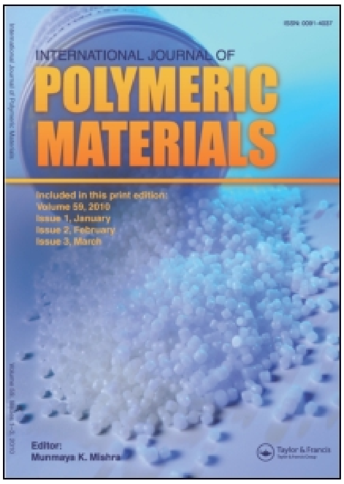
This article was downloaded by:
On: *23 January 2011*
Access details: *Access Details: Free Access*
Publisher *Taylor & Francis*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

A Study of Water Tree Frequency Dependence and Growth Rate in Polymer

A. A. Hossam Eldin[a]; Z. El Shazli[b]
[a] University of Alexandria, Alexandria, Egypt [b] E. C. G., Cairo, Egypt

To cite this Article Eldin, A. A. Hossam and Shazli, Z. El(1985) 'A Study of Water Tree Frequency Dependence and Growth Rate in Polymer', International Journal of Polymeric Materials, 11: 1, 79 — 87
To link to this Article: DOI: 10.1080/00914038508078655
URL: http://dx.doi.org/10.1080/00914038508078655

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Intern. J. Polymeric Mater., 1985, Vol. 11, pp. 79–87
0091-4037/85/1101-0079 $18.50/0
© 1985 Gordon and Breach Science Publishers, Inc.
Printed in the United Kingdom

A Study of Water Tree Frequency Dependence and Growth Rate in Polymer

A. A. HOSSAM ELDIN
University of Alexandria, Alexandria, Egypt

Z. EL SHAZLI
E. C. G., Cairo, Egypt

(Received July 12, 1982)

Downloaded At: 13:40 23 January 2011

This paper presents theoretical and experimental studies on the water tree (W.T.) growth rate frequency dependence. The high growth rate experienced is explained on the light of the simulating circuit components and parameters. The results are very sensitive to the assumed water content in tree and the original tree length. Attempts were made to correlate between W.T. theories and experimental results. The mechanisms of W.T. initiation and growth are explained.

INTRODUCTION

The extent of treeing problem is not yet defined [1]. Many investigations were carried out on the treeing phenomena [2, 3, 4, 5]. Water trees are initiated and grown in polymers when some insulated conductors are immersed into water [3]. However, due to the difficulty in simulating, experimentally, water treeing phenomena, the fundamental processes of the inception and extension of treeing have not yet been understood [6].

WATER TREE THEORY

It has been demonstrated [7] that W.T. growth rate can be written in the form

$$GR = \frac{1}{\delta t}\int_{r_0}^{r} \frac{dr}{E^2} \tag{1}$$

Where GR: rate of growth
r_0 : initial radius of tree
r : increase in length of tree
E : applied electric field

The expression was obtained on the assumption that the resistivity of tree is very small, and the tree can withstand considerable electric field. The equivalent circuit is as shown in Figure 1, Eq. (1) can be rewritten as

$$\begin{aligned} GR &= \frac{1}{V_0^2\delta t}\int_{r_0}^{r} \left(\frac{V_0^2}{V_t^2}\right) K\,dr \\ &= \frac{1}{V_0^2\delta t}\int_{r_0}^{r} F_w K\,dr \end{aligned} \tag{2}$$

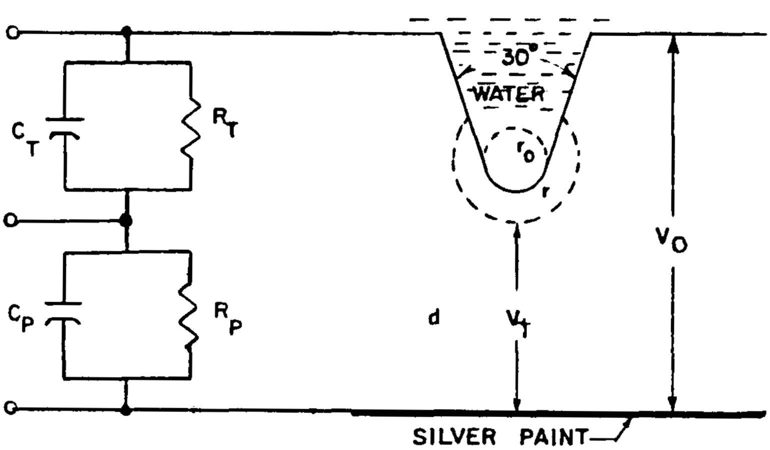


FIGURE 1 Water treeing equivalent circuit.

Downloaded At: 13:40 23 January 2011

The ratio

$$\frac{V_0}{V_t}=\frac{Y_p}{Y} \tag{3}$$

Comparing (2) and (3), then

$$F_w=\frac{[(G_p+G_T)^2+w^2(C_p+C_T)^2]}{(G_T^2+w^2C_T^2)} \tag{4}$$

$$K=\frac{(r+r_0)^2\left[\tanh^{-1}\dfrac{1}{[1+(r+r_0)/d]^{\frac{1}{2}}}\right]^2}{1+(r+r_0)/d} \tag{5}$$

Considering the appropriate conductivity and permittivity

$$F_w=\frac{(g_T+g_pr/r_0)^2+w^2\varepsilon_0^2(\varepsilon_T+\varepsilon_pr/r_0)^2}{g_T^2+w^2C_0^2C_T^2} \tag{6}$$

When w tends to infinity,

$$F_w=\left(1+\frac{\varepsilon_p}{\varepsilon_R}\frac{r}{r_0}\right)^2 \tag{7}$$

and the frequency factor is permittivity dependent; but at zero frequency the frequency factor depends on the conductivity ratio as

$$F_w=\left(1+\frac{g_p}{g_T}\frac{r}{r_0}\right)^2 \tag{8}$$

If the water content in polythene is 2% and assuming direct proportionality, $\varepsilon_p=2.25$, $\varepsilon_T=3.75$ [8], $r_0=5$ micron, then $F_{wh}=240\,F_{wl}$.

This would indicate that the rate of growth of W.T. is a frequency dependent (F_w). But it is sensitive to the amount of water content, and the original length of tree.

EXPERIMENTAL AND TESTING PROCEDURE

Samples: were casted from granules of polythene (PE) and (XLPE) at a temperature of 128°C in a disc form having a thickness of 10 mm. Seven holes were made in the sample by a needle of 5 μm radius to a depth as shown in Figure 2a.

Downloaded At: 13:40 23 January 2011

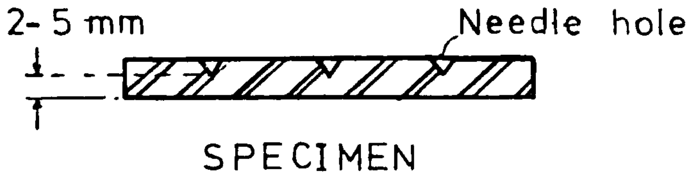


FIGURE 2a Specimen

Solutions: Distilled water of resistivity 1500 Ω−m, tap water 100 Ω−m and sodium chloride 4 Ω−m were used.

Test Cell: The high voltage electrode made of copper wire spring. The specimen was placed in a constant temperature bath at 25°C, as shown in Figure 2b. Solutions were poured with care not to produce bubbles.

A–C voltage was applied to the h.v. electrode starting from 1 kV and raised in steps of 0.5 kV/minute till the inception voltage was reached. The frequency of the voltage was variated as 50, 300, 1000, 3000, 8000 and 10,000 Hz. Tests were repeated with d–c voltages under same conditions.

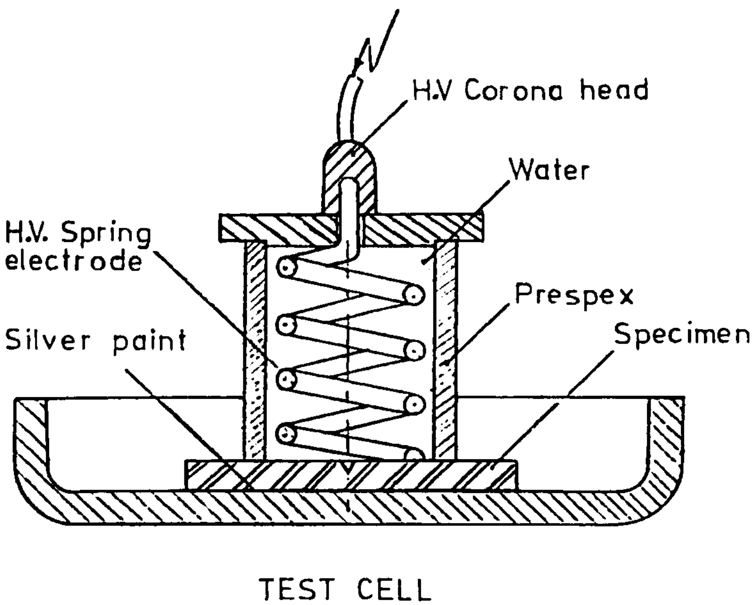


FIGURE 2b Test cell.

Downloaded At: 13:40 23 January 2011

Downloaded At: 13:40 23 January 2011

Specimens were cut into wafers and then dyed with methylene blue dye to be examined under microscope. The wafers were removed from dye after 2 to 3 minutes, and placed into hot mild soapy water for one hour. Then cleaned with alcohol and dried gently.

RESULTS AND DISCUSSIONS

Inception Voltage: The inception stress, as calculated [9], showed a frequency dependence as shown in Figure 3.

As the frequency increased the inception stress decreases. The inception of trees sometimes show a time dependence after voltage

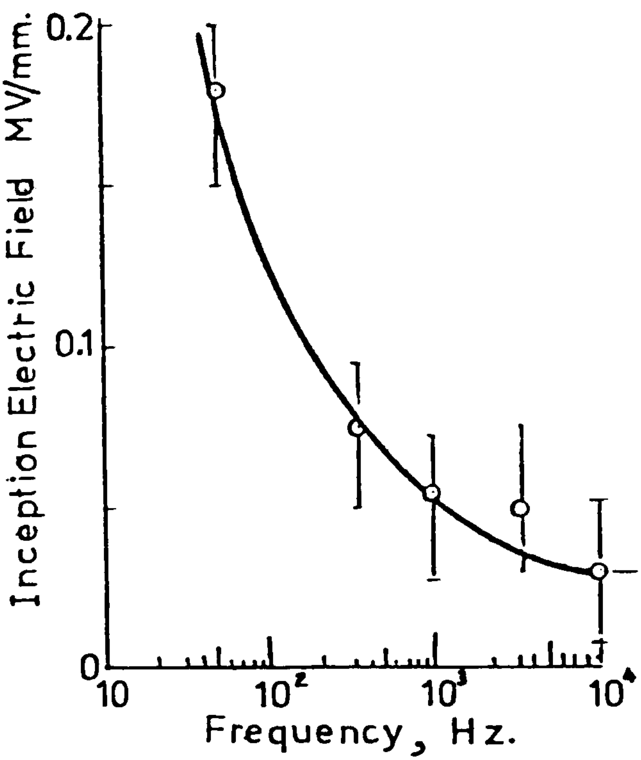


FIGURE 3 Frequency dependence of inception voltage.

application as shown in Figure 4, which indicates a decrease in inception time as the applied voltage and its frequency was raised.

Water Tree Growth. Figure 5 shows that W.T., for a voltage applied for one hour, rate of growth increases as the voltage and frequency were raised. W.T. rate of growth increases with decreasing the resistivity of water solution Figure 6. W.T. disappeared when specimens were heated and reappeared when reimmersed in solution. The original tree length does affect the rate of growth. As the time of voltage application (under certain frequency, voltage and temperature) increases the rate of growth highly increases. But W.T. grows rapidly at the beginning and then continues at a slower rate.

W.T. Under Direct Voltages: When positive or negative d–c of the range 20 to 30 kV were applied, no W.T. was observed. This would show that W.T. is an a–c phenomena.

Mechanism of Water Treeing: Maxwell forces, due to normal field component, works as a compression to the polymer at the high field

Downloaded At: 13:40 23 January 2011

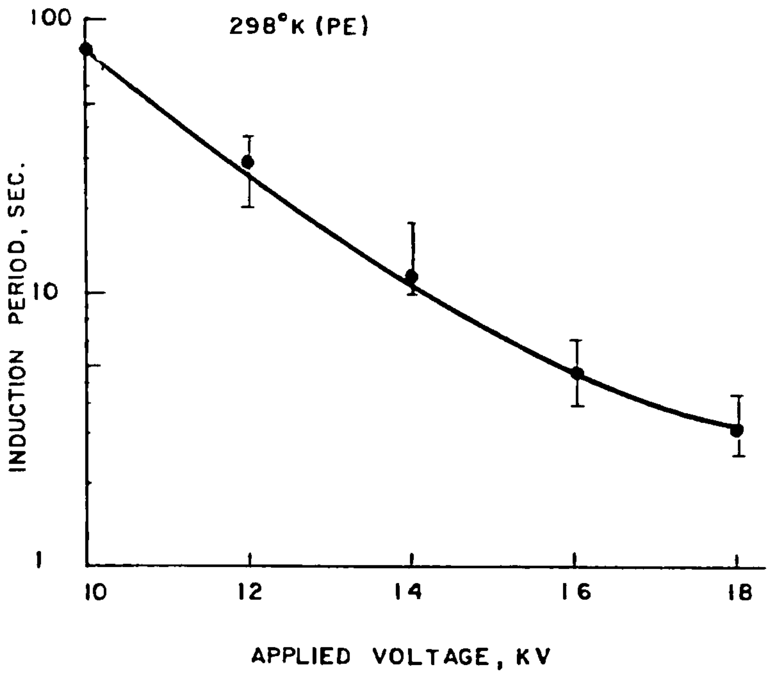


FIGURE 4 Relation between induction time and applied voltage.

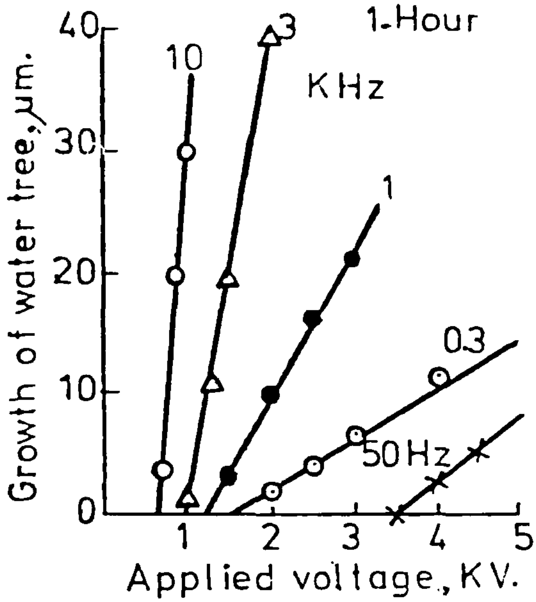


FIGURE 5 Relation between applied voltage and growth rate.

Downloaded At: 13:40 23 January 2011

region near the needle tip [9]. Then an induced stress perpendicular to the field direction may appear in polymer. When this stress exceeds a critical value, crazing action may take place from the micro-voids. When a gas discharges in a void-crack it forms an electric field more than the electric strength of the polymer at the apex of the void, and microscopic tree channel may appear due to the partial breakdown of polymer.

Dielectric loss and Joule heating make water to evaporate that increase in pressure and temperature which cause damage. The rate of rise in temperature due to dielectric losses in water is 1°C/s at a field of 10.

MV/m, 50 Hz [10]. The temperature rise may lead to vaporization or thermal degradation of water and PE when voltage is applied. When a–c field is applied water as $(H_2O)_n$ may undergo lattice vibrations that gets it decomposed into molecular groups (clusters). These clusters may penetrate into microvoids extending across molecules of PE by Maxwell force.

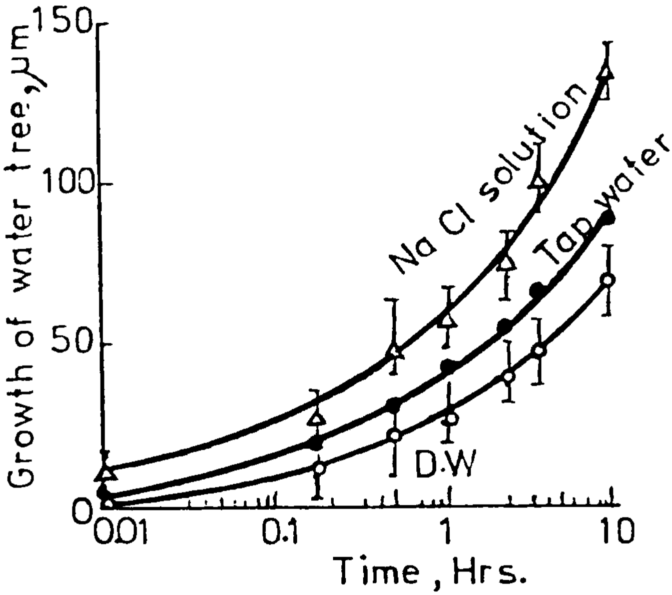


FIGURE 6 Relation between growth rate and time of voltage application.

Downloaded At: 13:40 23 January 2011

CONCLUSIONS

It is concluded that W.T. inception is frequency dependent. The growth of trees depends on the applied voltage, frequency and the electrical resistivity of solution. W.T. initiates and grows by penetration of clusters into the microvoids due to Maxwell stress and the dielectric loss and Joule heating make water expand and evaporate so that the increase in pressure and temperature may cause damage. Also the ionization discharges in clusters may cause more damage.

The growth rate frequency dependence is not solely explained by the frequency factor Fw obtained from theory.

The experimental results are consistent with theory and it can explain W.T. characteristics.

References

1. M. A. Martin and R. A. Hartlein, *IEEE Trans.* PAS-78, paper No. F79612-3, 1979.

2. M. Nawata, H. Kawamura and M. Ieda, *I.S.H.*, March 1972, pp 428–434.
3. Technical Report of IEE of Japan "No. 111, 1974.
4. W. Vahlstrom, *IEEE Trans.*, PAS–91, 1972, No. 3.
5. S. Isshiki *et al.*, *IEEE Trans.*, PAS-93, No. 5, 1974.
6. J. Sletbak, *IEEE Trans.*, PAS–98, paper No. F79 203–1, 1979.
7. A. C. Ashcroft, Moscow, USSR, Kabel item No. 52, June, 1977.
8. H. Mastsuba and E. Kawai, *IEEE Trans.*, PAS–95, 1976, pp. 660–670.
9. J. H. Mason, *Proc. IEE*, 102, 1955, pp 254–263.
10. T. Tanaka *et al.*, *IEEE Trans.*, PAS–93, 1974.

Downloaded At: 13:40 23 January 2011