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Dielectric Spectroscopy of Insulation Oils

***Abstract**. This article deals with monitoring of electrical properties in natural ester fluids and method dielectric spectroscopy eith IRC analysis and direst measurement with IDA 200. The paper describes property of dissipation factor tanδ of different types of oils. Test objects were measured in different temperatures.*

Keywords: oil life-time, dielectric dissipation factor, transformer oil, diagnostics.

Introduction

For diagnostics on insulations systems of power network equipments such as power transformers, dielectric analysis plays important role. Transformers and other oil-filled electrical equipment use only a tiny fraction on the total petroleum consumption, yet even this fraction is almost irreplaceable [1]. Electrical insulation systems are evaluated based on economic, safety, and environmental standpoints using total life cycle analysis. Because of the inherent high efficiency of liquid-cooled object designs, new developments focus on improving the environmental and safety properties of fire resistant (less-flammable, high fire point) fluids [2]. This article reports measurements of some dielectric parameters of natural ester fluids and mineral oils. Dissipation factor tanδ and permittivity were compared.

Electrical transformer insulation system is based on:

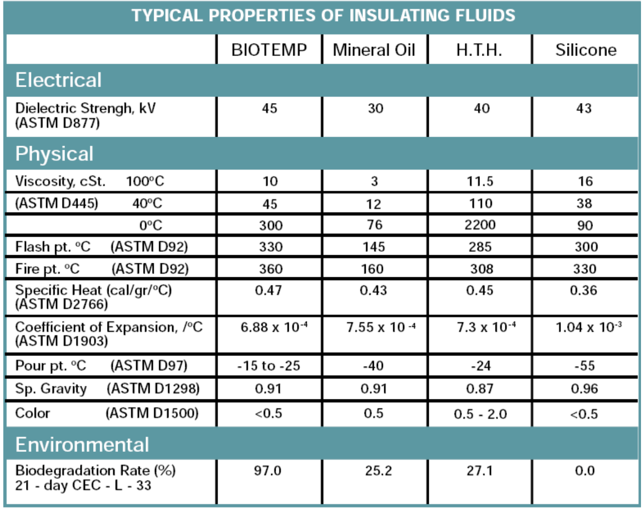
- economics,
- safety,
- environmental,
- standpoints,
- using total life cycle analysis.

Natural esters have several advantages and disadvantages as they are natural products, lower oxidation resistance than mineral oils. Overcome this potential handicap is possible with new blend of base oils and additives.

Generally it is possible to characterize natural esters as:

- does not contain any petroleum, halogens, silicones or other materials that might adversely effects the environment,
- fluid is based on a property-enhanced vegetable oil, combined with stabilizers to enhance oxidation stability,
- only 25% of the total volume of gasses generated from petroleum based oils are produced when vegetable oil based coolant is arced
- the fluid returned from a solid to a liquid state as the operating temperature increased without detrimental effects,
- higher thermal conductivity results in improved heat transfer,
- fire and flash points well above 300ºC,
- mixes in all proportions with mineral oils,
- concentrations of mineral oil in excess of 10% by weight may lower the fire point below 300ºC,
- does not or heavy mix with silicone fluids,
- suitable for application indoors and in areas of heightened environmental sensitivity where any insulating fluid spill could require expensive clean-up procedures,
- in use in small power and distribution transformers,
- success rate in heavily populated areas from the tropical environment of Hawaii to the frigid northern slopes of Alaska.

There are typical electrical and physical properties of insulation fluids in Fig. 1



TYPICAL PROPERTIES OF INSULATING FLUIDS	BIOTEMP	Mineral Oil	H.T.H.	Silicone
Electrical				
Dielectric Strengh, kV (ASTM D877)	45	30	40	43
Physical				
Viscosity, cSt. 100ºC	10	3	11.5	16
(ASTM D445) 40ºC	45	12	110	38
0ºC	300	76	2200	90
Flash pt. ºC (ASTM D92)	330	145	285	300
Fire pt. ºC (ASTM D92)	360	160	308	330
Specific Heat (cal/gr/ºC) (ASTM D2766)	0.47	0.43	0.45	0.36
Coefficient of Expansion, /ºC (ASTM D1903)	6.88×10^{-4}	7.55×10^{-4}	7.3×10^{-4}	1.04×10^{-3}
Pour pt. ºC (ASTM D97)	-15 to -25	-40	-24	-55
Sp. Gravity (ASTM D1298)	0.91	0.91	0.87	0.96
Color (ASTM D1500)	<0.5	0.5	0.5 - 2.0	<0.5
Environmental				
Biodegradation Rate (%) 21 - day CEC - L - 33	97.0	25.2	27.1	0.0

Fig.1 Typical electrical and physical properties of insulation fluids

IRC analysis

IRC analysis measured and analyzed charging currents of samples M (mineral oil) at temperature from 20 °C to 100 ℃ with step 10 ℃ up to 1000 s time responses (Fig. 2).

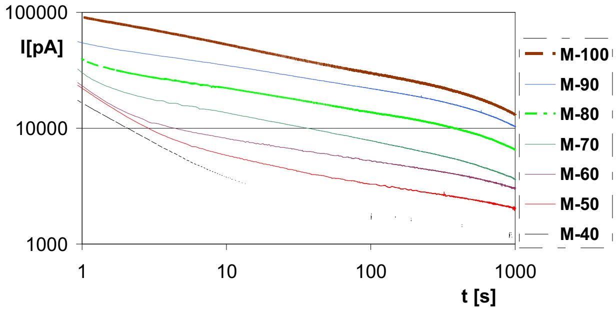


Fig. 2 Temperature dependences of the charging currents on time for the mineral oil (M) from T=40 ℃ to T=100 ℃

Relaxation currents and time constants were obtained to evaluate the charge characteristics in program Matlab. Applied voltage was restricted because of used electrometer Keithley 617 supply and request of absence of space charge generation assurance. Elements R_i, C_i of the Maxwell-Wagner equivalent dielectric model can be calculated from elementary currents and time constants [3]:

$$I_{mi} = \frac{U_0}{R_i} \Rightarrow R_i = \frac{U_0}{I_{mi}} \qquad (3)$$

$$\tau_i = R_i C_i \Rightarrow C_i = \frac{\tau_i}{R_i} \qquad (4)$$

where U_0 -applied DC voltage (100V),
R_i, C_i -calculated components of equivalent model,
I_{mi}, τ_i –values obtained from Matlab.

The replacement model of dielectric enables the conversion of dielectric loss factor into the frequency domain. The relationship below is valid for dielectric loss factor $tg\delta$:

$$tg\,\delta = \frac{\mathrm{Re}\{\overline{Y}\}}{\mathrm{Im}\{\overline{Y}\}} = \frac{\dfrac{1}{R_0} + \sum_{i=1}^{n} \dfrac{R_i.(\omega C_i)^2}{1+(\omega R_i C_i)^2}}{\omega C_0 + \sum_{i=1}^{n} \dfrac{\omega C_i}{1+(\omega R_i C_i)^2}} \qquad (5)$$

where: $\omega = 2\pi f$ - circular frequency,
C_0 - capacity of the empty oil tank, the geometric capacity of the sample,
R_0 - resistance in infinity time.

Dielectric loss factor $tg\delta$ was calculated from elements of dielectric equivalent model and measured value in frequency domain are shown in Fig. 3 up to Fig. 8 for sunflower, silicon and mineral oils.

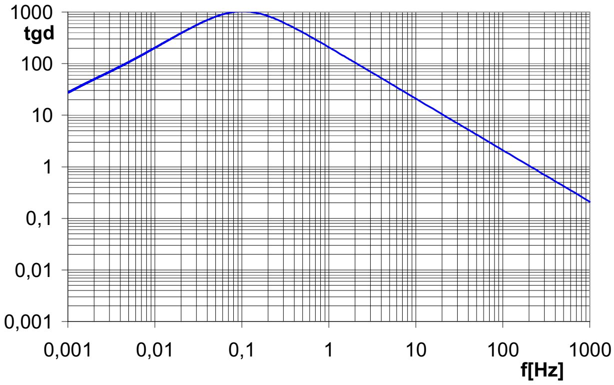


Fig. 3 Calculated frequency dependence of dielectric loss factor tgδ for the sunflower oil at temperature T=60 ℃

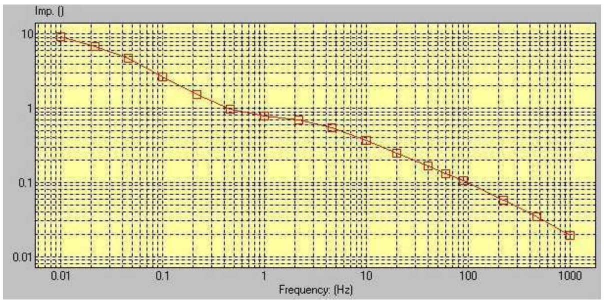


Fig. 4 Measured frequency dependence of dielectric loss factor tgδ with IDA 200 for the sunflower oil at temperature T=60 ℃

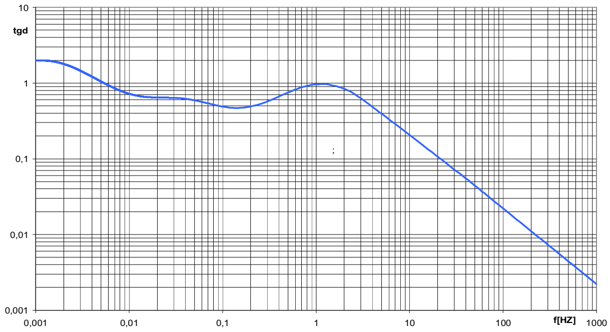


Fig. 5 Calculated frequency dependence the dielectric loss factor tgδ for the silicon oil at temperature T=60 ℃

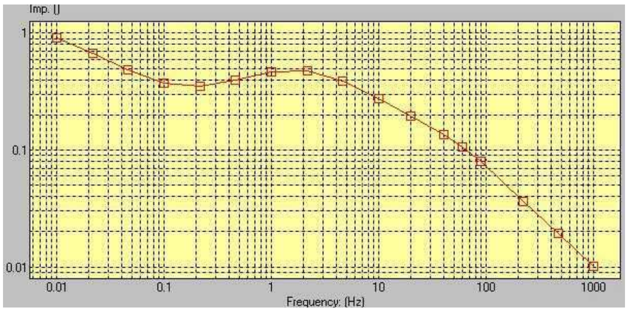


Fig. 6 Measured frequency dependence of dielectric loss factor tgδ with IDA 200 for the silicon oil at temperature T=60℃

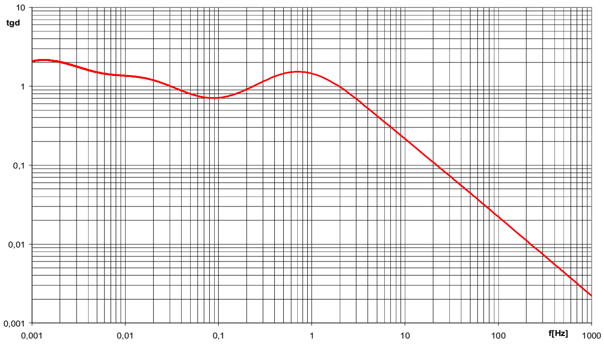


Fig. 7 Calculated frequency dependence of dielectric loss factor for the sample of mineral oil at temperature T=60 ℃

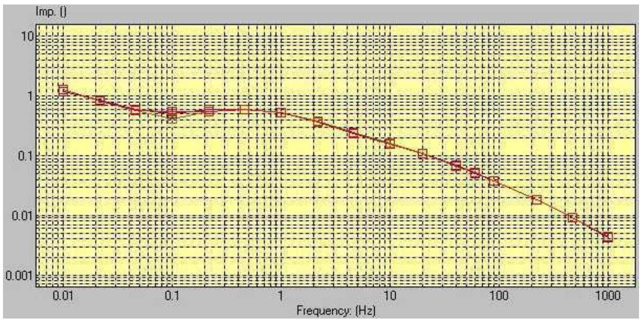


Fig. 8 Measured frequency dependence of dielectric loss factor tg δ using IDA 200 for mineral oil at temperature T=60℃

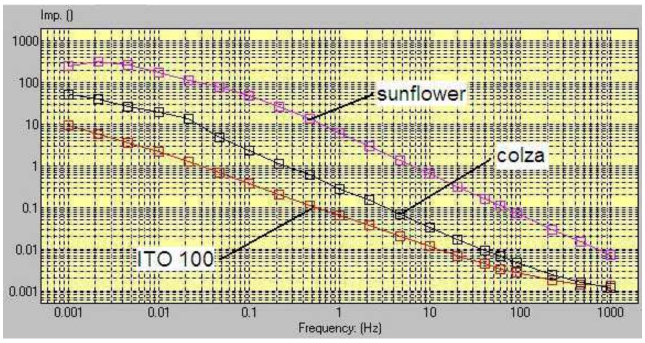


Fig. 9 Comparison of frequency dependences of dielectric loss factor tg δ using IDA 200 for mineral, sunflower and colza oil at temperature T=20℃

Another comparison was made for mineral, sunflower and colza oil at temperature T=20℃. The results are in Fig. 9

Conclusion

First investigations of electrical and dielectric properties of natural ester fluids, mineral oil ITO 100 and silicon oil were made. As natural ester fluids were used two types of fluids: sunflower oil and colza oil. Samples were achieved directly from manufacturer. It is necessary to add that natural ester fluids samples were without any additives.

The results show differences for a sunflower oil sample, if compared measured and calculated values. Measuring time begins about 0.4 seconds for the IRC analysis, and other values are calculated for shorter time only. It leads to the conclusion that other processes are present. These processes will be subjects for further study. Comparison of mineral and silicon oil samples points at coincidence between IDA 200 data measurement and the mathematical calculation of IRC analysis. We can assess that the IRC analysis is a universal method and the results of IRC analysis are comparable with results from other top-measuring device in the range of observing time corresponding frequency.

Tests will be proceeding with ageing of natural esters as well as mineral oil.

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