Journal of Engineering and Applied Sciences 11 (Special Issue 2): 3042-3046, 2016
ISSN: 1816-949X

Transformer State Diagnosis in Optical Spectra of Transformer Oils

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Abstract: The results are presented for the researchers research concerning the quality control of transformer mineral oils by various methods of optical spectroscopy. The main spectral ranges are presented which contain useful information for analysis as well as some information about the measurement features and analysis principles. It was shown that according to the studies of optical spectra one can determine a number of standardized indicators of oil quality, assess the degree of their hydrocarbon base degradation as well as to diagnose the presence of defects in a transformer.

Key words: Diagnostics of transformers, transformer oil, optical spectroscopy, base, measurement

INTRODUCTION

The main type of dielectric fluid for power oil-filled electrical equipment are the mineral insulation oils when a corresponding oil fraction is used for their production. The range of mineral oils used in the Russian energy sector is wide enough (Alekseeva *et al*., 2004; Lipshteyn *et al*., 1998). During the production of these oils various technologies are used as well as oils from different fields. The consequence of this is an inherently different chemical composition of oils which is reflected in their performance properties. According to RD 34.45-51.300-97, the normalized indicators of oil quality depend on oil brand (Alekseeva *et al*., 2004). While many quality indicators do not give a complete picture of an oil state without the reference to its brand, the prediction of oil operational properties demand the knowledge about the chemical composition of oil in its initial state as well as during the process of operation.

Optical spectroscopy is one of the most effective methods of chemical composition control for petroleum products. They may use different spectral ranges for optical studies: ultraviolet, visible, near infrared and infrared spectral ranges. Each region of the spectrum contains the useful information about chemical structure features of various compounds and their concentrations. Transmission T, the optical Density D and the luminescence spectra are used usually for quantitative and qualitative analysis. The obtaining of optical spectra is performed by using spectrophotometers which (according to a registration principle) may be of a scanning type (“classic” spectrometers), interferometric (Fourier spectrometers) as well as with multi-element photodetector of a matrix type without moving parts in the registration system (Kozlov and Garifullin, 2001a, b).

MATERIALS AND METHODS

Mineral insulating oils were obtained in the branch of OJSC “Network Company” Kazan electrical networks (Kazan). Oil discharges were modeled using the machine in order to determine the breakdown voltage-AIM-90.

UV absorption spectra were recorded in cuvettes within the range of 10 mm using the spectrophotometer Varian Cary 100 within the wavelength range (λ) of 200-800 nm with a slit width of 1.5 nm. The position of lines in the spectra is given with the accuracy of ±2.5 nm. The transmission spectra are recorded within the visible range in the cuvettes with the thickness of 50 mm for SF-56 spectrophotometer in the wavelength range of 400-1000. The slit width makes 1.5 nm. The wavelength setting accuracy makes ±1.0 nm.

The absorption spectra in the infrared region are recorded in the cuvettes with the thickness of 2 mm using Fourier spectrometer TENSOR-27. The spectral resolution makes 1 cm^{-1}. All spectra were recorded at a room temperature. The comparison cuvette is empty.

RESULTS AND DISCUSSION

Transformer oil optical study results in different spectral ranges: The result of our studies revealed different effects of thermal-oxidative and discharge processes in oil on the transmittance curve T(λ) in the range of 300-1000 nm: at the discharge-arc processes oil transmittance ratio is decreased within the specified range of wavelengths almost uniformly; under the oxidizing processes the reduction of transmittance ratio is more pronounced in the short-wavelength part of the spectrum (Kozlov and Garifullin, 2015) (Fig. 1).

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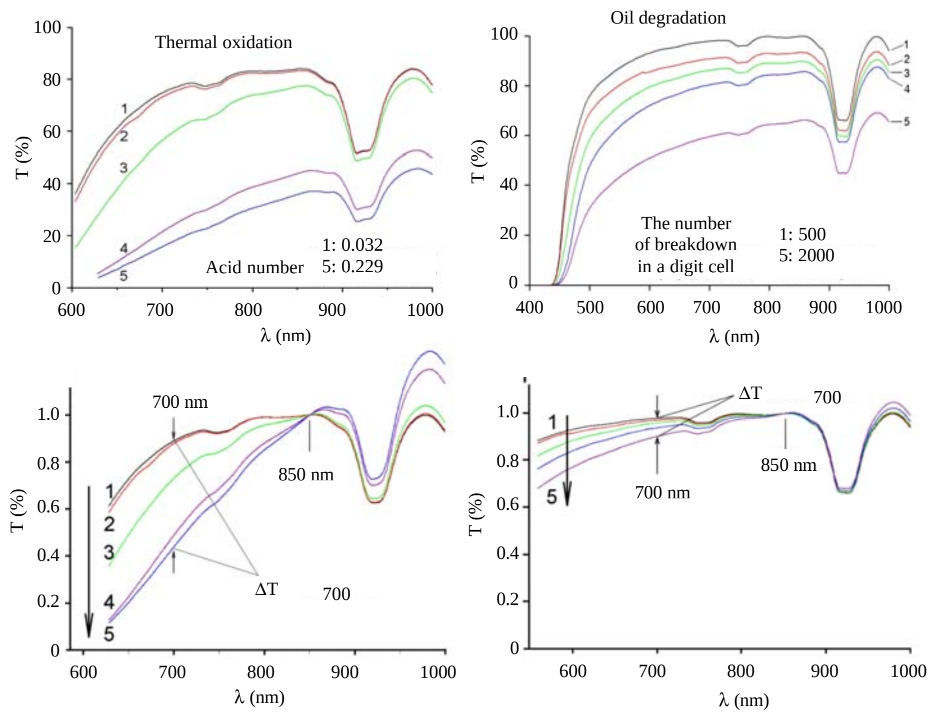

Fig. 1: The effect of thermal-oxidative and charge processes on the range of mineral oil transmission. The optical path length (cuvette thickness) makes 50 mm. Top: source spectra; below: normalized at the wavelength of 850 nm

During oxidation process the content of a dispersed phase in transformation oil increases through the association of oxygenated hydrocarbon molecules with a polar nature into colloidal particles (Shkalikov *et al*., 2011). The growth of colloidal particles in oil is detected according to the characteristic change of the transmission spectrum in the visible range and also according to oil luminescence intensity reduction as can be seen from the figure (Kozlov *et al*., 2012).

High-quality express analysis of the colloidal oxidation products is carried out in the spectrum of oil optical density $D(\lambda) = lg(1/T)$ in the range of 360-600 nm. In foreign practice the optical haze is determined for this according to ASTM D 6181 and the area under the optical density curve according to ASTM D 6802-02. The analysis features are given in the works of various researchers according to specified standards (Fofana *et al*., 2008).

It should be noted that oil degradation conditions differ in foreign and domestic power transformers while the structure of Russian transformers with the oil weight of 1,000 kg includes thermosiphon or adsorption filter (Gost, 2010), filled by large pore adsorbent (usually, by silicagel of KSKG brand). During the circulation of oil through a filter most part of oil oxidation products remains on silica gel surface. Thus, the optical density spectrum of oil in the range of 300-600 nm is conditioned mainly by the molecular absorption. Figure 2 shows the spectra of transformer oil optical density from the equipment (Rizvanova *et al*., 2015).

The result of mineral transformer oil study in the UV range of the spectrum showed that oil degradation process is accompanied invariably by aromatic compound content increase. At that complex aromatic compounds with several condensed benzene rings are developed (Rizvanova *et al*., 2015; Kozlov and Turanov, 2012). The obtained results allow to explain the change of mineral oil physical and chemical properties during the aging process, in particular, the increase of their hygroscopic properties. The successive change of oil color from pale-yellow to brown is observed in the series 1-10.

The features of oil oxidation processes can be controlled most conveniently by the analysis of the absorption spectra in the infrared spectrum region within the range of 2000÷1550 cm^{-1} (Fig. 3).

It was revealed that it is possible to accurately determine the acid number of oils ($v = 1710$ cm^{-1}) and the contents of various intermediate oxidation products ($v = 1735$ cm^{-1}, etc.) using an optimal thickness of an oil layer (cuvette thickness). Also according to IR spectra one may control the change of aromatic compounds in oil (the absorption band is about 1605 cm^{-1}) and mono-aromatics

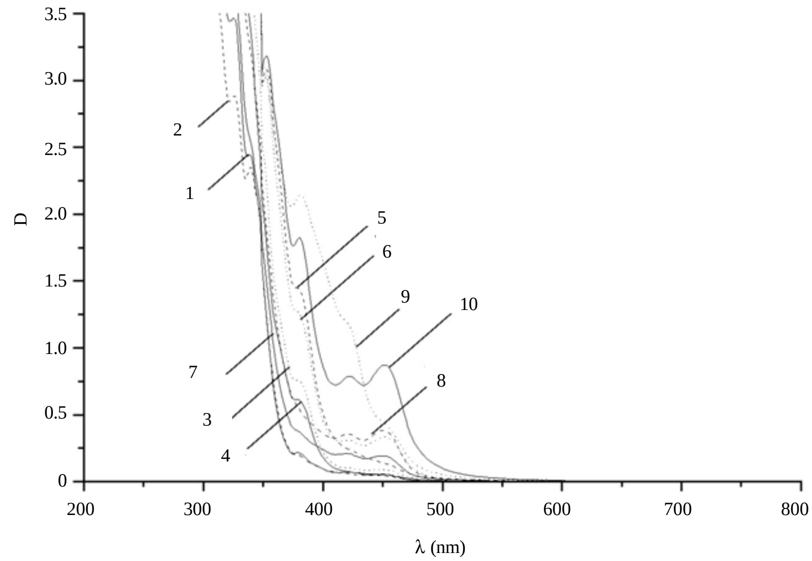

Fig. 2: Absorption spectra of oil samples from the equipment (Rizvanova *et al*., 2015)

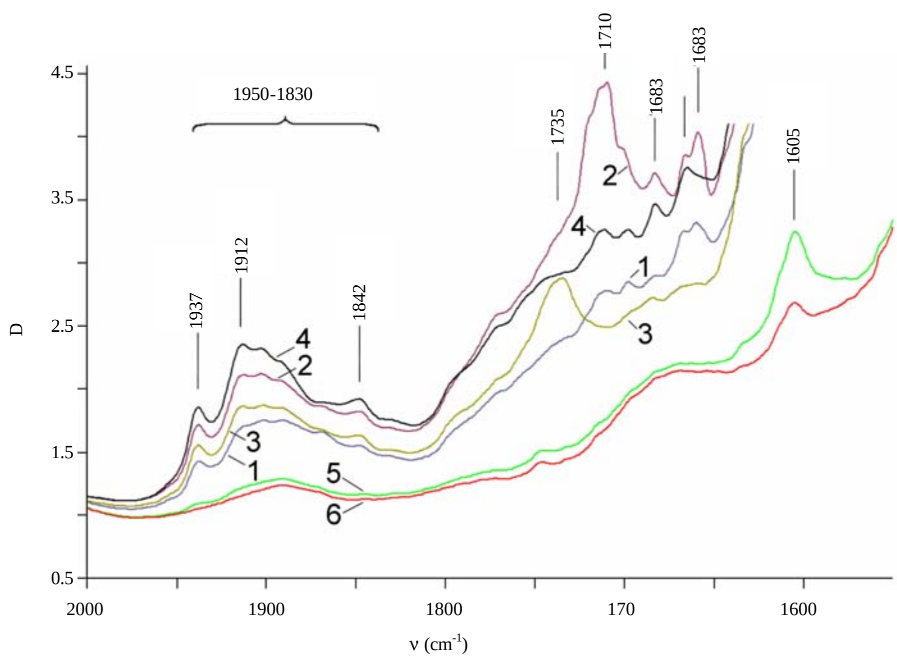

Fig. 3: The impact of oil oxidation products on their spectral characteristics. Samples 1÷4: TKp oil, acid number 0.047; 0.15; 0.026 and 0.055, respectively; Sample 5: purified GK oil from the equipment; sample 6: fresh GK oil

(the area of 1950/1830 cm^{-1}) and to assess the total amount of oil actuated in the ionol oxidation inhibitor (ν = 1659 cm^{-1}) (Garifullin, 2013).

It is known that during the thermal oxidative degradation the unsaturated compounds appear in oils (hydrocarbon molecules with -C = C- group) which are absent in fresh oils. The contents of these compounds can be determined according to an absorption band near 4600 cm^{-1} (Garifullin, 2013) (Fig. 4). The optical spectra analysis shows that despite the continuous cleaning of oils by silicagel the content of unsaturated hydrocarbons is increased with time. The undesirability of unsaturated molecule presence in oil is conditioned by their high reactivity.

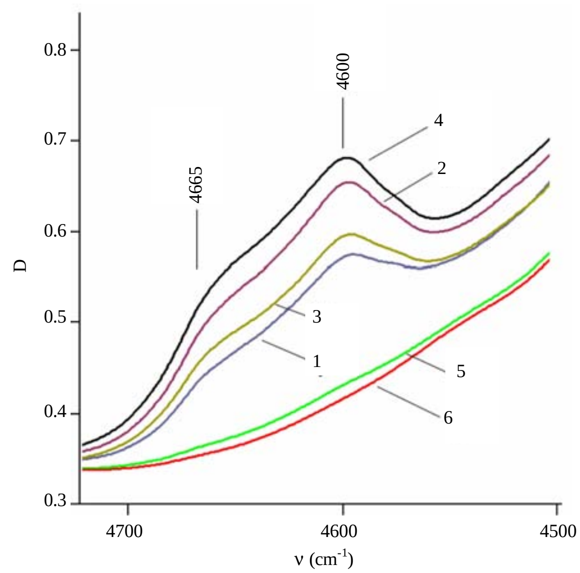

Fig. 4: The impact of unsaturated hydrocarbons on the IR spectra of oils (1/6 oil samples according to Fig. 3)

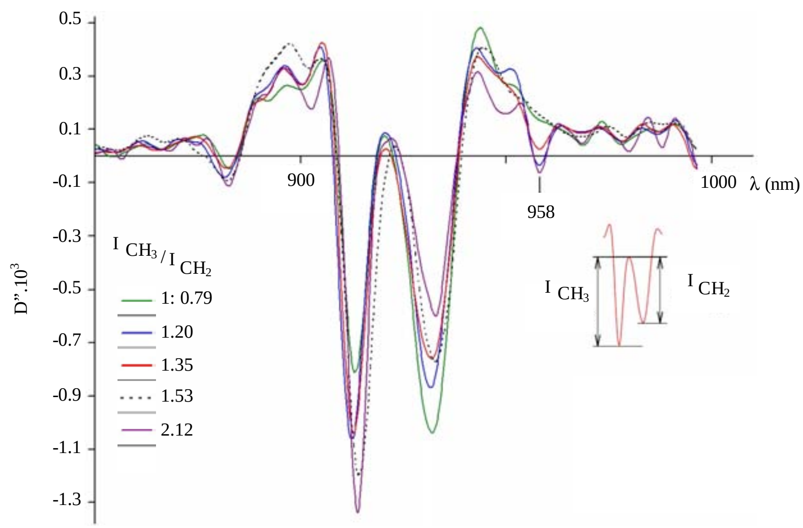

Fig. 5: The spectra of the second derivative from the optical density of different petroleum oils

In practice there is a need to identify a petroleum oil brand, which can be performed by oil IR spectrum analysis. The study procedure is described in ASTM D2144 standard. It is more convenient to use the range of 300-1000 nm for the express analysis of an oil grade. The researchers carried out the comparative analysis of transmission (absorption) spectra of transformer oils using the example of widely used brands: GK, VG, Nytro, TKp and T-1500. They detected the characteristics for each type of oil, conditioned by their production technology and an original oil raw material (Kozlov and Garifullin, 2015). In particular, one of the characteristics concerning the chemical composition of oils is the absorption ratio of methyl ($-CH_3$) and methylene ($-CH_2-$) groups, conditioned by the peculiarities of hydrocarbon oil base. In order to determine this ratio, you can use the spectrum of the second derivative from the optical density of oil D''(λ). Figure 5 demonstrated the principle of analysis using the example of several oil brands.

The showed spectrum D''(λ) noted the peak of about 958 nm, relating to the oxidation inhibitor-ionol additive.

By measuring the intensity of this peak one can determine ionol content in oil as an express analysis (Kozlov and Garifullin, 2001).

The results of these studies demonstrate a high diagnostic value of spectral methods to determine the quality of mineral insulating oils in various optical ranges. At that not only the state of the liquid insulation is determined, but the defects in transformer equipment are also revealed.

An important advantage of the optical control is the possibility of optical fiber probe use that can implement the measurements in the form of on-line monitoring.

CONCLUSION

One can identify the defects of thermal and discharge nature in equipment according to the spectra of transformer oil transmission. The optical studies of mineral transformer oils in different spectral ranges allow to determine the type of oil poured into the equipment, its oxidation, ionol content, the nature and the depth of hydrocarbon oil base degradation which allows to control its quality, as well as to predict the changes of physical and chemical properties. The most part of the optical research can be conducted in the form of rapid analysis, facilitating the timely detection of defects in the equipment.

ACKNOWLEDGEMENT

The researchers are grateful to Alexander Izrailevich Fishman for his assistance in spectral studies.

REFERENCES

Alekseeva, B.A., F.L. Kogan and L.G. Mamikonyants, 2004. The Volume and the Testing Standards of Electrical Equipment. Publishing House, Russia.

Fofana, I., A. Bouaicha, M. Farzaneh and J. Sabau, 2008. Ageing behaviour of mineral oil and ester liquids: A comparative study. Proceeding of the 2008 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, October 26-29, 2008, IEEE, Quebec, Canada, ISBN:978-1-4244-2548-8, pp: 87-90.

Garifullin, M.S.H., 2013. The use of optical spectroscopy methods for the diagnosis of mineral insulating oils. Basic Res., 10: 3299-3304.

Gost, 2007. Power Transformers General Specifications. Federal State Unitary Enterprise, Russian, Pages: 45.

Kozlov, V. and A. Turanov, 2012. Transformer oil and modern physics. IEEE. Trans. Dielectr. Electr. Insul., 5: 1485-1497.

Kozlov, V.K. and M.S.H. Garifullin, 2001a. Determination of ionol concentration and acid number in transformer oils by spectral method News of higher educational institutions. Energetics Prob., 5: 85-96.

Kozlov, V.K. and M.S.H. Garifullin, 2001b. The device for the spectral studies of insulating oils in the range of 600-1100 nm. Proc. Higher Educ. Institutions Energy Prob., 10: 114-116.

Kozlov, V.K. and M.S.H. Garifullin, 2015. The features of transformer oil optical characteristics (different brands). Proc. Higher Educ. Institutions Energetics Prob., 11: 11-19.

Kozlov, V.K., M.S.H. Garifullin and A.N. Turanov, 2012. Luminescence of GK brand transformer oil. Fuel Oil Chem. Technol., 6: 54-56.

Lipshteyn, R.A., T.V. Glazunov and E.E. Dovgopoly, 1998. Swedish transformer oils by: Nitro 11GX and nytro 10X brands. Electr. Stations, 1: 61-64.

Rizvanova, G.I., L.G. Gafiyatullin, M.S.H. Garifullin, V.K. Kozlov and A.N. Turanov, 2015. The features of transformer oil aging in actual use news of higher educational institutions. Energetics Prob., 10: 91-94.

Shkalikov, A.V., E.A. Yushkova, L.G. Gafiyatullin, Y.N. Osin and O.A. Turanova *et al.*, 2011. About the scattering of light in transformer oil. Opt. Spectrosc., 110: 768-772.