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폴리에틸렌 내에서 워터트리의 구조와 전기적 특성
Internal Structure and Electrical Behaviour of Water Trees in Polyethylene

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1. INTRODUCTION

Despite numerous studies made on water trees in the last ten years the detailed mechanisms of tree formation are not yet understood. One of the reasons for this situation is the fact that the very nature of the material degradation is not well known. In particular, the question of the internal structure of the water trees, the knowledge of which is essential fo for testing several proposed theories has been much debated for a long time.

Some authors consider that a water tree is made up of water-filled channels as suggested by observation with a microscope. From scanning electron microscope photographs, it has recently been asserted that continuous channels do exist, with diameters between 0.1 and 3.5 μm (1). Other authors have observed series of spherical cavities which do not seem to be connected. Again using a scanning electron microscope, a large number of cavities ranging from 0.8 μm to 9.8 μm with no evidence of channels interconnecting the cavities has been observed in treed regions on cross-linked polyethylene(2) These differences in opinion reveal the difficulty of direct observation of the internal structure of water trees. These are due in particuler to the cross section and to the fact that the observed situation in the cross section may be different from the actual one present during the water tree growth.

We present here two indirect methods for studying the internal structure of water trees. The first is based on the relationship existing between internal structure and electrical behaviour : a water tree made of adjoining conducting channels should behave as a conductor whereas if it is made of non-interconnected conducting cavities it should behave as a dielectric. The second is based on measurements of gas flow through freeze-fractured water trees, from which continuous channels may be detected.

2. RESULT & DISCUSSION

A. Electrical measurements

Water trees were grown via the water needle method using polyethylene specimens and a visualization system all of which have been previously described(3). The system, using microscope, video camera and television enables us to observe continuously the same tree and to measure its length throughout its propagation even under electrical stress. Some modification of our usual specimens were needed, to detect indirectly the variations of the electric field in polyethylene near the electrode facing the water tree during its growth. The voltage V between the water needle and the grounded electrode was divided into two parts which depend on resistance R and capacitance C between these two electrodes.

With the resistance R and the voltage V being constant, the possible variations of capacitance C due to the growth of the tree may be detected by the variations of voltage V across R.

The ratio of voltage V across resistance R with and without water tree V(L)/v(O) is given in fig.1(continuous line curve) as a function of the ratio L/L_0, L being the water tree length and L_0 the distance between the tip of the needle and the opposite electrode. One notices an increase in v(L)/v(O) which reveals an alteration of the electrical behaviour of the material. In order to compare the electrical behaviour of a water tree with those of a metal or of a dielectric,we carried out additional experiments on models. Models of the actual specimen were made on a scale 10 times larger, with polyethylene beeing replaced by air and water trees by metallic or dielectric spheres of different radii L (fig. 2). The voltage ratio v(L)/v(O) was measured as a function of the radius L for metal, nylon (permittivity : ε_r=3.3) and polyethylene (ε_r=2.3). Results are presented in fig. 1. using dotted lines. One can see that the curve for the water tree is located between those for nylon and polyethylene, which shows that a water tree has the behaviour of a dielectric and not that of a conductor.

Thus, it can be concluded that continuous channels do not exist and that the ionic solution is located in non-interconnected cavities. As our experiments are carried out under voltage, this result corresponds to the actual situation during the growth of water trees.

B. Gas flow measurements

Large water trees, from 500 to 600 μm long, were grown in the experimental conditions described in section A. Then, water was removed, in vacuo at room temperature, and specimens were immersed in liquid nitrogen for several minutes before being freeze-fractured in order to get cross sections of the trees. Five sections were obtained at distances from 200 to 400 μm from the needle tip. The sectionned end of each specimen was connected to a leak detector (LEYBOLD-HERAEUS, model ULTRATEST M2 BY) and helium gas was admitted at the other one (fig. 3)

Gas flow measurements corroborate the results on the internal structure of water trees deduced from electrical measurements. Experiments were performed on 5 water trees cut at distances between 200 and 400 μm from the water needle tip. The largest flow rate was obtained for L=200 μm and was about 4×10^{-10} mbar.litre/sec a number which has to be compared with that expected from the gas flow through channels. Considering a channel of 1 μm diameter and 200 μm long we have calculated the possible helium flow in the conditions of our experiments and we obtained about 5×10^{-7} mbar.litre/sec. This value is more than 1000 times the measured on the diffusion of helium gas through polyethylene. The result shows that there are no continuous channels from one end of the sample to the other, excluding regions of the water tree located at distances lower than 200 μm from the needle tip in which interconnected channels might exist.

3. CONCLUSION

Water trees grown in our test conditions do not behave as conductors but as mixed dielectrics made of polyethylene with water inclusions. They should not be considered as formed of adjoining conducting channels but of non-interconnected cavities.

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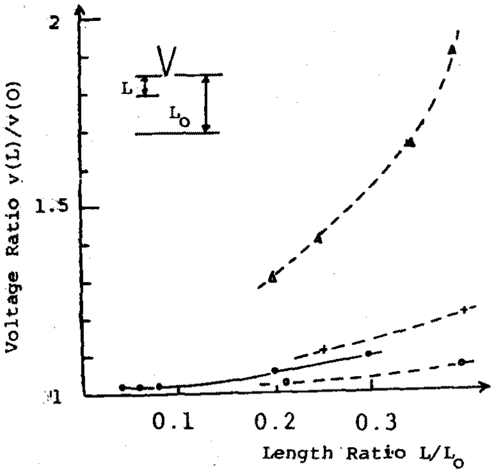

Fig.1 : Voltage ratio v(L)/v(O) with and without water tree(or model) versus water tree(or model) length L/L_0

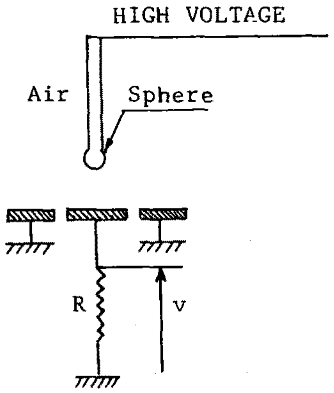

Fig.2 : Schematic Drawing of the model

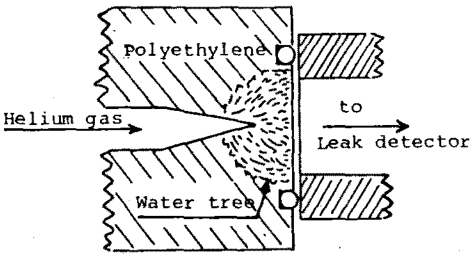

Fig.3 : Schematic drawing of the arrangement for gas flow measurement