



Determination of interfacial tension of insulating oils by using image analysis and multi-way calibration

Mariana S. Godinho^a, Anselmo E. Oliveira^b, Marcelo M. Sena^{a,*}

^a Unidade Universitária de Ciências Exatas e Tecnológicas, Universidade Estadual de Goiás, P.O. Box 459, 75000-000, Anápolis, GO, Brazil

^b Instituto de Química, Universidade Federal de Goiás, Goiânia, GO, Brazil

ARTICLE INFO

Article history:

Received 20 November 2009

Received in revised form 26 January 2010

Accepted 28 January 2010

Available online 4 February 2010

Keywords:

Power transformers

Insulating oil

N-PLS

Three-way data

Chemometrics

N-way image analysis

ABSTRACT

Power transformers are of great importance in the distribution of electrical energy. One of their most important parts is the insulating system, consisting of Kraft paper immersed in insulating oil. One of the most important parameters used for evaluating the degradation of this system is the oil interfacial tension. The aim of this study was to determine the interfacial tension in samples of insulating oils by using image analysis combined with a multi-way calibration method, N-PLS (multilinear PLS). Forty eight oil samples were obtained, whose values of interfacial tension were determined by a tensiometer, and divided into calibration (38) and validation (10) sets. Scanner images were obtained, converted to grey-scale, domain transformed and stacked in a three-way data array, before modelling. The best N-PLS model was obtained with mean centering and three latent variables and provided a RMSEP of 3 dyn cm^{-1} . This model provided individual prevision errors between -14 and 16% , which were acceptable for electric energy companies. The proposed method was rapid and non-destructive, showing great advantages over the traditional ones, which are slow and produce chemical waste.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Power transformers are of great importance in the transmission and distribution of electrical energy and its most important part is the insulating system, which consists of Kraft paper immersed in insulating mineral oil. Kraft paper is obtained by Kraft process, in which bonds that link lignin to cellulose are broken. Insulating oil consists mainly of naphthenic and parafinic hydrocarbons with a minor amount of aromatic hydrocarbons. The extent of a transformer's life is largely determined by the maintenance of this system and insulation degradation is a major concern about its ageing. The main causes of degradation of insulating materials are the high operating temperatures and the presence of oxygen and moisture [1]. Generally, thermal ageing of paper is considered the predominant life limiting process. The major degradation products of paper's cellulose are furfurals, water and gases, such as H_2 , CH_4 , CO and CO_2 , which can be found in the insulating oil [2,3]. Oil hydrocarbons are degraded by peroxidation yielding, as final products, carboxylic acids and derivatives.

The electrical power industry requires reliable methods to assess the conditions of transformers and the current ones are limited. Dielectric measurement techniques, such as recovery voltage mea-

surement (RVM) and polarization and depolarization current technique (PDC), do not provide good measurement of the ageing of system insulation [4]. Some authors have evaluated the ageing of Kraft paper determining its degree of polymerization (DP) or average molecular weight by using chromatographic techniques, such as GPC [5,6] and SEC [3,7], or X-ray photoelectron spectroscopy (XPS) [6]. Nevertheless, these techniques are destructive and need violating the transformer. In practice, they only can be applied during refurbishment or following failure of the transformer. Analysis of insulating oil is an alternative, but most of the available methods are also destructive, such as moisture determination by Karl Fischer titration [8], dissolved gas analysis (DGA) [1,9] or furan analysis by HPLC [1,10]. There is a need to develop non-destructive methods to assess the condition of transformers. In this way, Baird et al. have developed a portable system using fiber optics and NIR spectroscopy that was used to predict DP [11] and water content [12] in transformer insulating paper.

In Brazil, the assessment of transformers' conditions in electrical power industry is carried out by dielectric and physico-chemical assays, such as dielectric rigidity, power factor, moisture, neutralization index and interfacial tension [13]. Among these properties, interfacial tension is the most sensitive to the effects of oil and paper degradation/oxidation, particularly to the presence of polar substances. Since these substances are derived from both, oil and paper, this assay is a way to monitor the whole insulating system. The official method used in Brazilian industry for this assay is slow, destructive and has low precision [14]. Thus, the aim of this work is to propose a

* Corresponding author. Present address: Department of Chemistry, ICEX, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil. Tel.: +55 31 34096389; fax: +55 31 34095700.

E-mail address: marcsen@ufmg.br (M.M. Sena).

new simple, rapid and non-destructive method to determine interfacial tension of transformers' insulating oils by using image analysis and second order calibration. Images of oil samples in Petri plates were obtained by using a simple scanner and correlated with interfacial tension values by using multi-way chemometric methods.

2. Image analysis and multi-way methods

2.1. N-way image analysis

Digital images have a finite number of elements with particular coordinates and values, called pixels. Univariate or grey-scale images are two-dimensional functions, where each spatial pair of coordinates (x,y) has an intensity (grey) value. Multivariate or colour images have different channels for each pixel [15]. The most common system for colour images is RGB, which can be described by a histogram of frequency distributions of red, green and blue values, and is used in monitors, scanners and video cameras. An alternative is HSV (hue, saturation, value) system, which is closer to the way that humans discern colour sensations. The use of simpler RGB or grey-scale images can be advantageous over spectroscopic images in some situations, due to their smaller files size, rapidity of acquisition, and simplicity of apparatus required (digital cameras or scanners) [16].

N-way image analysis is used when multiple images are handled simultaneously, and is applied to a stack of images with similar properties (chemical, physical, biological, etc.) [17]. Multivariate image analysis (MIA) is a particular approach to N-way image analysis, which has been applied to chemical data since the last decade [18–20]. MIA employs not true multi-way chemometric methods, such as unfold-PCA/PLS. These methods are not considered truly multi-way, because they firstly unfold three-way data array into two-way, followed by ordinary two-way decomposition, instead of utilizing the intact multi-way structure during the modelling. In general, true multi-way methods, such as PARAFAC [21] and N-PLS [22], have many advantages over unfold methods. They are more parsimonious, restrict (less degrees of freedom) and robust, fitting less noise. Huang et al. have performed a comparative study about the use of multi-way methods in image analysis and demonstrated that true multi-way methods are more suitable for certain kind of applications, in particular, for predicting a physico-chemical property from non-spectroscopic images [17], an application similar to the one of the present work.

Another important aspect highlighted by Huang et al. is the use of domain transformations in image analysis [17], discussed in the following. In the used codification, **O** denotes an object mode, while **V** denotes a variable mode. RGB images obtained for oil samples in the present work are **OOV** (pixel \times pixel \times colour channel) arrays. If images for several samples are stacked, a four-way array is obtained (**OOOV**). In order to simplify the manipulation of these images, they were firstly converted to grey-scale images (**OO**) and then stacked, yielding a three-way array **OOO** (sample \times pixel \times pixel). This step involves reducing one data dimension through a simple conversion of multivariate RGB colour channel values to univariate grey-scale intensity image. An **OOO** data array is non-congruent and obviously not trilinear. Thus, it cannot be used directly for N-way analysis, demanding the use of domain transformations techniques, such as fast Fourier (FFT) and wavelet transforms, to convert **OOO** to **OVV** (sample \times frequency component \times frequency component) data arrays. It has also been pointed out that true multi-way methods are more suitable for **OVV** arrays, while unfold methods (MIA) are better suited for **OOV** image data arrays.

2.2. Multi-way chemometric methods

Instruments that generate a data matrix per sample provide second order data. When data matrices collected for several samples are stacked, a three-way data array is obtained. Methods to deal with this kind of data are called multi-way (or N-way or second order) methods.

The most popular multi-way calibration methods are PARAFAC and N-PLS, which have been applied to data generated mainly by spectrofluorimetry, image analysis and hyphenated techniques to obtain quantitative models in several areas, such as environmental [23], food [24], pharmaceutical [25] and clinical [26] analyses.

PARAFAC [21] is a generalization of PCA to higher order data, which presents unique solution independent of rotation. The PARAFAC model is found to minimize the sum of squares of the residues and it is not robust to trilinear deviations, which limits its application on multivariate image regression. N-PLS (multilinear PLS) [22] is an extension of PLS regression to multi-way data. N-PLS algorithm decomposes the three-way array **X** into a set of triads. Each triad (latent variable) consists of a score vector, **t**, related to the first way, and two weight vectors, **w^J** and **w^K**, related to the other two ways. The model is given as follows:

$$x_{ijk} = \sum_{f=1}^F t_{if} w_{jf}^J w_{kf}^K + e_{ijk} \quad (1)$$

where e_{ijk} are the model residues, t_{if} , w_{jf}^J and w_{kf}^K are the elements of vectors **t**, **w^J** and **w^K**, respectively, and F is the total number of triads. N-PLS incorporates information from dependent variables in the data decomposition step, which turn it more prone to deal with trilinearity deviations than PARAFAC.

3. Materials and methods

3.1. Insulating oil samples and reference method

Forty-eight insulating oil samples were obtained from CELG (Centrais Elétricas de Goiás S. A.), a state electrical power company. They were collected from March to September 2008, during the local dry season, from transformers through the whole state of Goiás, which is located in the center-west region of Brazil. These transformers presented a wide variety of conditions, with their lifetimes varying from one to about thirty years. Interfacial tension water/oil of these samples was measured by using a torsion Krüss K8 tensiometer, according to Brazilian norm NBR 6234 [14].

3.2. Acquisition of images

Images were acquired using a simple table scanner Genius. Petri plates were filled with 15 ml of each oil sample and positioned under the scanner central region. A white screen was used to block the light from external sources. Images were digitalized in RGB system and bitmap format, with resolution of 300 dpi. Fig. 1 shows obtained images for twelve different oil samples. Each oil was sampled three times and each triplicate was scanned three times, totalizing nine images per oil.

3.3. Data treatment

Data were treated in MATLAB version 6.5 (The Math Works, Natick, USA) and images were processed using Image Processing Toolbox, version 3.2. PARAFAC and N-PLS models were obtained with the N-way toolbox for Matlab, version 2.10 [27]. From the center of each original image, a fixed positioned square of 200×200 pixels was selected. RGB images were converted to grey-scale and processed. This processing consisted in applying a special unsharp filter, followed by a two-dimensional fast Fourier transform (2D-FFT) and a logarithmic transform. Unsharp filter is a contrast enhancement filter used in image analysis which enhances image edges (and other high frequency components in an image), via a procedure which subtracts a smoothed, or unsharp, version of an image from the original one [28,29]. Finally, for each oil sample, the nine obtained replicate matrices were averaged.

Download English Version:

<https://daneshyari.com/en/article/1227822>

Download Persian Version:

<https://daneshyari.com/article/1227822>

[Daneshyari.com](https://daneshyari.com)