INNOVATION IN POLYMER NANOCOMPOSITES

"GREEN" POLYMER ADDITIVES AND POSSIBILITIES OF EFFICIENT USE OF EPOXY WASTE (EVENT–PUBLIC)

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Properties of liquid-solid insulation composed of bio-oil and bio-polymer (cellulose), used in power transformers

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1. Introduction

In the new power transformers cellulose is almost dry (***x* < 0.8 wt.%**).

The increase of moisture in cellulose insulation during many years of exploitation have influence on the safety transformers..

According to the operative pertinent US standard doubling of the moisture content level in the insulation reduces the insulation lifetime by a half. Additionally, at the moisture content higher than **2.5 wt.% the degradation process accelerates.**

For ***x* > 5.5 wt.%** it may be an accident (explosion) of the transformer.

The dominant part of the moisture there is in the cellulosic insulation component. Water release from cellulose insulation may lead to increased pressure in the vat, partial discharge in water vapor bubbles (bubble effect), which may result in fire or explosion of the transformer.

2. Properties of insulationg liquids

The paper and pressboard has been used as a basic insulation material for high voltage power transformers. For many years to the impregnation of cellulosic materials has been used for **mineral oil**. Paper - oil insulation has very good insulation and cooling properties. This insulation, despite its advantages, doesn't completely meet the requirements of today.

	Units	Synthetic ester	Natural ester	Mineral oil
Physicochemical properties				
Solidification temperature	°C	-60	-21	-50
Flash-point	°C	316	360	170
Smoking temperature	°C	260	316	150
Biodegradable	%	89	97	10
Dielectric properties				
Breakdown voltage	kV	>75	>75	70
tgδ in 90C°	-	3,2	3,1	2,2

2. Properties of insulationg liquids

Innovative new transformer fluid

Nynas recently launched a game-changing product – its second bio-based oil – within the power transformer space. NYTRO® BIO 300X is designed to meet the increased environmental awareness and rising pressure on electricity networks.

	NYTRO® BIO 300X	NYTRO® LYRA X	NATURAL ESTER	SYNTHETIC ESTER
Viscosity 40°C [cSt]	3.7	9.5	35	29
Density 20°C [kg/dm^3]	0.785	0.870	0.920	0.968
Oxidation Stability IEC 61125	>500 hours	>500 hours	48 hours	164 hours
Biodegradability OECD 301	Readily	Inherently	Readily	Readily
Bio-Based Carbon ASTM D6866	>99%	0%	≈95%	≈50%

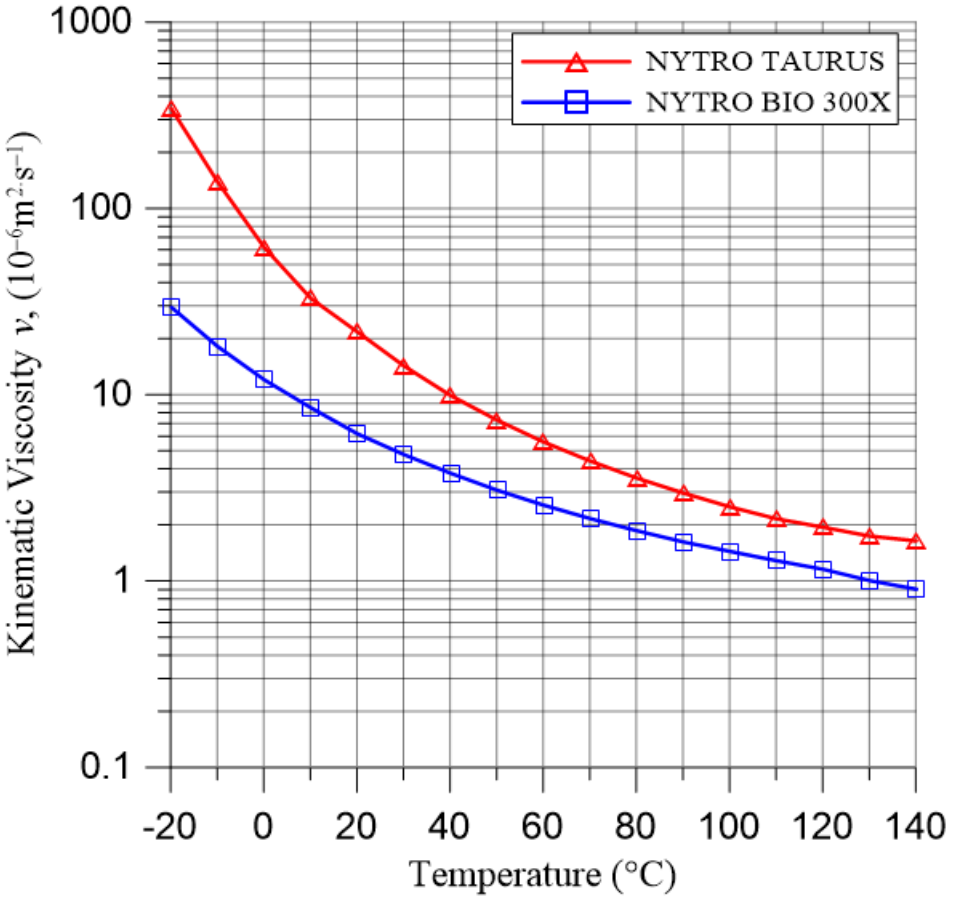
2. Properties of insulationg liquids

The most commonly used materials for constructing the insulation of power transformers have been mineral insulating oil and cellulose in the form of pressboard and paper. This type of insulation is called paper-oil insulation or alternatively, liquid-solid insulation.

The oil in transformer insulation performs three basic functions.

- cooling the active part of the transformer – mechanical parameters (kinematic viscosity and density) and thermal parameters (thermal conductivity and specific heat);
- participation in the insulation system (breakdown voltage);
- impregnation of the cellulose component (increases the electrical strength of cellulose, slows down the aging processes in cellulose).

3. Mechanical and thermal parameters of Nytro Bio 300X

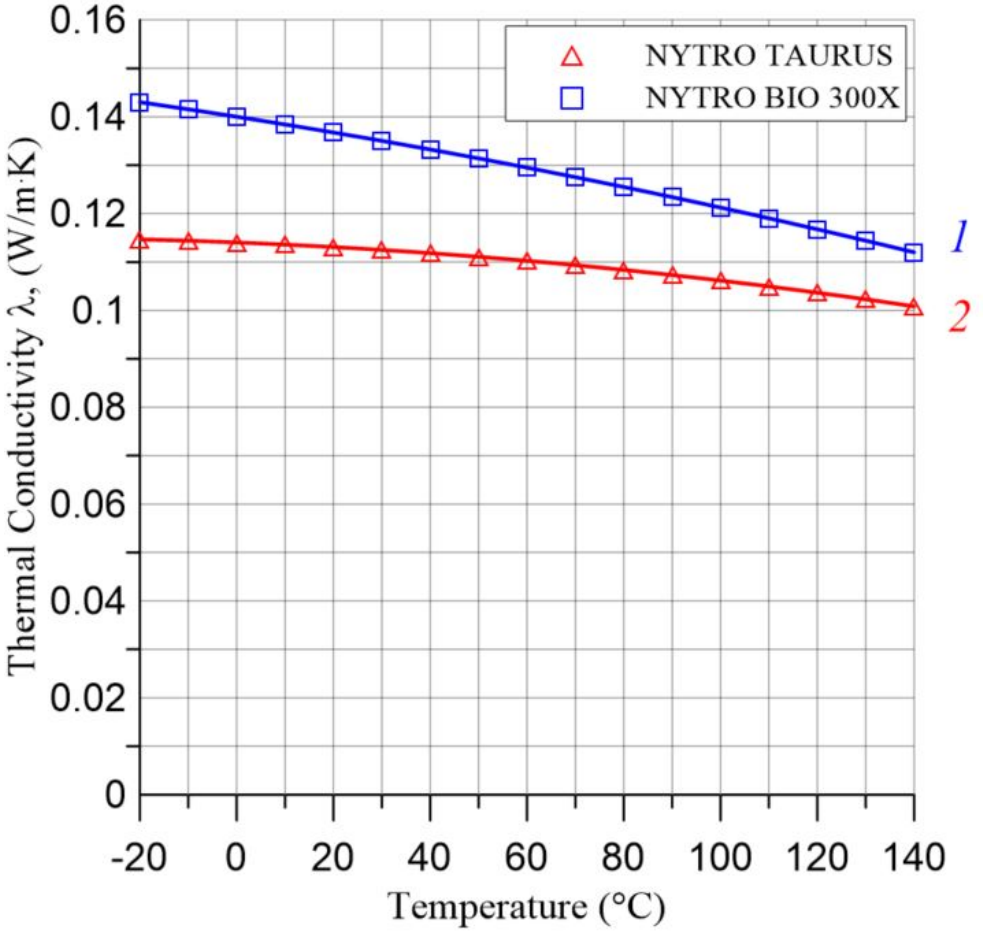


Kinematic Viscosity

- standard ISO 3104:2022
- The lower the kinematic viscosity value, the better the oil flow and cooling conditions of the active part of the transformers.

Fig. 1. Temperature dependence of kinematic viscosity of NYTRO® BIO 300X oil and Nytro Taurus petroleum-based mineral oil.

3. Mechanical and thermal parameters of Nytro Bio 300X



Thermal conductivity

- standard ASTM D7896-19
- The higher the thermal conductivity cause faster heat dissipation from the active elements of the transformer

Fig. 2. Temperature dependence of thermal conductivity of bio-oil – 1 and petroleum-based mineral oil – 2.

3. Mechanical and thermal parameters of Nytro Bio 300X

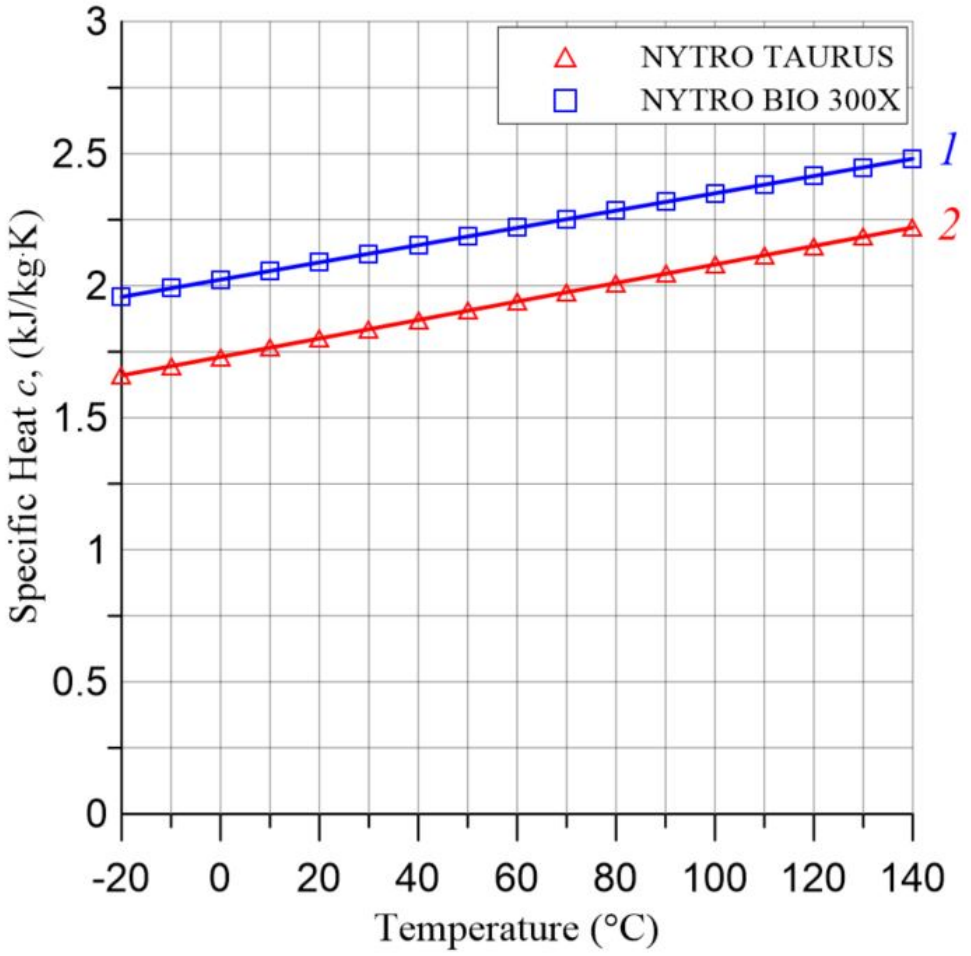
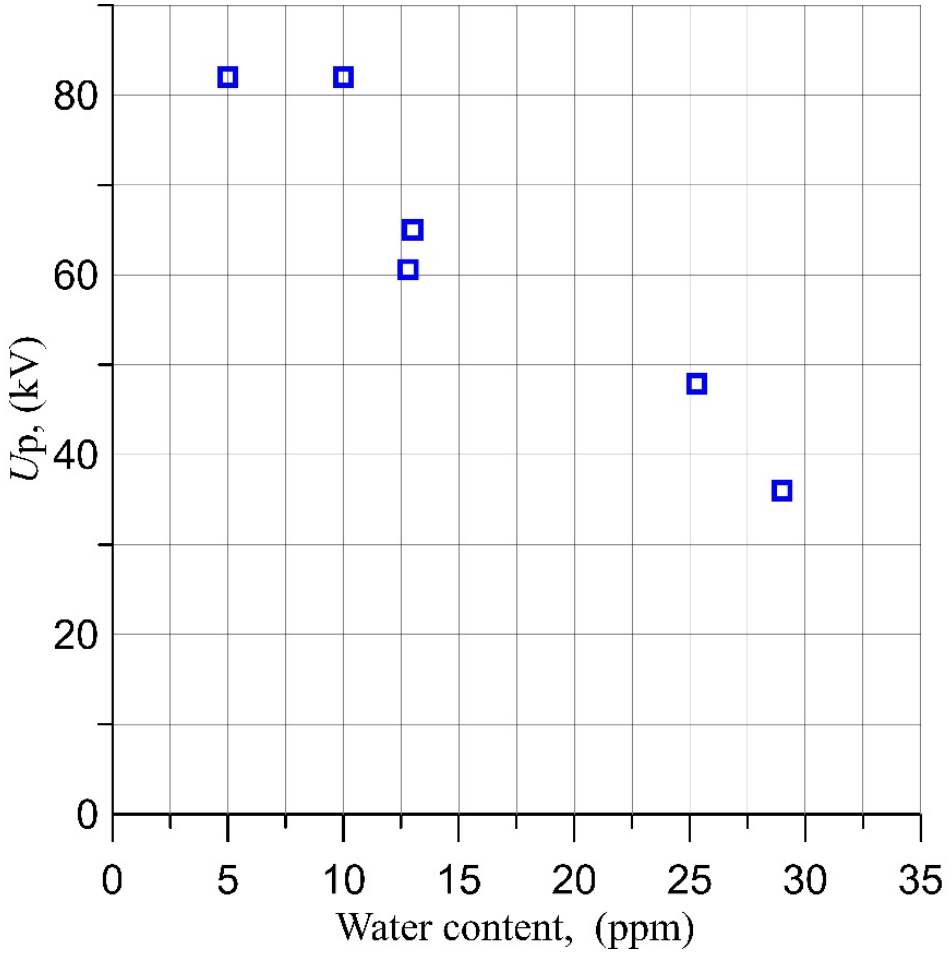


Fig. 3. Temperature dependence of specific heat bio-oil – 1 and mineral oil – 2

Specific heat

- standard ASTM D2766
- The higher the specific heat cause higher heat removal from the active elements of the transformer per unit mass of oil

4. Electrical parameters of Nytro Bio 300X



Breakdown voltage

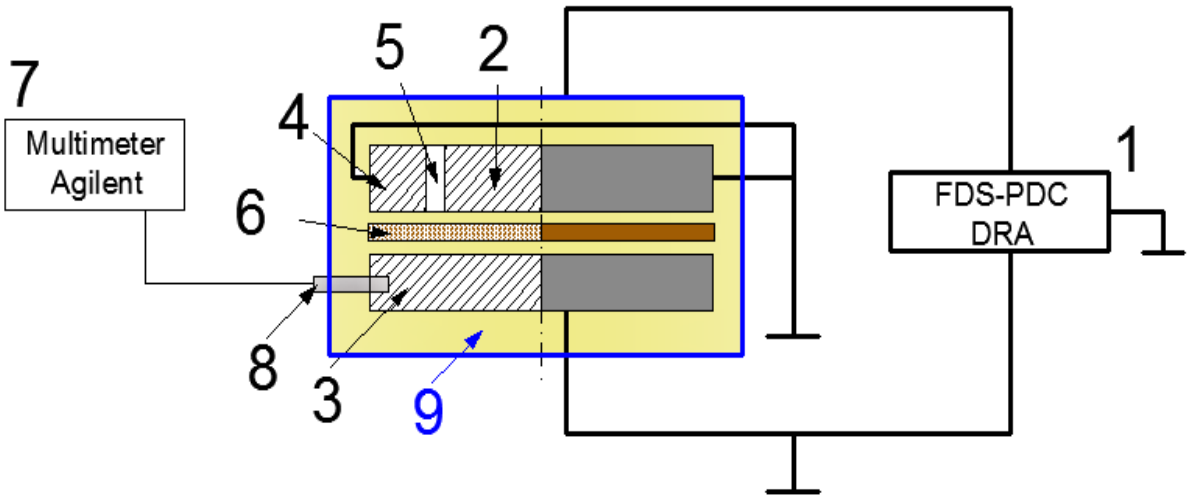
- standard IEC 60156:1995
- Breakdown voltage for mineral oil and Nytro Bio 300X is the same (approximately)

Fig. 4. Dependence of breakdown voltage of NYTRO® BIO 300X bio-oil on water content.

5. Measurement stand

The problem of moisture gathering in the solid component of power transformers containing oil or bio-oil makes it very important to determine it precisely.

Non-destructive electrical methods are most often used for this. Those methods fall into two main groups. The first one includes methods based on measurements in the time domain like the return voltage measurement (RVM) and the polarization-depolarization current measurement (PDC), while in the other group there are methods based on measurements using frequency-domain spectroscopy (FDS).

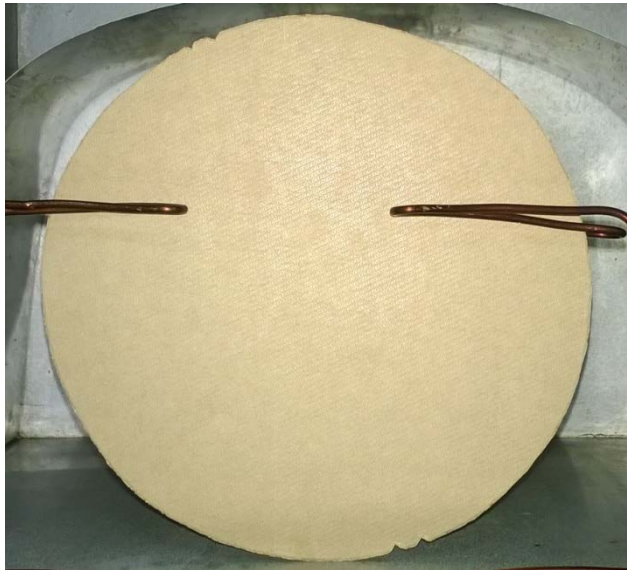


Measuring temperature range: from 293 K to 343 K

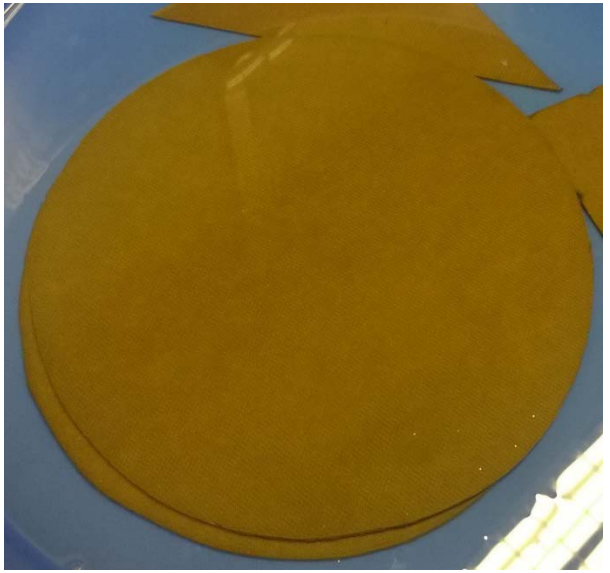
Fig. 5. Block diagram of the stand for direct current measurements of the electrical properties of the liquid-solid insulation, 1 – FDS-PDC Dielectric Response Analyser (Dirana meter); 2 – voltage electrode; 3 – measuring electrode; 4 – protective electrode; 5 – insulator; 6 – pressboard impregnated with bio-oil; 7 – Agilent temperature meter, 8 – PT 1000 temperature sensor; 9 – climatic chamber.

6. Samples preparation

- Drying in a vacuum chamber at a temperature of T = 80 °C, t = 72h,
- samples of pressboard absorbs moisture from the atmosphere increasing your mass,
- pressboard immersed in bio-oil to the impregnation process
- the sample was seasoned for 14 days at 318 K (45 °C)
- Prepared 6 samples about 1 wt.% to 6 wt.% with step 1 wt.%



(a)



(b)

Fig. 6. Pressboard sample before impregnation (a)
during the impregnation of the bio-oil – Nytro Bio 300X (b)

7. Electrical properties of pressboard impregnated bio-oil

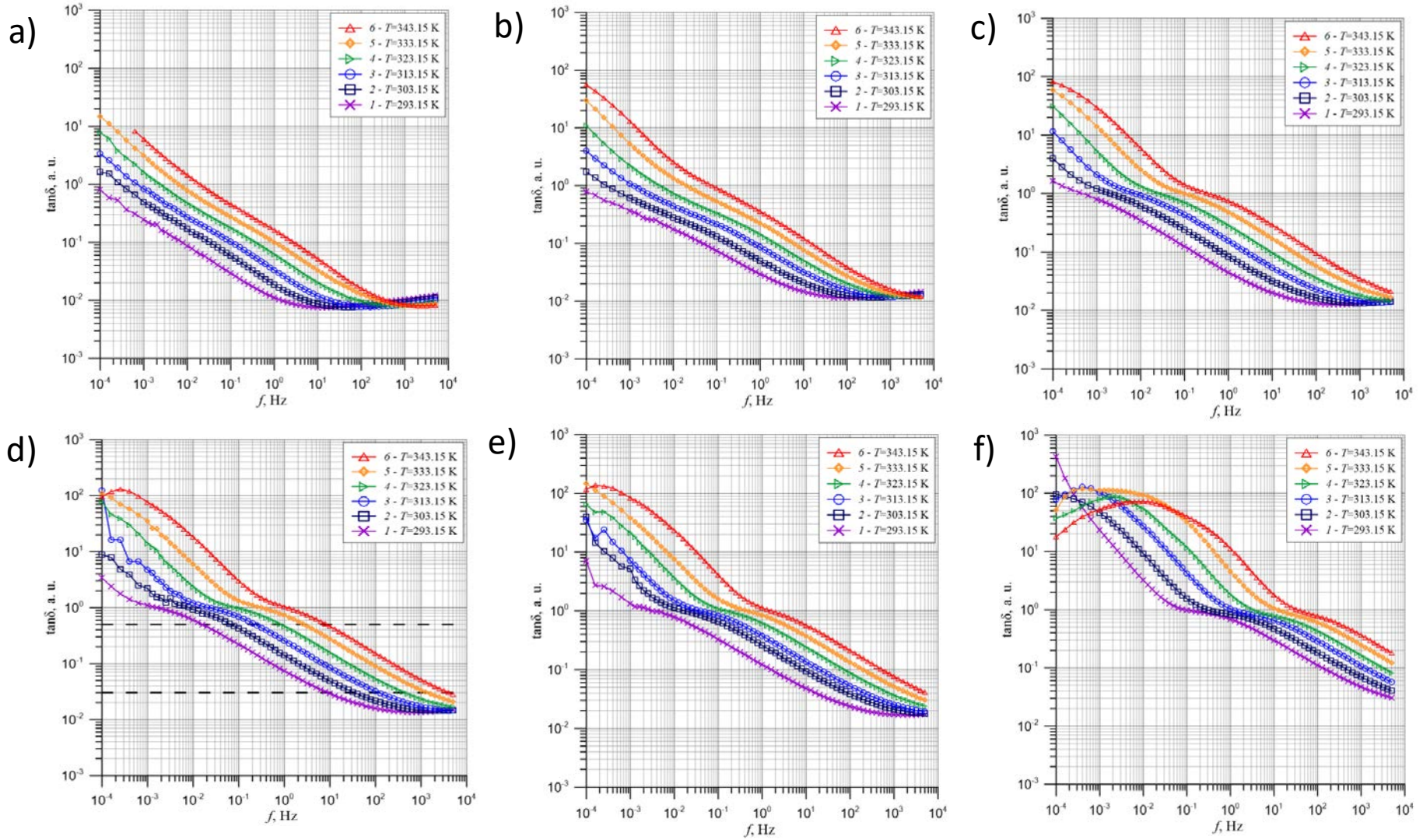


Fig. 7. Frequency dependencies of the tangent of the loss angle of moistened pressboard impregnated with NYTRO® BIO 300X bio-oil: a – moisture content 1 % by weight; b – 2 % by weight; c – 3 % by weight; d – 4 % by weight; e – 5 % by weight; f – 6 % by weight at temperatures from 20 °C to 70 °C.

7. Electrical properties of pressboard impregnated bio-oil

a)

b)

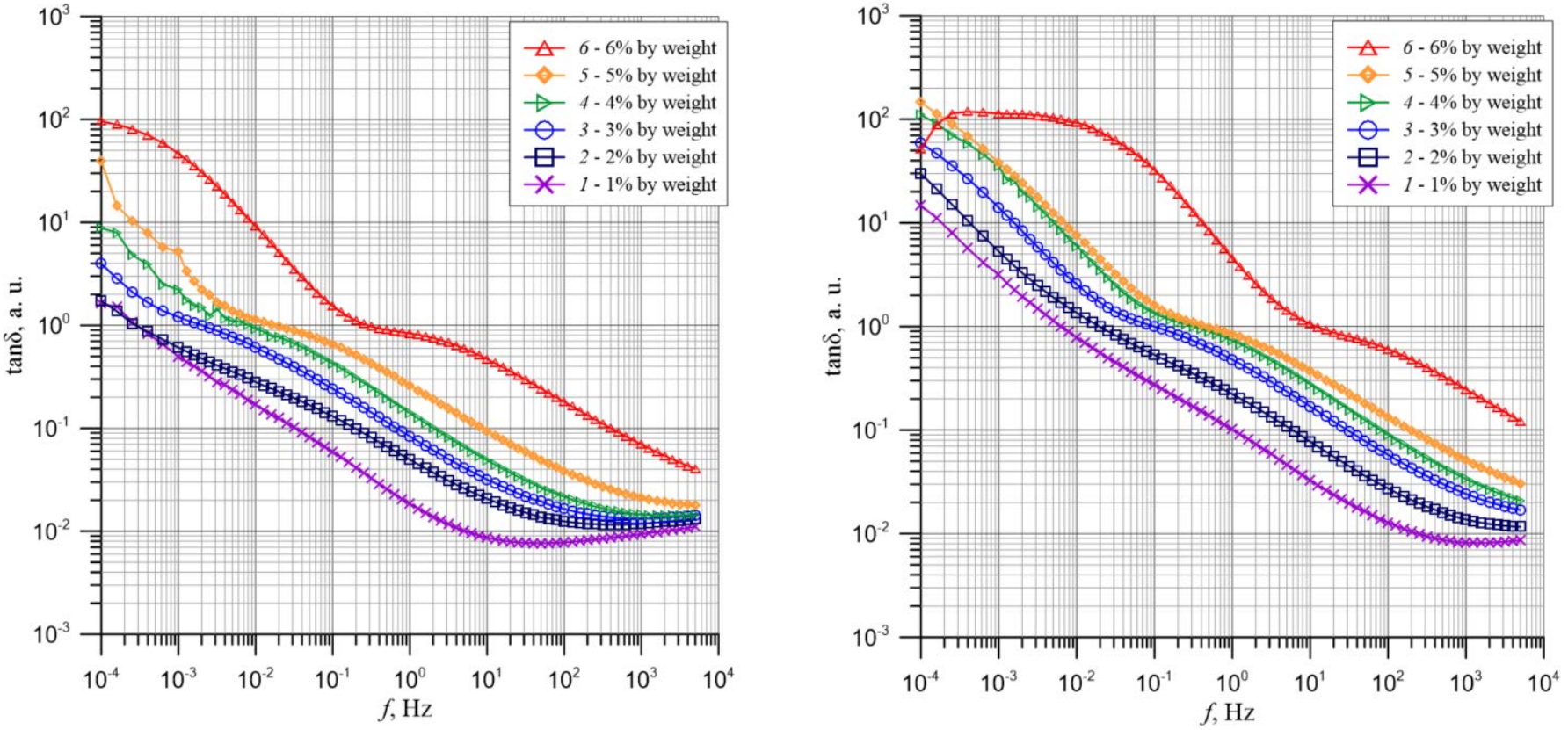


Fig. 8. Frequency dependencies of tanδ measured at 30 °C (a) and 60 °C (b) for moisture content from 1 % by weight up to 6 % by weight.

7. Electrical properties of pressboard impregnated bio-oil

The measurement results, presented in Figure 9d, were made for the same sample at different temperatures. The activation of energy we will calculated by transform the formula:

$$\tau = A\exp\left(\frac{\Delta W_\tau}{kT}\right) \qquad (1)$$

where: A = const.

Formula shows that in the tested sample, due to the constant concentration of the potential well, the relaxation time depends only on the temperature.

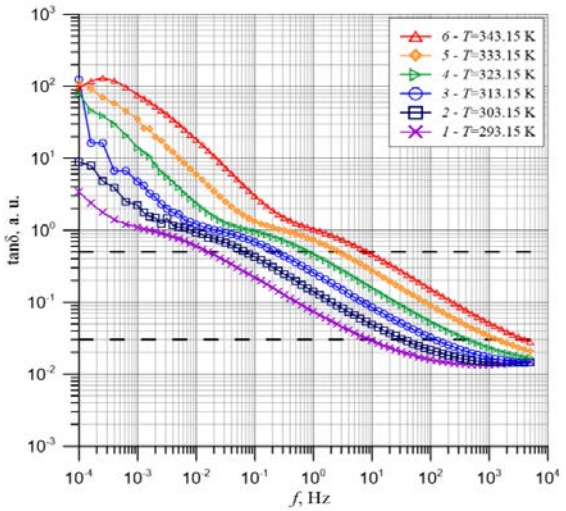


Fig. 9. Frequency dependencies of the tangent of the loss angle of moistened pressboard impregnated with NYTRO® BIO 300X – 4 % by weight;

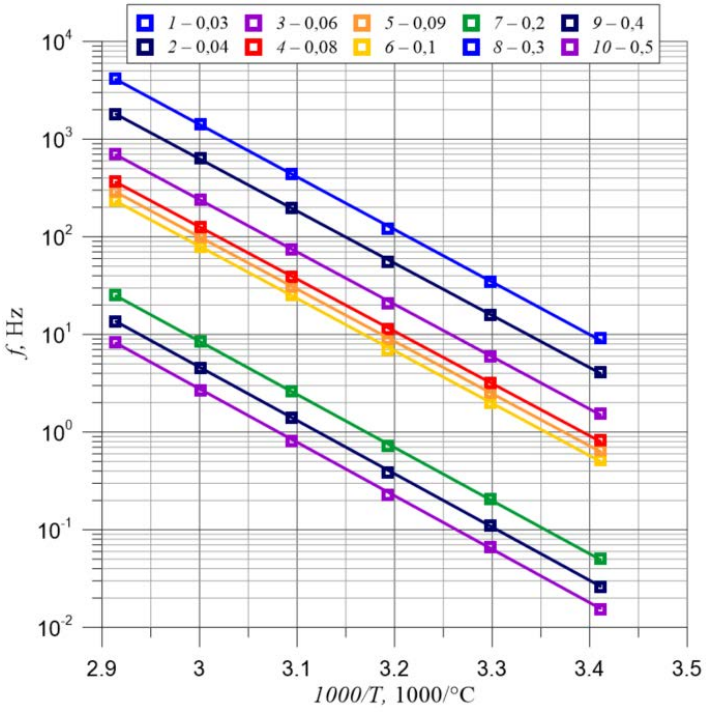


Fig. 10. Arrhenius plots for frequencies at which 10 selected values of tanδi occur as a function of inverse temperature 1000/T and the results of their linear approximations using the least squares method.

7. Electrical properties of pressboard impregnated bio-oil

Table 1. The values of tanδ, for which the Arrhenius relations were determined, the activation energy of the relaxation time, the values of the coefficient of determination R^2 and the average values of ΔWτ and R^2 for the water content of 4 % by weight

No.	tgδ, a.u.	ΔW_τ, eV	R^2
1.	0.50	1.086	0.99994
2.	0.40	1.083	0.99999
3.	0.30	1.079	0.99999
4.	0.20	1.079	0.99999
5.	0.10	1.064	0.99999
6.	0.09	1.061	0.99997
7.	0.08	1.061	0.99997
8.	0.06	1.063	0.99998
9.	0.04	1.060	0.99977
10.	0.03	1.067	0.99998
Average value		1.070	0.99996
Uncertainty of measurement		0.0097	0.000066
$\Delta W \approx (1.070 \pm 0.0097)$ eV, $R^2 \approx (0.9999 \pm 0.000066)$			

8. Conclusion

- Comparative analysis were performed the temperature dependencies of thermal and mechanical parameters, breakdown voltage as a function of water content of bio-oil NYTRO® BIO 300X and petroleum-based oil Nytro Taurus.
- In laboratory tests, so-called standard characteristics were determined of frequency-temperature dependencies of the loss tangent of moistened NYTRO® BIO 300X bio-oil impregnated pressboard. Standard characteristics are the basis for diagnosing the condition of the insulation of power transformers and estimating the moisture content in the cellulose insulation component.
- It has been established that the activation energy of tanδ relaxation time does not depend on the water content, and its value is $\Delta W_{\tau tan\delta} \approx (1.020 \pm 0.0493)$ eV. This allows for the use of this value to convert the tanδ waveform obtained for the transformer to the nearest measurement temperature used in the study for pressboard impregnated with bio-oil.

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