

저밀도 폴리에틸렌의 전하축적 특성

Charge Accumulation Characteristics in LDPE

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Abstract - Charge accumulation characteristics in low density polyethylene (LDPE) has been discussed based upon the internal charge distribution measured by the pulsed electroacoustic technique. When the negative voltage with respect to earth is applied to the upper electrode, the negative charges near the anode and the positive charges near the cathode are accumulated in LDPE. Also, there was an asymmetric behavior of charge accumulation exhibiting that the charge accumulation near the anode keeps increasing whereas that near the cathode increases first and then decreases. Besides, under the present test conditions the internal charge distribution becomes stabilized eventually. When the positive voltage with respect to earth is applied to the upper electrode, on the other hand, no such asymmetric charge accumulation was found. Therefore, it can be concluded that the heterocharges are accumulated at the surface region of LDPE subjected to high dc voltages and that the behavior of charge accumulation depends on the polarity of dc voltage and the position of charge accumulation.

Key Words : · Polyethylene · Charge Accumulation
· Space Charge · Homocharge
· Internal Charge Distribution · Heterocharge
· PEA(Pulsed Electroacoustic) Method · Charge Injection

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1. Introduction

In the case of low density polyethylene(LDPE), one of the major base materials for insulating power cables, the charges are accumulated inside the material mainly by the injection of electrons and/or holes from the metal conductor[1~4]. These accumulated space charges distort the

distribution of electric field in the polyethylene as well as in other solid dielectrics so that almost always no uniform field profile is obtained[5~8]. For example, when heterocharges are accumulated at the surface of dielectric, the internal electric field at interfaces may get higher than the externally applied one, so that the charge injection might be enhanced. On the other hand, when homocharges are accumulated the opposite effect can be observed. That is, the internal electric field at the surfaces may get lower so that the charge injection from the electrode might be suppressed. In these cases, the extent of modification should depend on the type, amount and location of space charges within the dielectric.

Recently, a great effort has been made in improving the measurement techniques such that now an additional signal processing is not necessary because the measured output signal is directly proportional to the intensity of charge distribution [9, 10]. Also, internal charge distributions even in coaxial cables were successfully measured [10~12]. Based on the literature information, the charge accumulation behavior in polyethylene seems to change drastically in an initial stage of voltage application, particularly within a few tens of hours. For example, homocharges are accumulated at both surfaces in an early stage of voltage application whereas in a rather stabilized stage both homocharges and heterocharges are developed. A multilayer of homocharges and heterocharges was also frequently observed especially in the bulk region [9]. These results indicate that the charge accumulation behaviors in polyethylene are still quite ambiguous and a further study may be needed for a full characterization.

In this study, therefore, the internal charge distribution in LDPE was measured using a pulsed electroacoustic (PEA) technique and the charge accumulation characteristics in LDPE were also discussed. The PEA technique is a useful method because it appears to be more advantageous than the ones using a high energy laser pulse due to its excellent averaging technique, a critical factor for improving the S/N ratio.

2. Experimental

The specimen used in the study is the LDPE film. Its density and melt index are 0.920g/cc at 25°C and 0.2g/10 min at 190°C [13]. A 2mm thick plate of LDPE was compression molded at 180°C and cleaned by plenty of alcohol and acetone before subjected to testing. About 200 μm thick semiconductive film was prepared by compression molding at 180°C and attached on both surfaces of the test specimen.

A home-built instrument, the schematic block diagram of which is in Fig. 1, was used for measuring the internal charge distribution in LDPE. As shown in Fig. 1, it consists of the pulse generator to produce the electric pulses of desired pulse widths and amplitudes, the power supply to apply dc voltages for injecting charges into the specimen, the test cell which holds the electrode and

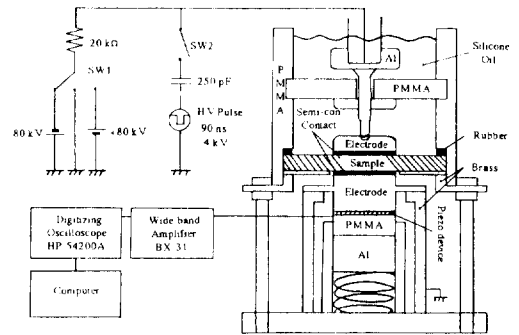


Fig. 1 Experimental set up for measuring internal charge distributions by the PEA technique :

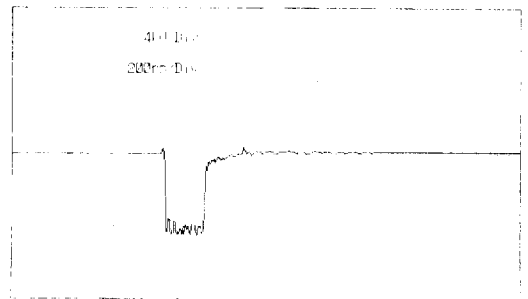


Fig. 2 The shape of typical electric pulse generated by a pulse generator : Pulse width : 90 ns, Pulse height : -4kV

specimen, the detector made of the piezoelectric film, and a wide band digitizing oscilloscope (1 GHz, Hewlett Packard, Model #: 54100A). Besides, the general purpose interface board (GPIB)-installed personal computer was used for the data acquisition. With this system no additional signal processing to get the correct internal charge distribution was necessary.

An electric pulse generator was fabricated to produce stable source electric pulses with the output amplitudes up to -4kV and the pulse width changable from 10 to 90ns. The shape of typical electric pulse produced by our home-built pulse generator is shown in Fig. 2. In this case, the pulse width is 90ns and the pulse height is -4kV . The upper electrode was designed to apply the source electric pulses and high dc voltages at the same time when needed. It is a combination in parallel of a $20\text{k}\Omega$ resistor and a 250 pF capacitor.

A piezoelectric transducer was fabricated to convert the mechanical (electroacoustic) pulse signal generated by the charges inside the LDPE into an electric signal. Basically it is a combination in series of a metal electrode, a thin piezoelectric sensor, and a polymer block. A $110\mu\text{m}$ thick PVDF film was used as a piezoelectric sensor because of its excellent wide band characteristic in a frequency domain. On the other hand, a polymer block was used as a backing plate to delay the reflected signal so as not to interfere with the first signal coming out.

The measurement of internal charge distribution in LDPE was conducted as follows: A 2mm thick LDPE sheet with semiconductive electrodes on both surfaces was placed in the test cell at the ambient condition and then the selected dc voltage was applied to the specimen. Right after the set time for the voltage application was collapsed, the source electric pulse was generated and the resultant output signal was collected by a digitizing oscilloscope. Then, the digitized data were transmitted to the personal computer through a GPIB. When the test voltage was below 20kV_{dc} the measurements were carried out, in an ambient condition, with the voltage on. However, when the test voltage exceeds 20kV_{dc} , the measurements were carried out, in an oil-immersed test cell to

prevent a flash-over, with the voltage off. In this case, the measurement was completed immediately after the voltage was turned off and then the voltage was ramped up to the test voltage for further voltage loading.

3. Results and Discussion

3.1 Typical charge distribution in LDPE

Internal charge distributions of LDPE electrically stressed at three dc voltages, -20 , -50 , and -80 kilovolts, are shown in Fig. 3. All measurements were carried out using a source electric pulse with the pulse width of 90 ns and the amplitude of -4kV . All portions representing the induced charges were removed by a computer program so that the curves in the figure represent the real charges residing in the polyethylene.

Three characteristic regions are distinguishable in Fig. 3. These are designated in the figure as I,

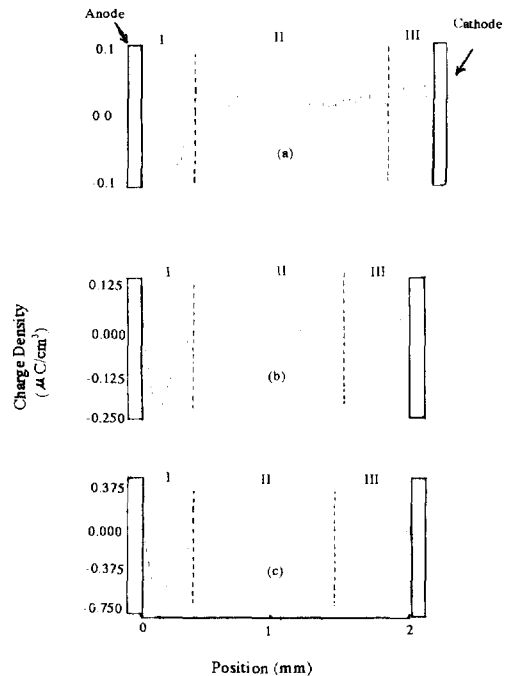


Fig. 3 Charge distributions in LDPE subjected to dc voltage: (a) $-20\text{ kV}_{\text{dc}}$ for 77hrs, (b) $-50\text{ kV}_{\text{dc}}$ for 45 hrs, and (c) $-80\text{ kV}_{\text{dc}}$ for 45 hrs.

Ⅱ, and Ⅲ. I represents the spatial profile of charges at the surface near the anode, Ⅱ that in the bulk region, and Ⅲ that at the surface near the cathode. One can see immediately that the charge accumulation takes place predominantly at the surface region.

When $-20kV_{dc}$ was applied for 77hours, as shown in Fig. 3-(a), the positive charges were accumulated near the cathode and the negative charges near the anode. A similar charge distribution but with a larger charge amount was observed at $-50kV_{dc}$ (Fig. 3-(b)). When $-80kV_{dc}$ was applied for 45hours the situation becomes somewhat different in the sense that the charge peak near the anode is large compared to that near the cathode(Fig. 3-(c)). Besides, the charges are located dominantly at the surface area at $-20kV_{dc}$ whereas at both $-50kV_{dc}$ and $-80kV_{dc}$ some real charges are developed in the bulk region in addition to the ones at the surfaces. Nevertheless, as expected, the larger amount of charges were accumulated at higher voltages.

3.2 Time evolution of charge distribution

Time evolution characteristics of charge accumulation in LDPE were investigated at the same voltages to see how the charge accumulation is evolved as a function of time under voltage. The results are shown in Fig. 4 to 6. Fig. 4 is the one at $-20kV_{dc}$, Fig. 5 at $-50kV_{dc}$, and Fig. 6 at $-80kV_{dc}$. Here, (a) in each figure represents typical charge distributions at several loading times and (b) a three dimensional arrangement of all measured charge distributions.

When $-20kV_{dc}$ was applied, a somewhat complicated charge distribution was observed. In Fig. 4-(a), the positive charges near the anode(i.e., homocharges) are seen at 10 minutes of voltage application and after that the negative charges near the anode(i.e., heterocharges) are accumulated. This feature can be seen more clearly in a three dimensional plot. Near the anode, as shown in Fig. 4-(b), the positive charges(i.e., homocharges) are accumulated. Its peak height increases during the first 10 minutes and then starts decreasing. Finally the negative charges(i.e., heterocharges) start accumulated from about 8 hours after the voltage

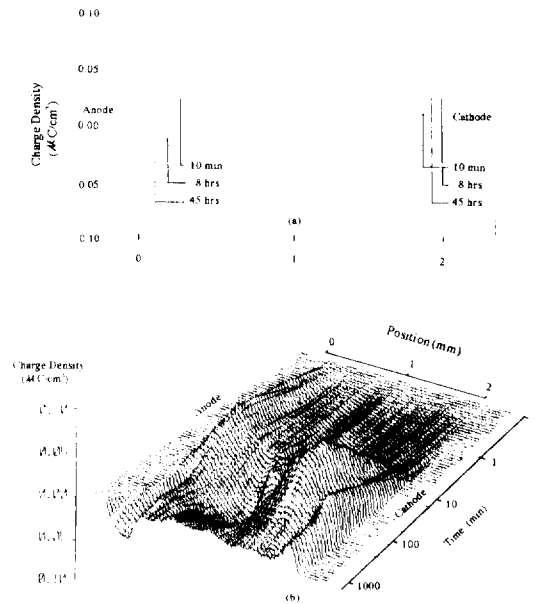


Fig. 4 (a) Internal charge distributions in LDPE subjected to $-20kV_{dc}$. Time under voltage: 10min., 8 hrs., 45hrs., (b) Time evolution of charge distribution

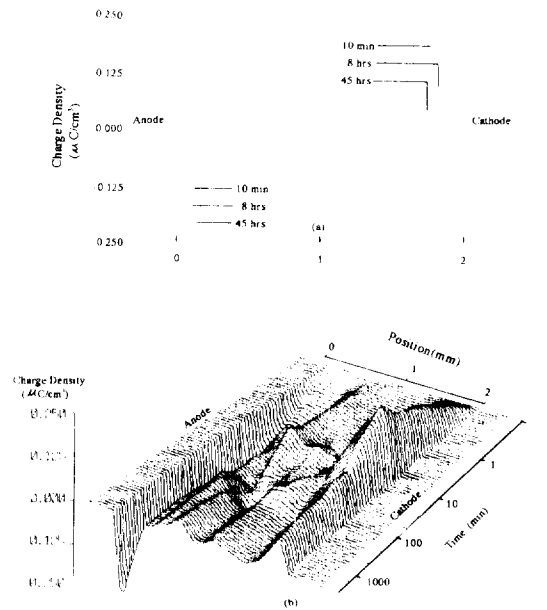


Fig. 5 (a) Internal charge distributions in LDPE subjected to $-50kV_{dc}$. Time under voltage: 10min., 8 hrs., 45 hrs.,(b) Time evolution of charge distribution

application. Near the cathode, on the other hand, heterocharges start accumulated just after the voltage application. In this case, also, the peak height increases during the first 2 hours and then decreases. Charge accumulation behavior in the bulk region seems to be a little more complicated. Large homocharge peaks were developed for a certain period of time near the anode and then disappeared. A maximum bulk charges can be found at about 2 hour loading time and then the internal charge distribution seems to become more or less stabilized.

Somewhat different features can be observed when -50kV_{dc} is applied, as shown in Fig. 5. Right after the voltage application, the heterocharges, i.e., the negative charges near the anode and the positive charges near the cathode, start accumulated. In this case, however, the charges penetrate into a deeper region than in a -20kV_{dc} case. Near the cathode, as can be seen in Fig. 5-(a), the charge density at 10 minutes is larger than those at both 8 and 45 hours. A maximum

charge density was found to be about $0.2\mu\text{C}/\text{cm}^3$ at about 10 minutes after the voltage application. A complicated charge distribution can be seen in the bulk region, but from about 24 hours after the voltage application the charge distribution becomes stabilized. Differing from the -20kV_{dc} case, some charges are observed in the bulk region even after the stabilization. Besides, it seems that the peaks near the anode become larger, as the loading time increases, than those near the cathode. It was also found that the surface charge near the cathode increases first and then decreases.

When -80kV_{dc} is applied, the observed features are almost the same as those at -50kV_{dc} , as shown in Fig. 6. For example, the heterocharges are accumulated at both surfaces and the amount of accumulated heterocharges increases as the duration under voltage increases. Also, some charges are developed in bulk region. Near the anode, the peaks representing the heterocharge accumulation become larger with a longer duration under voltage. Near the cathode, on the other hand, the height of heterocharge peaks increases first and then decreases. The same feature was observed in a -50kV_{dc} case. The maximum peak height occurs within a few minutes after the voltage application and then stays unchanged for a while. It is, however, stabilized eventually about 23 hours later.

3.3 Discussion

This work was initiated to investigate the charge accumulation characteristics in LDPE. Regarding this, a three dimensional arrangement of the collected charge distributions appears to be attractive in picturing the progress of charge accumulation, because it gives a clear outlook on the time evolution of charge distributions[9, 13].

In terms of speculation of the charge accumulation characteristics, the present results clearly indicate that under the present conditions eventually the heterocharges are accumulated within the LDPE. This feature holds true for all cases tested. The heterocharge accumulation has been frequently reported in LDPE and XLPE and was attributed to the impurities either diffused from the semicon-

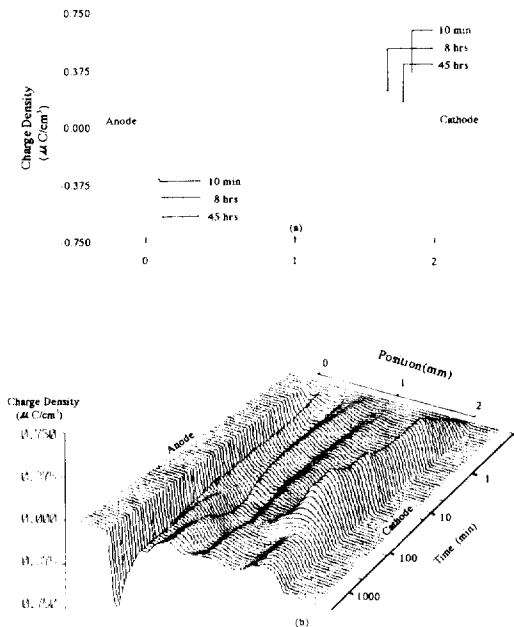


Fig. 6 (a) Internal charge distributions in LDPE subjected to -80kV_{dc} . Time under voltage : 10min., 8 hrs., 45hrs., (b) Time evolution of charge distribution

ductive compounds used as an electrode or residing in the bulk [9, 10]. In either case, the charged particles are generated possibly by the dissociation of impurities, which in turn might be enhanced by a local electric field.

In addition, the charge accumulation was found to be very complicated in an early stage of voltage application, but the internal charge distribution becomes more or less stabilized in a final stage of voltage application. Besides, when the negative voltage is applied, the charge accumulation near the anode keeps increasing whereas that near the cathode increases first and then decreases. That is, an asymmetric charge accumulation was observed.

It will be quite interesting to study whether such asymmetric behavior is dependent on the polarity of applied voltage or not. Therefore, a separate testing at $+80\text{kV}_{\text{dc}}$ was carried out. Internal charge distributions at several loading times and its time evolution characteristics at $+80\text{kV}_{\text{dc}}$ are shown in Fig. 7. When $+80\text{kV}_{\text{dc}}$ is applied, the heterocharges, i.e., the negative charges near the

anode and the positive charges near the cathode, are accumulated. No marked decrease of charge accumulation near the cathode was observed in this case. Instead, broad charge distributions were observed in an early stage of voltage loading and then disappeared about 24 hours after the voltage application. Similar phenomena might be expected at both $+20\text{kV}_{\text{dc}}$ and $+50\text{kV}_{\text{dc}}$.

From this result, one can see that the asymmetric behavior of charge accumulation takes place predominantly when the negative voltages are applied. The exact reasons for the observation of such asymmetric feature may not be possible at this moment. However, it may be postulated by the neutralization of accumulated heterocharges by the injected homocharges. At an early stage of voltage application, the heterocharge accumulation may take place predominantly. At this stage, the homocharge injection might take place, but its amount may not be large enough to neutralize significant amount of heterocharges. As the duration under voltage increases, on the other hand, the homocharge injection becomes considerable so that the amount of injected homocharges increases. Then, a significant amount of heterocharges are to be neutralized by the injected homocharges, the net result being a gradual decrease of heterocharge accumulation near the cathode. However, this postulation may not be able to explain a monotonical increase of heterocharge accumulation near the anode. More study is needed to explain this feature. Nevertheless, the present results indicate that the polarity of electric stress imposes some influences on the charge accumulation characteristics in LDPE.

A direct comparison of the present observations with the reported ones might not be possible due to the different test conditions. However, some features are similar in a rough approximation. First, in the present study, maximum densities of surface charges at the positive electrode side range roughly from 0.1 to $1.0 \mu\text{C}/\text{cm}^3$ for the voltage range of -20 to -80kV_{dc} . Similar values were reported [10]. Second, the internal charge distribution becomes eventually stabilized, as pointed out by others [5, 10]. In the present study, the heterocharge accumulation seems to be predominant for all

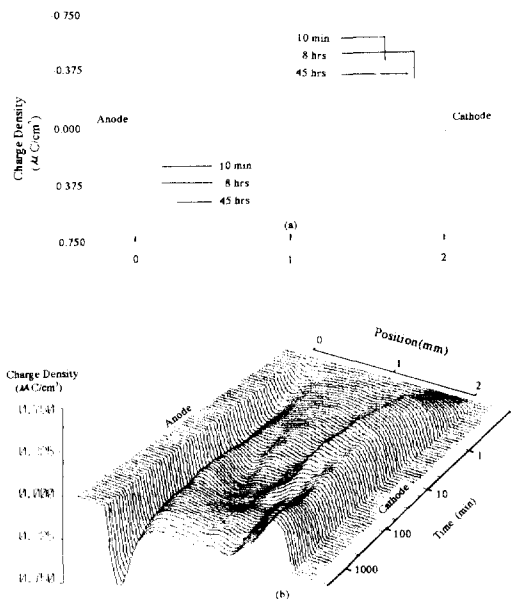


Fig. 7 (a) Internal charge distributions in LDPE subjected to $+80\text{kV}_{\text{dc}}$. Time under voltage : 10min., 8 hrs., 45hrs., (b) Time evolution of charge distribution

voltages, although the accumulation of both homo-charges and heterocharges was observed at an early stage of -20kV_{dc} . However, in other cases [5, 10], both homocharges and heterocharges are reported to be accumulated at the surface region. An answer for this discrepancy is not available at this moment.

Two observations seem to be important in a practical experimentation, which is in turn closely related to the interpretation of the measured charge distributions. These are (1) the evolution of complicated charge distribution in the bulk region and subsequent stabilization and (2) the different charge accumulation characteristics depending on the polarity of dc voltage. These indicate that the charge distribution might be different depending on the test conditions, which strongly suggests that a great attention may have to be paid to both experimentation and data interpretation. In an extreme case, for example, the collected charge distribution might not represent the characteristics of specimen under test, if just some are collected.

4. Conclusions

The behavior of charge accumulation in low density polyethylene has been discussed based upon the internal charge distribution measured by a PEA method. The major observations are

- (1) In general, the negative charges near the anode and the positive charges near the cathode, i. e., the heterocharges, are accumulated in LDPE.
- (2) When the negative voltage is applied, the charge accumulation near the anode keeps increasing whereas that near the cathode increases first and then decreases. That is, an asymmetric charge accumulation was observed.
- (3) Under the present test conditions, however, the internal charge distribution becomes stabilized eventually.

Therefore, it can be concluded that the heterocharges are accumulated at the surface region of LDPE subjected to high dc voltages and the charge accumulation characteristic depends on the polarity of dc voltage and the position of charge accumulation.

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