Measurement of Teflon Membrane Characteristics Used in Electret Microphones

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This paper present the results of laboratory tests of electrical, thermal and mechanical characteristics for elastic membranes made from Teflon varieties, such as: per-fluoro-alkoxy (PFA) and fluoro ethylene propylene - (FEP), these membranes being used in construction of high stability microphones. Main parameters studied are acoustic sensitivity, relative electrical permittivity, volume resistance, density and rugosity. All these quantities are studied related with temperature and relative humidity of electrets working environment and with sound waves that hit membrane surface.

Keywords: electrets, microphone, Teflon membrane

The use of electrets as membranes for making superior quality microphones began in the 30's when such models were produced for the first time [1]. Electrets gradually developed so that in the 40's mass-production and trading of electret microphones began, based on better and better improved patents [2]. Electrets are non-conductive materials with implanted electrical charge or polarization charge. Advantages in using electrets as elastic vibrating membranes are multiple: lack of external power source, simple construction and high ruggedness, very good working characteristics, good frequency feedback, reduced vibrations and low harmonic distortions. The electret microphones with very good qualities have appeared relatively recently (after 1980) and are working very well. They can be miniaturized avoiding small sensitivity losses and have the ability to resist well in rough environmental conditions. Moreover, these microphones do not require an external voltage source since their own surface potential is already providing the necessary amount of voltage.

At the present time it does not know very well how a microphone behaves in difficult climatic conditions, especially it's electret membrane, neither how the surface potential of the electret is influenced by various metal parts of the microphone itself. Since making of electrical membranes and electret microphones with good characteristics began recently it is difficult to know the lifespan of these membranes and how their polarization is maintained in various conditions.

There are several methods for obtaining electrets, of which the most important ones are described in paper [3]. A classification depending on fabrication method is as follow: thermo electrets, photo electrets, radio electrets and implanted electrical charge electrets.

Thermo electrets are obtained by polarizing the dielectric at high temperature. Molecular dipoles and also electrical charges inside the dielectric become active when rising temperature and rotate in space after an outside electrical field E of approximately constant value is applied. If the cooling of dielectric is rapidly the dipoles and electrical charges block themselves in such positions so that finally a thermoelectret results.

Photoelectrets and radio*electrets* are obtained in the same manner as thermoelectrets, by introducing the dielectric into an electrical field, simultaneously with powerful outside optical field excitation, respectively with sonic field excitation that block the dipoles or electrical charges, thus resulting the electret.

*I*mplanted electrical charge electrets are obtained by irradiating the dielectric membrane in vacuum of conditions 0.0001 Pa with a mono-energetic electron beam, with an energy of 5 to 50 keV. In order to get an even irradiation, the beam is diverted by 2 perpendicular directions. The density of the electron beam current is about 0.0001 A/m^2 and irradiation takes somewhere between a few seconds to a few tens of seconds. Usually, for implanting the membranes from polymeric fluoroplastic materials are used with a thickness between (12...50) μm, the most widely used being Teflon type polymers like per-fluoro-alkoxy (PFA), fluoro ethylene propylene (FEP) and polytetrafluoroethylene (known as PTFE, or simply TFE). Paper [4] shows a layout for electret type PFA and FEP making by electrical charge implantation. The result consists in electrets with good time stability of surface potential, which can be determined in a more simply way than described in paper [5]. Paper [6] presents the behaviour and lifetime of electrets obtained by electrical charge implant, during heavy climatic conditions like temperature and humidity. The lifetime of an electret is defined as the amount of time elapsed starting at polarization, with initial surface potential V, until this potential decrease to 0.5 V. Concerning this, paper [6] states an empirical rule as follows: the maintaining time of the surface potential of an electret increases one order of magnitude if the surrounding environment temperature decreases by 30°C, the relative humidity remaining at dry air value. The lifetime of an electret microphone can reach up to 20 – 30 years in normal working and environment conditions.

A characteristic parameter for electrets is the density of superficial electric charge, ρ_S. The higher is this value the better the qualities of the electret are. Determination of ρ_S can be done by directly measuring the electrostatic force applied to the electret when it is placed in an electric field of known value [7]. Density values usually vary between ($1.3 \cdot 10^{-5}$ - $2 \cdot 10^{-4}$) C/m^2. Directly linked to superficial charge of the electret is also electret surface potential. Surface potential is a quantity which characterizes the surface and entire volume of the material [8]. The testing samples were as 2.5 cm wide squares. Considering these dimensions, after polarizing and depolarizing the dielectric plates in electric field, the surface potential resulted in values up to

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350 V. These values, measured as described in paper [4] are reasonably high enough, knowing that an electret microphone can well be used until its surface potential drops to 175 V, therefore until the electret is functioning throughout his entire lifetime. In other words, the guaranteed lifetime of an electret is ensured if its surface potential has a value of at least 350 V.

The quality of an electret microphone is directly linked to acoustic sensitivity S, defined as the ratio between the surface potential V with which the electret has been polarised and the sonic pressure p_o of the sound picked up by the microphone. An expression (3) giving an aproximative correlation of sensitivity with the microphone dimensions:

$$S = \frac{D s_o \rho_s}{\varepsilon_o \gamma p_o \cdot (D + \varepsilon_r s_1)} \quad (1)$$

where

D is the displacement of the microphone membrane due to the sonic pressure,

s_o and s_1 are the thicknesses of the air layers between the diaphragm and the metal support of the microphone in conditions when the diaphragm is not sonically stressed, and respectively, when it receives a sonic wave,. Other parameters involved in equation (1) are p_o the value for atmospheric pressure, $\varepsilon_o = 1/(4\pi \cdot 9 \cdot 10^9)$ [F/m] is the electrical permittivity of vacuum, ε_r is the relative electrical permittivity of the electret dielectric and γ is a non-dimensional coefficient, depending on construction type of the microphone. We find that the acoustic sensitivity does not depend on the Teflon electret membrane surface area, a major advantage which has lately led to miniaturization.

Experimental part

Our paper presents the experimental determinations of the working characteristics and measuring the basic parameters of Teflon dielectrics which are the basis in electret microphone making. These determinations lead, many times, to long time experiments, a disadvantage for researches in this area.

In order to measure the electret dielectric properties (electrical permittivity and dielectric phase angle) a disk capacitor with both metal armatures was used. The first armature is a square metal plate 100mm wide, over which the dielectric of same shape and size is settled, with good adherence. The second armature is a circular metal electrode, 50 mm in diameter, made by vacuum deposition over the electret dielectric (fig. 1).

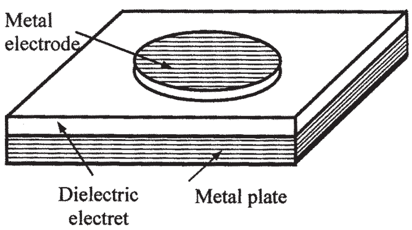

Fig. 1. Capacitor layout for measuring electret dielectric properties

Results and discussion

The preservation of electret microphone qualities depends on keeping the electric and acoustic properties of the used membranes. These properties refer to: surface potential, superficial electrical charge density, membrane surface rugosity, microphone sensitivity, relative electrical permittivity, volume resistivity and membrane density. Of course, each of these parameters is directly linked to temperature and environmental humidity, as well as to sound wave frequencies picked up by the microphone membrane. As resulting from paper [4], the surface potential decreases very little in time in normal conditions. Also, microphone sensitivity decreases not significant in time, that should be an advantage for this type of microphone. In this respect, the measuring of electrical and mechanical characteristics of electrets laboratory can take a lot of time to complete. For example, determining the acoustic sensitivity of an electret microphone can take up to 20 months. The acoustic sensitivity can be determined experimentally using its definition or expression (1). We found out that it depends mostly on the surface potential value of the electret. Using expression (1), our measurements have been made at intervals of about one month, in 20 months total time. Acoustic sensitivity have been determined for two distinct values of environment humidity: 95% humid air and dry air at a constant environment temperature of 20°C in both cases.

One can find that small differences between the two cases exist, in both situations the value being approximate constant in time (varying about 5% in 20 months).

Microphone sensitivity does not depend on the surface of its elastic membrane as seen in expression (1). Thus, by decreasing the geometric dimensions does not lead to loss of acoustic sensitivity, a fact which encouraged miniaturization of electret microphones.

A very important feature in describing the electret is the rugosity of the Teflon membrane which has to be less than 2000 Å. Improving microphone membrane quality can be done by its superficial layer surface with silicon, silicon dioxide, gold, chrome, copper, etc. using specific micro-electromechanical systems MEMS.

The relative electrical permittivity, dielectric constant, ε_r characterizes the electret dielectric nature offering information about the specific electrical energy stored, energy loss and electrical polarization. While temperature increases, the thermal agitation of molecules is amplified and the orientation of electrical moments to the direction of the electric field is reduced resulting in immediate fall of electrical permittivity [9].

In case of strong environmental temperature variation, the electrical permittivity of the Teflon membrane varies significantly.

The capacitor shown in Fig.1 is placed into a Faraday cage with one electrode linked to ground while the other is linked to the voltage terminal of the measuring bridge (Hewllet-Packard 4284A Bridge). Measurements were made according to NF-C-26-200 and NF-C-26-230 standards. Figure 2 exhibits how electric permittivity of an electret with fluoro-ethylene-propylene (FEP) membranes varies with temperature.

From figure 2 we find that if environmental temperature increases from -60°C up to 240°C, electric permittivity decreases from a value of 2.28 down to 2.03. The decrease is linear with higher steepness within (50°C – 100°C) temperature interval.

Electrical permittivity of polymeric membrane also varies with the frequency applied to the dielectric, exhibiting a dielectric dispersion. However, for audio frequencies, up to $2 \cdot 10^4$ Hz which are applied to the electret, this variation is altogether non-important. We noticed that values from which electrical permittivity varies significantly have much higher values compared to audio frequencies, in the domain of (10^8...10^9) Hz [10].

Figure 3 shows how the dielectric constant of fluoro-ethylene-propylene (FEP) membrane varies with frequency. During measurements polymer temperature was

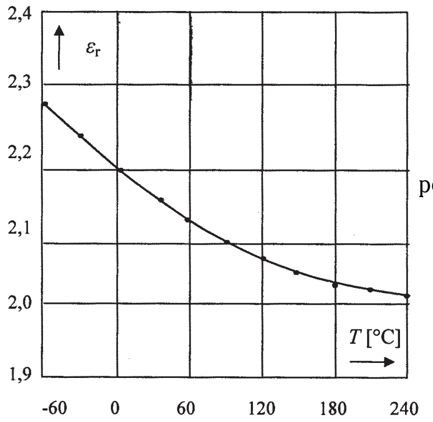

Fig. 2. Electrical permittivity/temperature ratio for FEP polymer

maintained constant at 20°C. For frequencies below 10^7 Hz, FEP relative electrical permittivity is practically constant, descending very slowly as frequency increases. At usual working frequencies for electret microphones (acoustic domain), electrical permittivity maintains almost constant, decreasing an average of 0.3‰ as frequency increases (fig. 3).

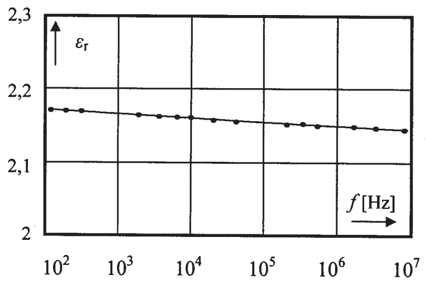

Fig 3. Semi-logarithmic dielectric dispersion of FEP polymer

Due to high values of biding energy between C and F atoms, fluoro-plastic polymeric materials (Teflon) have high thermal stability. For this reason their dielectric and mechanical proprieties are well preserved up to 250°C, a temperature which is more than twice of the thermal stability temperature of most polymerizing resin based materials like PVC, polystyrene, polyethylene, etc. [10]. This good thermal behavior makes fluoroplastic materials useful for practice at high temperatures thus having numerous applications in technology.

The polymer electrical resistivity is influenced by a series of factors, like polymer chemical nature and structure, temperature, environmental humidity, outside electrical field, impurities. All these factors must be known and controlled when resistivity is measured. The method used for measuring resistivity is the four probes method. In case of electret microphones, the membrane is settled upon a metal support with good adherence. For this reason, as thickness increases, the resistivity decreases. This happens due to the presence of the metal support immediately close to the Teflon layer. Fig. 4 shows the resistivity variation of the Teflon-metal support ensemble with Teflon layer thickness for FEP membrane. Measurements were made in dry air at constant temperature of 175°C.

Teflon density highly varies with temperature, which is an important disadvantage. The high temperature variations can produce cavities in the structure. Also if working in intense electrical field areas, partial discharges may occurs, prematurely damaging the materials. This is why they are used in low intensity electrical field environments. Although Teflon lasts very well at high temperatures and high humidity environments, it doesn't work as well in the presence of intense electrical fields as other sensitive-like materials.

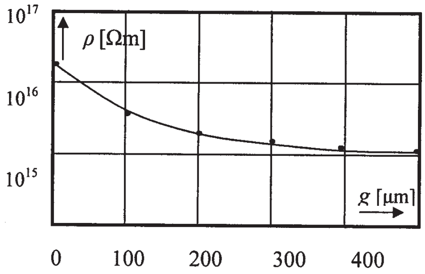

Fig. 4. Variation of Teflon-metal support ensemble with thickness for FEP membrane

Depending on its crystalline structure, Teflon can be: crystalline, semi crystalline or non-crystalline. Thus the corresponding variations of density with temperature are linear up to melting point. Figure 5 show the linear straights obtained for PFA and FEP polymers. As it can see, there are very little differences between FEP or semi crystalline PFA densities comparing the same crystalline structures. Meaningful differences are found between crystalline or semi crystalline with non-crystalline Teflon.

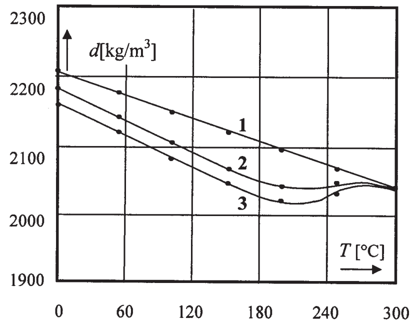

Fig. 5. Density/temperature dependence for PFA and FEP Teflon types: 1 – non-crystalline Teflon; 2 - semi crystalline Teflon; 3 – crystalline Teflon

Conclusions

Teflon, as a polymeric material with all its varieties, is used for electret microphones because it has remarkable electrical, thermal and mechanical properties compared to other materials used for the same purpose. Among these qualities we can mention: ability to be polarized with high surface potentials (up to 350 V), good behavior at high temperatures (up to 250°C), very good water resistance which enables it to be used in high moisture environments (up to 99%), very long lifetime in normal environmental conditions (over 20 years), good acoustic sensitivity (independent of diaphragm surface), which can be maintained for long time at high values, very good behaviour at high frequencies (up to 10^7 Hz).

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„NOUTĂŢI ÎN CONSERVAREA ŞTIINŢIFICĂ A LEMNULUI VECHI POLICROM"

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Lucrarea propune o abordare interdisciplinară privind implicarea unor noi materiale şi procedee de prezervare şi restaurare a lemnului vechi policrom, prin studierea impactului unor componente active asupra caracteristicilor chimice, fizico-structurale şi mecanice ale suporturilor din lemn vechi indigen.

Partea bibliografică a lucrării se bazează pe o atentă prelucrare şi sistematizare a unui material de referinţă recent şi bogat, constând într-un mare număr de studii publicate în ultimii ani, până în 2009, menţionat la sfârşitul fiecărui capitol. Cele şase capitole, desfăşurate pe parcursul a 282 de pagini, aduc în discuţie diverse teme, de la aspecte privind analiza stării de conservare a lemnului vechi policrom, până la o serie de experimente, care au urmărit mai multe direcţii de cercetare:

- stabilirea unor *relaţii de complementaritate (coroborare şi coasistare)* şi *interdisciplinaritate* între diversele *tehnici de analiză,* în vederea realizării unui protocol experimental, cu implicaţie în studiul *naturii chimice, structurii fizice* şi a unor *caracteristici mecanice* ale componentelor din structura lemnului vechi policrom pentru stabilirea stării de conservare, respectiv ale unor noi materiale şi procedee implicate în prezervare activă şi restaurare, în vederea elaborării de tehnologii compatibile de intervenţie;
- fundamentarea problematicii legate de domeniul normal de variaţie a echilibrului hidric şi elaborarea unei metode, cu tehnica aferentă pentru determinarea acestuia şi a metodologiei de implicare în diverse experimente, cum ar fi: evidenţierea unor caracteristici arheometrice şi respectiv, evaluarea impactului tratamentului de prezervare activă asupra conservabilităţii lemnului;
- studii privind comportarea în timp a unor tratamente de prezervare activă a lemnului vechi policrom.

Astfel, în capitolul I se prezintă structura lemnului policrom, respectiv a unei picturi pe lemn, urmată de prezentarea celor mai frecvente cazuistici ale stării de conservare întâlnite des, în deosebi la iconografia ortodoxă. De asemenea, tot în acest capitol se au în vedere factorii şi procesele de destrucţie şi de alterare, respectiv formele de deteriorare şi degradare ale picturilor pe lemn, precum şi influenţa altor materiale (de exemplu: metale) asupra conservabilităţii lemnului vechi pus în operă.

Capitolul al II-lea este consacrat descrierii materialelor, proceselor şi operaţiilor implicate în prezervarea şi restaurarea lemnului policrom, avându-se în atenţie principalele sisteme moderne cu acţiune multiplă insectofungică, ignifugă şi hidrofobizantă pentru lemnul vechi pus în operă (substanţe pe bază de bor, piretroizi de sinteză, compuşi organofosforici, produse organice naturale).

În capitolul al III-lea se prezintă principalele tipuri de lemn, care permit structuri policrome, mai ales cele utilizate în vechime. Apoi se prezintă modul de prelevare şi prelucrare a probelor pentru analize, provenienţa, starea de conservare şi caracteristicile dendrocronologice ale acestora. De asemenea, tot în acest capitol se descriu metodele şi tehnicile implicate în analiza suporturilor din lemn şi a policromiilor, în studiul impactului tratamentelor de prezervare activă asupra lemnului vechi pus în operă şi în analiza solvenţilor şi a principiilor active utilizate în reţetele de prezervare activă şi restaurare. Autorii au avut şansa de a dispune şi folosi tehnici micro-distructive sau ne-invazive moderne de investigare ştiinţifică, prin implicarea sistemelor de coasistare şi de coroborare, cum ar fi: microscopia optică de reflexie şi de transmisie (MO), cu procesare statică sau dinamică digitală, microscopia electronică de scanare sau baleere (SEM), cuplată cu microsonda de Dispersie Electronică de raze X (EDX), spectroscopia IR, FT-IR sau micro FT-IR, Microscopia optică în „cross-sections", cuplată cu „staining tests" şi altele.

În capitolul al IV-lea sunt analizate caracteristicile dendrologice, arheometrice, chimice şi fizico - structurale ale unor probe de lemn reprezentative ca suporturi pentru bunuri de patrimoniu cu structuri policrome, alături de o serie de caracteristici ale stratului pictural, ambele implicate în analiza stării de conservare a celor două componente (suport şi policromie).

Capitolul al V-lea abordează noi materiale folosind sisteme organice pe bază de petrol roşu de Câmpeni, propolis şi tanin şi procedee de prezervare activă a artefactelor din lemn policrom.

Captolul al VI-lea cuprinde studii privind evaluarea impactului tratamentelor de prezervare activă şi restaurare a lemnului natur şi policrom cu unele principii active.

Lucrarea are un grad ridicat de originalitate şi reprezintă o contribuţie importantă în domeniul cercetării unor noi materiale şi procedee utilizate în tratarea lemnului policrom din bunurile de patrimoniu, în vederea stopării proceselor evolutive de deteriorare şi degradare. Este meritoriu de semnalat câteva dintre elementele originale ale lucrării: obţinerea unor soluţii organice ecologice pentru tratarea lemnului policrom, care au fost brevetate prin trei procedee; apoi fundamentarea, în premieră prin experiment, a termenului de domeniu normal de variaţie a echilibrului hidric al lemnului, cu elaborarea unei metode de determinare a acestuia (de asemenea, brevetată) şi care are multiple aplicaţii practice, printre care amintim: evidenţierea modificărilor unor caracteristici sub influenţa tratamentelor de prezervare a lemnului vechi pus în operă. Aceasta a permis prin studiul proceselor de hidratare – deshidratare, folosind sistemul de corelare a curbelor de sorbţie-desorbţie a apei higroscopice reversibile şi prelucrarea matematică a acestora, prin derivatele de ordinul I şi II, determinarea impactului diverselor tratamente de prezervare şi restaurare asupra lemnului şi stabilirea unor caracteristici cu valoare arheometrică, dintre care amintim: *timpul critic de corelaţie, umiditatea medie de corelaţie* şi *umiditatea maximă de adsorbţie*. De altfel, autorii au implicat un protocol experimental simplu prin utilizarea sistemelor de coasistare şi coroborare între o serie de metode şi tehnici moderne de investigare ştiinţifică, cum ar fi: micro-FT-IR, SEM-EDX, microscopia optică prin „cross-sections", cuplată cu „staining tests" şi altele, care au permis evidenţierea puterii de penetrare a principiilor active utilizate în tratamentele de prezervare şi a conservabilităţii constituenţilor structurali din lemnul tratat; evaluarea modificările fizico-structurale (variaţiile dimensionale traduse prin dilatare şi contragere, densitatea şi porozitatea) ale probelor de lemn (tei, plop) în urma tratării cu sisteme disperse (petrol roşu şi soluţie alcoolică de propolis).

Lucrarea se adresează, în primul rând, studenţilor, masteranzilor şi doctoranzilor de la specializările de conservare a bunurilor culturale şi naturale, dar şi specialiştilor şi colaboratorilor din reţelele Ministerului Culturii, Ministerului Mediului şi Dezvoltării Durabile, Ministerul Transporturilor, Construcţiilor şi Turismului, precum şi proprietarilor de monumente şi alte obiecte de artă din lemn.

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