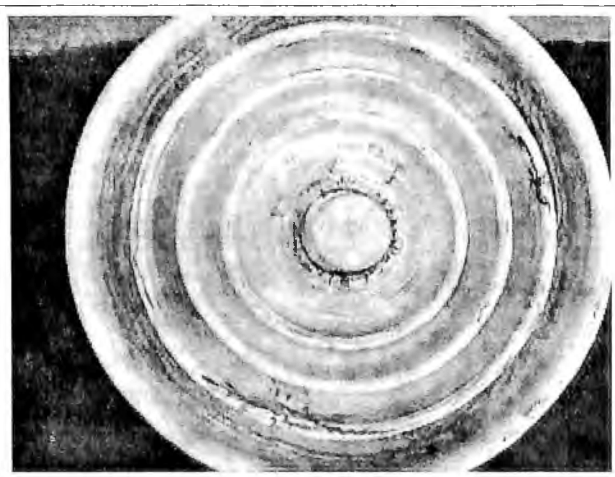

FIG. 8. SAMPLE AGED IN 25 mS/m, SHOWING CARBONIZATION OF THE OUTER MOST UNDER RIB

confirms that the leakage current in low conductivity solution, represents better aging process on RTV coated insulator. It is so because, the scintillations embrace the surface unlike the high conductivity solution, where much of the arc is in air. Hence, there is a possibility of better aging (which is representative of field situation) of the RTV coating with the low conductivity fog[15,16].

4.5 Dependence of charge on pressure and flow rate

In Fig. 9, curves 1 and 4 show the variation of the charge Vs time for 330 kPa and 100 kPa, respectively using a 1160 mS/m and 400 ml/min. It can be observed that a higher air pressure resulted in more charge. The values were 325 and 250 C, respectively at 40 h.

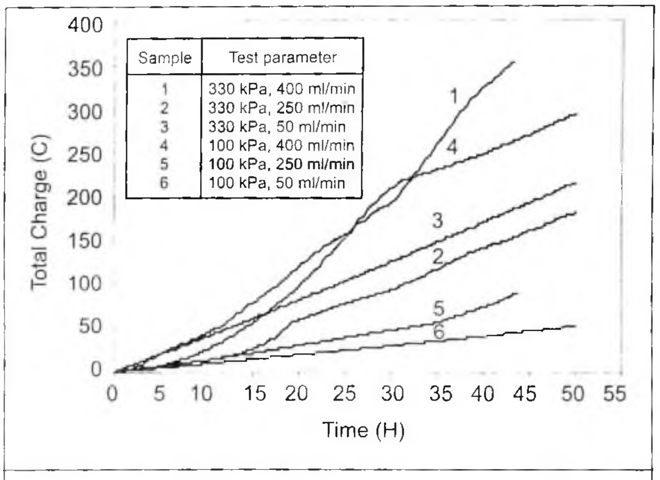

FIG. 9. TOTAL CHARGE VS TIME FOR THREE FLOW RATES AND TWO PRESSURES IN 1160 mS/m SOLUTION

More charge was conducted at lower pressure between 25 and 32 h. This is an anomaly, which was corrected for subsequent tests. Also in Fig. 9, curves 2 and 5 show the variation of the charge with respect to two different pressures at high conductance but using 250 ml/min. It can be observed that a higher pressure resulted in a higher charge of 155 C compared to 91 C at low pressure, after 44 h. Curves 3 and 6 show the value of the charge conducted on the surface of RTV coating for similar test conditions using 50 ml/min. It can be seen that higher pressure conducted 216 C and low pressure 53 C of charge. Curves 4,5 and 6 show the charge for high conductivity and low pressure for three different flow rates. The general trend observed is that higher flow rate yielded higher charge. These results suggest that increasing the speed of the fog droplet by increasing the pressure at the fog nozzle, led to increased charge on RTV insulator surface. Water droplet size increases due to higher flow rate. The increased water droplet size on the RTV surface at higher flow rates increased the charge[4].

4.6 Dependence of charge on flow rate and pressure at low conductivity

Curves 7,8 and 9 of Fig. 10 show the variation of the charge Vs time for 330 kPa and low conductivity fog for different flow rates. It is observed that the highest flow rate caused a maximum charge conduction. Similarly, curves 10,11 and 12 show the charge variations for different flow rates at 100 kPa. The results obtained are the same as for high pressure. Similar trends were observed by Kim and Hackam[4] on RTV coated FRP rods.

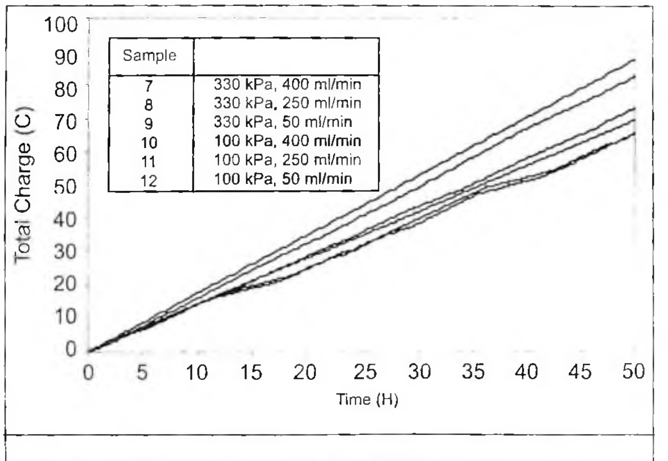

FIG. 10. TOTAL CHARGE VS TIME FOR THREE DIFFERENT FLOW RATES AND TWO DIFFERENT PRESSURES IN 25 mS/m SOLUTION

5.0 CONCLUSIONS

A PC based leakage current integrator has been developed using digital capacitive current compensation. The charge and the average leakage current on RTV coated porcelain insulators were obtained.

The test combination of higher conductance (1160 mS/m), higher pressure (330 kPa), higher flow rate (400 ml/min) yielded the highest values of charge and average leakage current. The study demonstrates that the total charge and average leakage current were similar to those published with rods as test samples.

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