A Multi Regression Approach For Predicting The Age Of Transformer Oil In Thermal/Electrical Degradation

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Abstract

Power transformers are considered capital investments in the infrastructure of every power system in the world. They are the heart of electric power distribution and transmission systems, and it is essential that they function properly. It is knowing that insulating fluid is highly used in a composite or impregnated dielectric system with reference to both dielectric strength and ease of contamination, many investigators have devoted great efforts to investigate fluids behaviours under operating conditions.
The objective of this study is to examine the gassing tendency under electrical discharge of aged and unaged mineral oil, and analyze the parameters in degradation, with the aim to see the most significant parameters which can really presents the degradation severity.
In this regard, various scenarios were considered. The study was carried on new and aged oil submitted electrical field. The 6802, 6181 and 924 tests are used in measure of parameters in degradation.
In this work, the water contents, Interfacial tension, and gas pressure generated, are considered as a parameter significant of degradation process. These parameters were used as inputs in approach model for prediction the transformer age (life), the result show that the water can be used for detection of early stage of degradation.

Keywords- *mineral oil, Thermal ageing, electrical discharge, water contents, loss factor interfacial tension, gassing tendency, stepwise regression.*

1. Introduction

Power transformers are critical, highly loaded and expensive part of the electricity generation and distribution network. In these expensive equipments, large quantities of fluids are used, with a two-fold function: to insulate electrically and to dissipate the heat generated by the windings. [1].
Since gas evolvement deteriorates the dielectric properties of insulating fluid, its ability to resist decomposition under electrical discharge is of paramount importance for the safety of power transformers under operating conditions. [1]
In this contribution, investigations were performed in fluids during the electrical/thermal aging, and studying the parameters degradation by measuring the physical-chemical parameters (ASTM D1533-ASTM D971), and electrical propriety (ASTM 924).
The experimental results obtained are used to developing a technique model by stepwise regression method. Three transformer oil parameters, which are dissolved water contents, interfacial tension, and gas pressure generated under electrical discharge, are proposed to be predictors of transformer thermal age. Moreover, stepwise regression is used to found a model by selecting the most significant predictor.
This model uses the parameters in degradation as inputs and the function of gassing is then developed by the substitution of measured values of parameters obtained from our experimental tests in Laboratory of Research in Insulating Liquids and Mixed Dielectrics for Electrotechnology (ISOLIME), University of Quebec at Chicoutimi, Qc, Canada.

2. Experimental procedures

For this study, accelerated ageing in laboratory condition has been performed. An open beaker oxidative ageing method have been used (similar to that described in the ASTM D 1934)[2].
Samples of paper specimens were impregnated with dehydrated and degasified oil for 24 hours. The paper samples were used as received from the manufacturer without being dried. To simulate the effects of metallic components in the transformer, metallic catalysts (3 g/l

of zinc, copper, aluminum, and iron) were introduced in a filter paper immersed in the oil. (Figure 1).

(a) (b)

Figure.1. a) Dehydration and degassing of oil
b) Dehydration and impregnation of paper

- The beakers were placed in a convection oven at 115°C. Specimens were heated for 250, 500, 750 and 1000 hours. Electrical and physical tests were then performed on the aged samples.
- For each period, 50 ml of aged oil is tacked from oven and placed it in the discharge cellule for 5 hours, according to the D 6180 test [3].
- For each ageing period, the electrical, chemical and physical propriety are measured using the ASTM standards.
- To provide base line for comparison investigations were also performed with unaged oil samples submitted electrical discharge.

3. Insulating fluids under electric discharge

The amount of gases evolved under the impact of electrical stress by a sample of fluid was accurately measurable by using the ASTM Test Method D6180 [3], which simulate conditions close to real life conditions. A Merell-based test cell type, defined in the ASTM Test Method D6180, was used (Figure 2). The free electrons are generated by a cylindrical copper electrode 15 mm (0.6 inches) in diameter and 10 mm long sealed in a 500 ml Erlenmeyer glass.

Figure 2. Oil sample placed in discharge cell according to ASTM Designation D6180

The electrode is placed in the center of the discharge cell and suspended above the oil. An oil volume of 100 ml was used. As oil generates gas, the remaining volume of liquid reduces as well. The results were reported in figure 3.

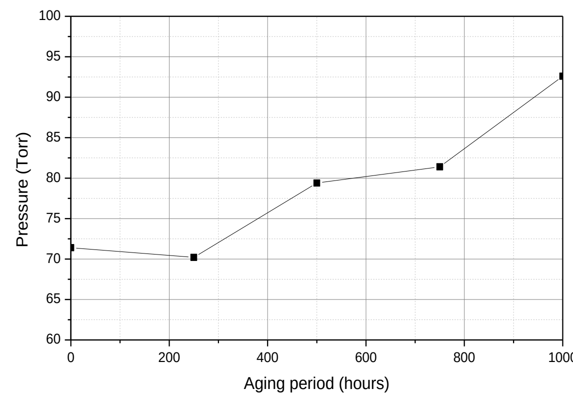

Figure3. Experimental results of gassing under electrical discharge in function of aging period

- The figure 3 show that the gas generated under electrical discharge decrease with the thermal aging period.

4. Measure of loss factor

The measurements of the loss factor were performed with the Insulation Diagnostic Analyser IDA200 using the liquid test cell type 2903 for liquid insulants by Tettex [4].

The figure 4 reflects the differences between oil before and after electrical discharge.

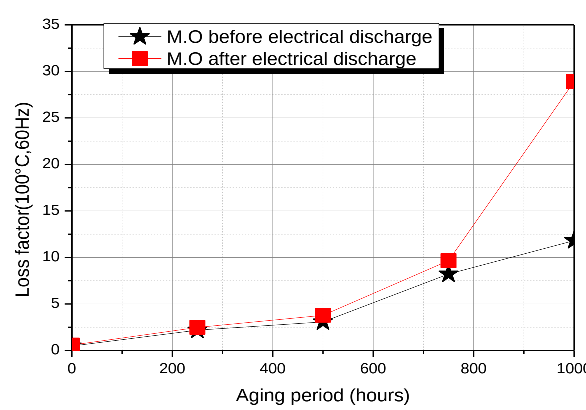

Figure 4. Comparison of Loss factor evolution before and after Electrical discharge

-MO always represents the Naphthenic type based mineral oil (brand insulating oil made from fully refined naphthenic base stocks).

As the population of free radicals increases, their unpaired electron can be coupled with a free electron to become a charge carrier that tends to increase the dissipation factor of the fluid as shown in figure 4.
The loss factor is affected by the thermal aging period specially for the high period, the electrical field increase this parameters for aged oil, the loss factor go up for the double after 1000 hours of thermal aging.

5. Measure of water contents

By using Coulometric Karl Fisher titration apparatus (Karl Fischer 831 KF) , the quantity of water content in the oil will be determined.

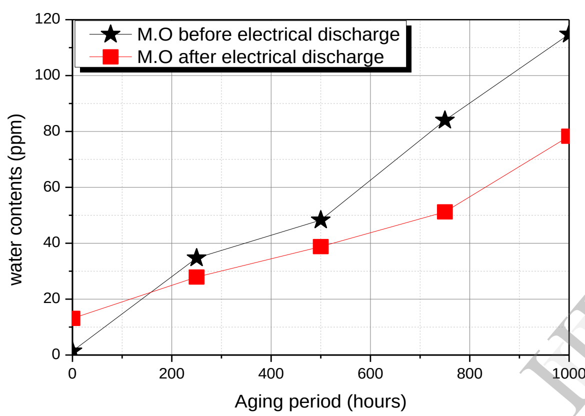

Figure 5. Comparison of water contents evolution before and after Electrical discharge

Test will be repeated three times for each series of tests by injecting 1 ml of oil sample each aging time; the result will be recorded in PPM. These measurements were performed according to the ASTM D1533 [5].

The figure 5 show that the water contents increase in function of thermal aging period and decrease under electrical discharge

6. Measure of Interfacial Tension:

This test method covers the measurement of the interfacial tension between mineral oil and water, under non-equilibrium conditions. The tensiometer used in this study is represent in figure 6

Figure 6 . Tensiometer For interfacial tension (IFT) measumes [6]

The measures were effectuated according to the ASTM D 971 standard [7]

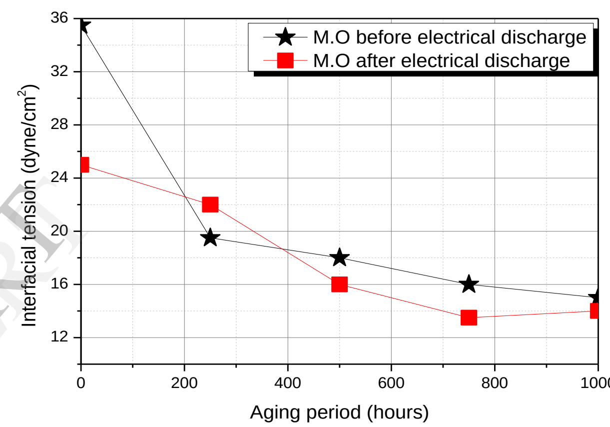

Figure 7. Comparison of Interfacial tension evolution before and after Electrical discharge

7. Prediction of degradation age

The experimental results obtained, indicate that the interfacial tension and water contents are the more parameters affected by the thermal aging period.
For the loss factor it affected by the electrical field, the variation in its values in function of thermal aging is no significant, still keep the admissible values.

After application of D6180 test, the variation in DDF value is very high.
These lead us to predict water contents and interfacial tension in function of thermal aging. Also there is a mutual dependence and interaction between the interfacial tension, and water contents. Therefore it can be concluded that a model for the transformer age that incorporates these two parameters will be comprehensive and this represents a justified conclusion from this study.

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8. Modeling of aging period as function of water contents, IFT and gas pressure:

The experimental results presented in this paper, are obtained from ASTM tests in ISOLIME laboratory in Canada, this ASTM tests are :

- ASTM designation 6180 standard Test Method for Stability of Insulating Oils of Petroleum Origin under Electrical Discharge [3]
- ASTM Designation 1533, standard Test Method for Water in Insulating Liquids [5]

- ASTM D 971, ASTM Standard Test Method for Interfacial Tension of Oil against Water by the Ring Method [7].

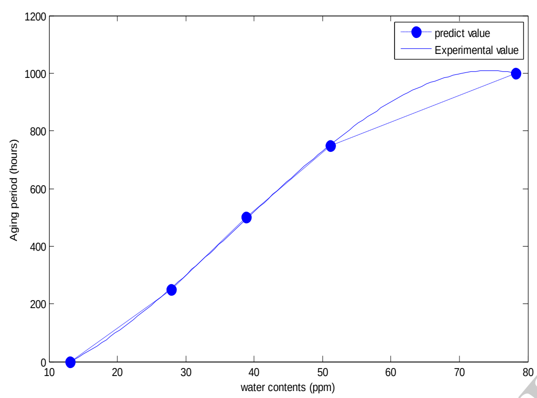

Figure 8. : Aging period prediction in transformer oil with water contents as input

We can obtain the individual model of aging time of oil as a function of the oil parameters by the following form:

$$Y(x) = A_o + A_1 x + A_2 x^2 + A_3 x^3 + \cdots + A_n x^n \quad (1)$$

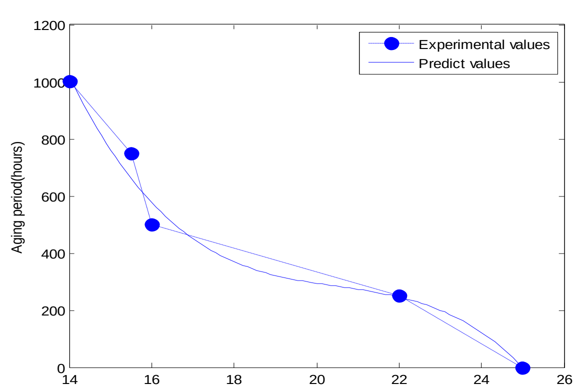

Figure 9. : Aging period prediction in transformer oil with Interfacial tension (IFT) as input

Where: Y (x) is the dependent variable A0, A1… are the model constants which are required to be determined, and x is the oil parameter uses as inputs (water contents, IFT, or pressure). The figures 8-10 show the approach model using the three parameters as inputs.

This model is tested on laboratory sample, to investigate the effect of each parameters used as inputs to the prediction model, and conclude the significant parameters which can give the high accuracy, a sample of modeling results is given in Table 1.

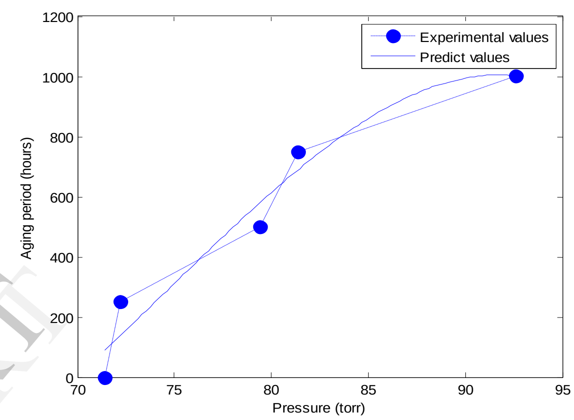

Figure 10. : Aging period prediction in transformer oil with Gas pressure as input

Tab.1: Results of approach model using the three parameters

Inputs	Water contents		IFT		Pressure	
	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
Sample1	250 h	248.9h	250 h	245h	250 h	89,4
Sample 2	750h	755.3	750h	--	750h	694.6
Sample 3	1000 h	999.7h	1000 h	1015h	1000 h	1001.9

From the results in table1, we can see clearly that the model with the water content as input, give a good accuracy.

8. Conclusion

Experimental studies and modeling of the effects of thermal/electrical aging on the transformer oil properties have been carried out by monitoring an insulating fluid, which is the mineral oil frequently used in power transformer, under thermal and electrical aging for specific period. Internationally adopted testing methods are used during this study, and the following conclusions are inferred:

- The gassing tendency of aged mineral oil under electrical field, increase with the aging periods, especially for the high time.
- The transformer oil parameters, are continuously deteriorating with extended aging periods, the influence of electrical discharge depend strongly of the aging period.
- The loss factor and water contents increase during the thermal aging, but under electrical discharge the water contents values decrease. The interfacial tension (IFT), is strongly affected by thermal aging, and keeps still its low decrease under electrical discharge.
- Mathematical models with stepwise regression, is proposed to evaluate the electrical/thermal age of insulating fluids, the gas pressure, water contents and interfacial tension have been used as inputs.
- A laboratory sample is used to verify the results obtained from the model. These results show that the model using the water contents as input give the high accuracy. The adequacy of this model has been proved and its applicability for the estimation of the degradation age has been justified.

9. References

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