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Dielectric Response of Oil Impregnated Nomex in Frequency and Time Domain

Abstract. *Nomex has been introduced to electrotechnical industry, mainly as high voltage insulating material, used for example in power transformers. The aim of this paper is to identify the influence of moisture on dielectric relaxation of solid-liquid insulation consisting of Nomex impregnated with transformer oil. From practical measurements a series of FDS (Frequency Domain Spectroscopy) and PDC (Polarization Depolarization Current) characteristics were obtained for Nomex-oil insulating system.*

Streszczenie. *Nomex znalazł ważne zastosowanie w branży elektrotechnicznej, głównie jako wysokonapięciowy materiał izolacyjny stosowany w transformatorach energetycznych. Niniejsza publikacja dotyczy rozpoznania wpływu zawilgocenia na relaksację dielektryczną stało-ciekłej izolacji złożonej z Nomexu impregnowanego olejem transformatorowym na podstawie pomiarów metodą spektroskopii dielektrycznej FDS (Frequency Domain Spectroscopy) oraz rejestracji pradów polaryzacji i depolaryzacji PDC (Polarization Depolarization Current). (**Odpowiedź dielektryczna impregnowanego olejem Nomexu w dziedzinie częstotliwości i czasu**).*

Keywords: Nomex, dielectric relaxation, FDS, PDC.
Słowa kluczowe: Nomex, relaksacja dielektryczna, FDS, PDC.

Introduction

X-ray pictures showed that water molecules penetrate free spaces between aromatic polyamides molecules, without disturbing polymer's crystal structure, which makes aramids moisturization reversible. The number and size of spaces where water can be stored depends from the level of fibers packing. Some aramids are more packed and have more crystal structure (e.g. Nomex type 410), which can be seen at SEM pictures (Figure 2) and has its confirmation in water sorption charts (Figure 3) [2].

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In 1967 chemical company DuPont introduced to the market Nomex – aramid paper, material from polyamides family (PA). Aramids are aromatic polyamides, their fibers are called synthetic silk and have tensile strength five time bigger than steel, if compared at the same weight [1].

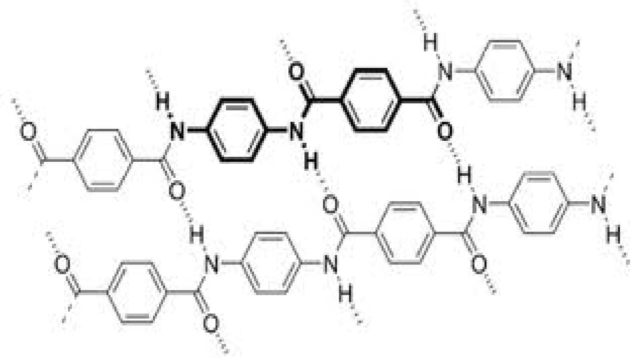
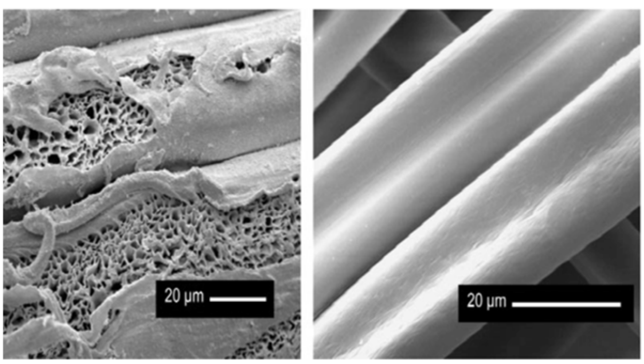


Fig.1. Chemical structure of Nomex



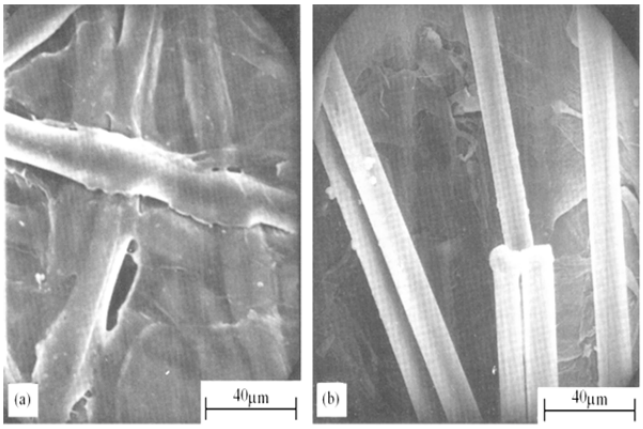


Fig.2. SEM pictures of Nomex type: 410 (a) and 411 (b) [2]

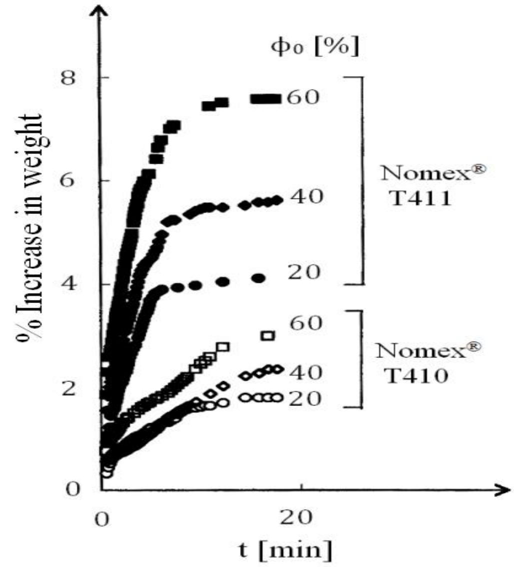


Fig.3. Water sorption curves of Nomex material at various relative moisture levels of air distances [2]

Thanks to stiff structure of macromolecules, they easily crystalize, both during production and processing. Nomax at 340-360°C crystalizes to so-called fibrils. In addition para-aramids in solutions may create liquid-crystal state, which makes their processing easier. Chemical structure of Nomex is presented on Figure 1.

The paper presents research on the moisture influence on dielectric relaxation of solid-liquid insulation based on Nomex impregnated with transformer oil.

Test object and methodology

To perform such research a special measurement set-up has been prepared with steel electrodes 20x20 cm large. Between these electrodes the sheet of Nomex type 410 was placed 0.76 mm thick (Figure 4).

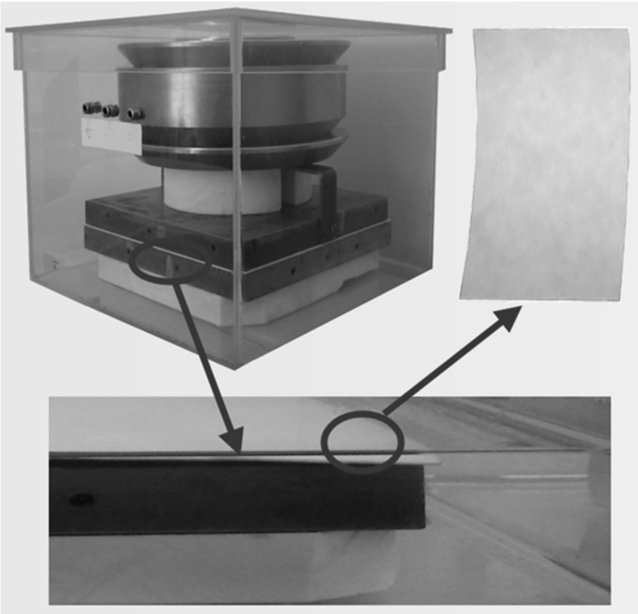


Fig.4. Test object – electrodes with Nomex

Required values of moisture level were achieved by drying Nomex at 150°C in laboratory vacuum chamber or through moisturization in Feutron climate chamber at relative air humidity 90% and temperature 24°C. The moisture level has been estimated on the base of weight changes measurements. The aramid paper after impregnation with Nytro Taurus transformer oil with moisture level 20 ppm was put into the climate chamber again, to perform measurements in temperature range from 0-50°C, at relative air humidity 30±5%. Relaxation processes were measured with FDS method (Frequency Domain Spectroscopy). As a measuring equipment a commercial system DIRANA OMICRON has been used, with frequency range from $10^{-4} \div 10^{3}$Hz. For presentation and analysis of test results Origin v.8.0 program has been used as well as WinFit Novocontrol. Basic parameters of relaxation functions in frequency domain were determined with general H-N equation (Havriliak-Negami) [3].

(1) $$\varepsilon(\omega) = -\mathrm{j}\left(\frac{\sigma_0}{\varepsilon_0 \omega}\right)^N + \sum_{k=1}^{2}\left(\frac{\Delta\varepsilon_k}{\left(1+\left(j\omega\tau_k\right)^{\alpha_k}\right)^{\beta_k}} + \varepsilon_{\infty k}\right)$$

where: $\Delta\varepsilon$ – polarizability, τ – relaxation time, ε_∞ – optical permeability, α, β – H-N constants, σ_0 – AC conductivity parameter.

Relaxation processes in time domain were examined with PDC method (Polarization Depolarization Current), with electrometer Keithley 6517A. Time domain characteristics of polarization current have been approximated with Jonscher LFD equation in wide time interval, in the form [4]:

(2) $$f(t) = A_1 t^{-n_1} + A_2 t^{-n_2}$$

where: t – time, A_1, A_2, n_1, n_2 – relaxation coefficients.

Test results of FDS and PDC method

From measurements there were taken series of FDS curves for insulating system Nomex-oil (Figure 5). It can be seen that the increase of moisture causes the capacitance value to grow in the whole frequency spectrum (Figure 5a) [5].

Observed relaxation time of process related to water presence in Nomex is several thousands of seconds (1) (Figure 6). The increase of moisture level leads to obtaining longer values of time constant of this process. It is characteristic for low frequency relaxation with ion mass transport to macroscopic. For moisture contents over 3÷3.5% there was observed rapid increase of this time, related probably with creation of large water agglomerates.

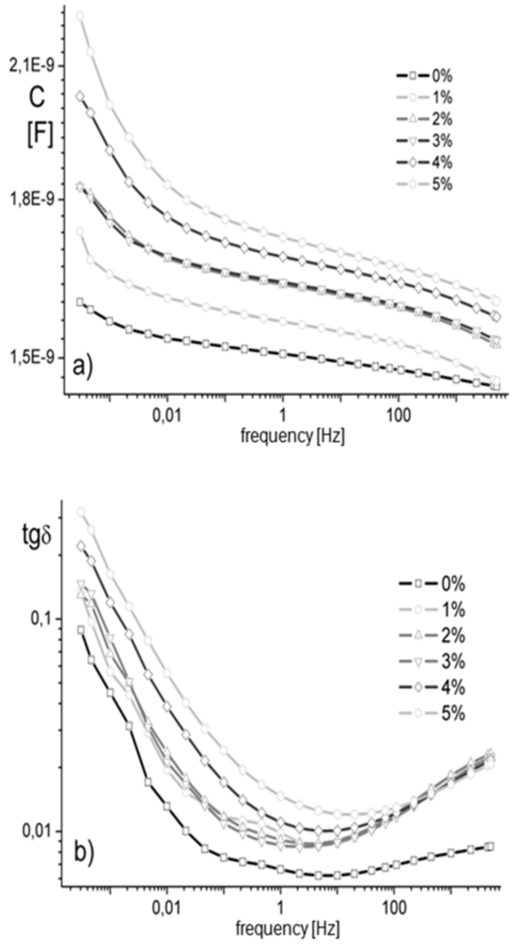


Fig.5. FDS characteristics for various moisture contents of Nomex-oil. Changes of capacitance C (a) and dielectric losses coefficient tanδ (b) [5]

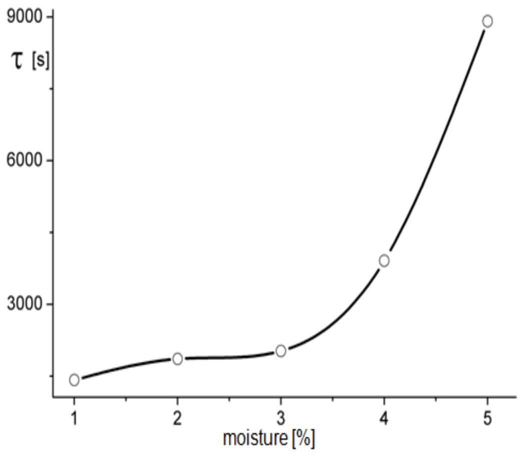


Fig.6. The change of time constant τ of low frequency relaxation process for various values of moisture

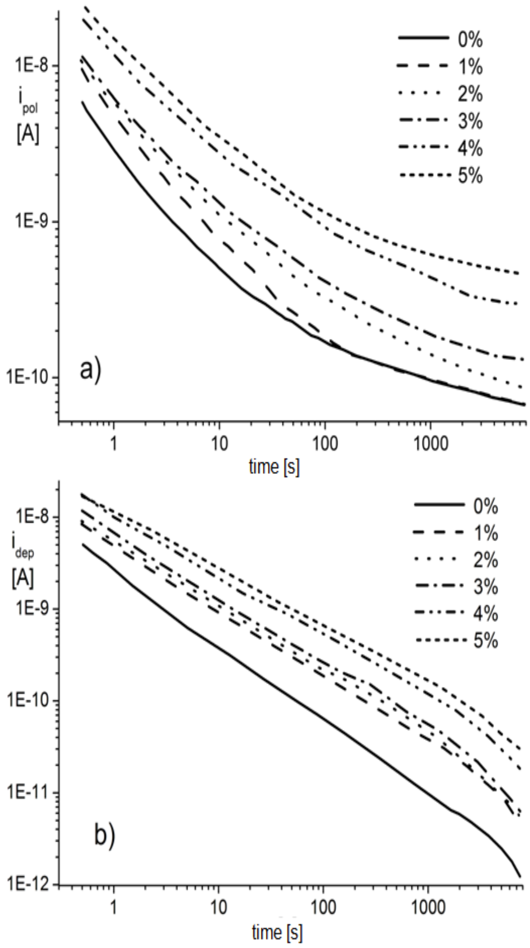


Fig.7. Dependences of polarization (a) and depolarization (b) current of mineral oil impregnated Nomex for various moisture contents

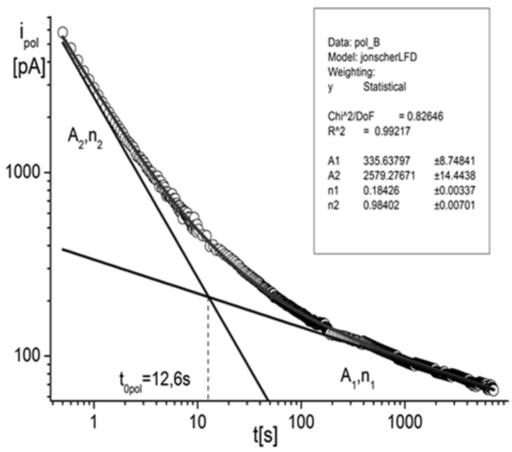


Fig.8. The analysis of relaxation process in time domain for dry Nomex impregnated with mineral oil

From measurements there were taken series of PDC characteristics for Nomex impregnated with transformer oil (Figure 7). It can be seen that the increase of moisture level causes polarization and depolarization currents to grow in the whole range of time. The characteristic feature of dielectric response of moist Nomex is that above 3% of moisture contents there is observed significant increase of polarization current, if compared to samples with lower water contents (Figure 7a). Similar effect has been observed during depolarization process (Figure 7b). It was noted, that the change of moisture level in range 1 ÷ 3% insignificantly influences the current value and dynamics of polarization and depolarization processes [7].

The qualitative analysis of dielectric response in time domain for oil impregnated Nomex having various levels of water contents was conducted with Jonscher LFD dependency (2). The exemplary analysis for impregnated, but dry Nomex sample has been presented on Figure 8.

The analysis allowed to determine t_0 parameter for various Nomex water contents. The physical interpretation of t_0 parameter is that it represents characteristic time after which relaxation process changes. For Nomex containing water amount up to 3% the value of time t_0 insignificantly raises, while above that value there is its rapid grow (Figure 9).

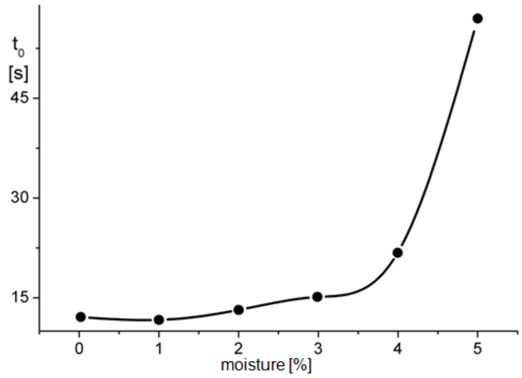


Fig.9. The dependency of t_0 parameter from moisture contents of impregnated Nomex

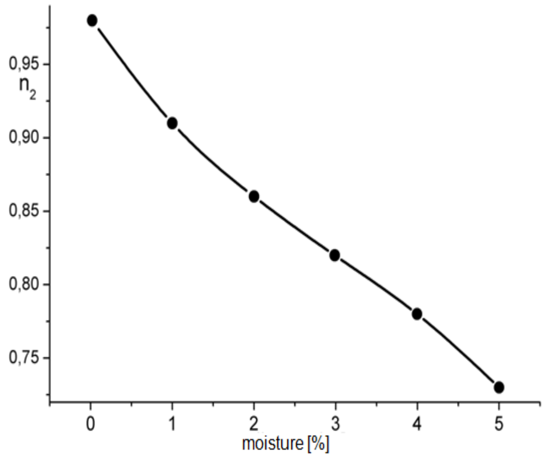


Fig.10. The dependency of n_2 parameter from moisture contents of impregnated Nomex

Parameter n_2 characterizes dynamics of fast changing relaxation process. With the increase of Nomex water contents parameter n_2 decreases linearly. For tested Nomex samples n_2 value is in the range 0.73 ÷ 0.98 (Figure 10). The analysis of results shows that assessment of HV insulation based on the oil and Nomex may be difficult in the range 0 ÷ 3.5% of water content. It is the result of low sensitivity of dielectric response on moisture level of impregnated Nomex.

Conclusion

Measurements of FDS and PDC of mineral oil impregnated Nomex for various level of water content showed that:

a) water amount in Nomex causes significant increase of dielectric losses in frequency range $10^{-4}÷10^{4}$ Hz, these loses seem to be related to water particles,

b) for moisture contents in the range 1 ÷ 3% the dielectric response of Nomex is practically constant and do not depend on water amount. It can be observed both for relaxation processes and AC conductivity,

c) for moisture level above 3 ÷ 3.5% there is rapid increase of conductivity current and relaxation process is significantly longer, which probable is the effect of creation of large water agglomerates or exceeding a percolation level for water particles in area of Nomex aramid fibres,

d) the comparison of test results with PDC and FDS methods allows to draw the conclusion that application of polarization processes and conductivity to assessment of moisture level of oil impregnated Nomex may be difficult, especially if compared to paper-oil insulation [8, 9].

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