AGING PERFORMANCE OF NATURAL ESTER-BASED DIELECTRIC FLUIDS FOR TRANSFORMER SYSTEM

Suh Joon Han
The Dow Chemical Company
hansj@dow.com

Tirso Gaglio
The Dow Chemical Company
tagalio@dow.com

Xiaodong Zhang
The Dow Chemical Company
xzhang3@dow.com

ABSTRACT

In recent years, natural ester-based dielectric fluids are receiving significant attention as a safer, less-flammable alternative fluid to mineral oil in transformers due to fire resistance at high temperature and improved environmental properties. The life of a transformer depends critically on the performance of the paper insulation system. It has been reported that natural ester-based dielectric fluids can extend the life of cellulose paper insulation upon aging, which can help to improve the power reliability and efficiency of a transformer. In this study, the gassing characteristics of natural ester-based dielectric fluids and thermal life characteristics of cellulose insulation with different types of natural ester-based dielectric fluids under accelerated thermal aging condition of insulation system are investigated. These results will help to correlate the relationship between the type of natural ester-based dielectric fluid and its aging effect on the paper insulation system.

INTRODUCTION

Petroleum-based mineral oils have been applied in liquid-filled transformers for over one hundred years [1]. In the 1990s, the industry introduced new dielectric fluids from alternative natural sources of seed oils. The primary drivers to use natural ester-based dielectric fluids in industry are environmental benefits from excellent biodegradability, fire safety from high fire points, and other potential electrical benefits such as less moisture impact on the dielectric strength of paper insulation and preservation of insulation system in transformers for reliability [2] [3].

While in service in a transformer, insulation fluids will be subjected to heating at elevated temperatures for extended periods of time in the presence of air and water unless the transformer is completely sealed. The insulation fluids undergo a wide range of complex chemical reactions from thermal oxidation, hydrolysis, and polymerization. Undesirable constituents and byproducts are developed in the insulation fluids as a consequence of these chemical reactions. Dissolved gas analysis of insulation fluids in transformer service has been widely practiced as an important fault diagnosis in power transformers [4] [5] [6].

As natural ester-based dielectric fluids are more sensitive to thermal oxidation in comparison to mineral oils, the quality of the natural ester fluid is a critical factor to maintain the high quality dielectric fluid's performance in transformer applications. The rate of oil degradation is influenced by several factors including the temperature of operation, exposure to air, stability of the oil against oxidation, and the moisture content of the dielectric fluids. The oxidative stability of the dielectric fluid will increase with higher oleic content and lower level of unsaturations.

In this paper, it is investigated the gassing characteristics of natural ester-based dielectric fluids at low temperature, and aging characteristics of paper insulation system with different types of natural ester-based dielectric fluids. The paper insulation aging studies were conducted under accelerated thermal aging conditions at high temperature.

EXPERIMENTAL

Materials

In this study, two high oleic natural ester-based dielectric fluids and a low oleic natural ester-based dielectric fluid are tested for comparison. The properties of these transformer oil materials are listed in Table 1. The Kraft cellulose insulation paper used in this study is an electrical grade thermally upgraded paper.

Table 1 Properties of Transformer Fluids

Properties	ASTM	High oleic natural ester-based dielectric fluid 1	High oleic natural ester-based dielectric fluid 2	Low oleic natural ester-based dielectric fluid 3
Color	D1500	0.5	0.5	1
Water, PPM	D 1533	22	28	25
Dielectric strength, kV	D877	50	53.0	46
Interfacial tension, nN/m	D971	28	27	22
Neutraliation number, mg KOH/g	D974	0.06	0.03	0.03
Relative density	D1298	0.92	0.92	0.92
Power factor at 25 C, %	D924	0.089	0.115	0.347
Flash point, C	D92	330	330	330
Pour point, C	D97	-20	-25	-21

Tests

The gassing characteristics of natural ester-based dielectric fluids were tested after conditioning under thermal stress at 120 ^{o}C for 164 hours without the influence of an electrical stress. The generation of combustible gases is used to simulate the condition of an oil-filled transformer. In our testing, a portion of the test specimen is sparged for 30 minutes with dry nitrogen before thermal aging. After aging, dissolved gas-in-oil analysis was performed by gas chromatography

The accelerated thermal aging tests were performed in sealed stainless steel aging vessels. The paper insulations were filled with natural ester-based dielectric fluids to simulate aging in a modern sealed transformer. The insulation system specimens were aged at 150 ^{o}C for 66.2 days, 160 ^{o}C for 29.2 days and 170 ^{o}C for 13.4 days, which is represented from the minimum life expectancy curve of mineral oil-filled insulation system according to IEEE C57.100 Annex A. Temperature dependent aging performance of the insulation paper was estimated by retained tensile strength of insulation paper.

RESULTS and DISCUSSION

Gassing Characteristics

Stray gassing, according to the definition of CIGRE TF15/12.01.11, is a phenomenon that occurs when insulating fluids are heated at relatively low temperatures, such as at 100 to 120 ^{o}C, producing hydrogen and hydrocarbons. It is reported that the main gas generated in mineral oil under these conditions is hydrogen, followed by methane [7]. This test determines the propensity of the oil to generate certain gases as hydrogen and other hydrocarbons.

In natural ester-based dielectric fluids, in addition to the hydrogen and hydrocarbons, noticeable amounts of carbon dioxide and carbon monoxide can be generated. As the natural ester-based dielectric fluids are composed of a triglyceride structure with ester groups, it can convert to carbon dioxide and carbon monoxide. Our studies showed that high oleic natural ester-based dielectric fluid 1 and high oleic natural ester-based dielectric fluid 2 generated less hydrogen than low oleic natural ester-based dielectric fluid 3 in nitrogen sparging condition as shown in Figure 1. It can be hypothesized that lower level of hydrogen abstraction from triglyceride in this thermal oxidation is related to the level of unsatration in the triglyceride structure. Figure 2 and Figure 3 illustrate that carbon dioxide is generated less from high oleic natural ester-based dielectric fluid 1 and high oleic natural ester-based dielectric fluid 2 than low oleic natural ester-based dielectric fluid 3. A similar trend was also observed for carbon monoxide generation.

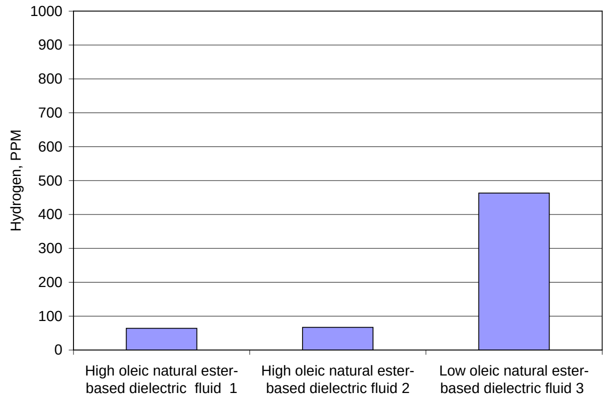

Figure 1 Hydrogen generation in transformer oils

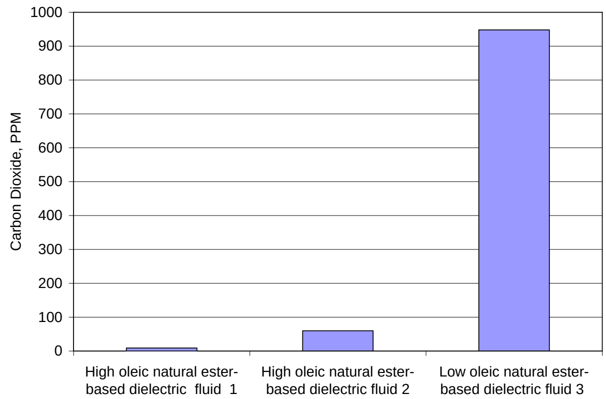

Figure 2 Carbon dioxide generation in transformer oils

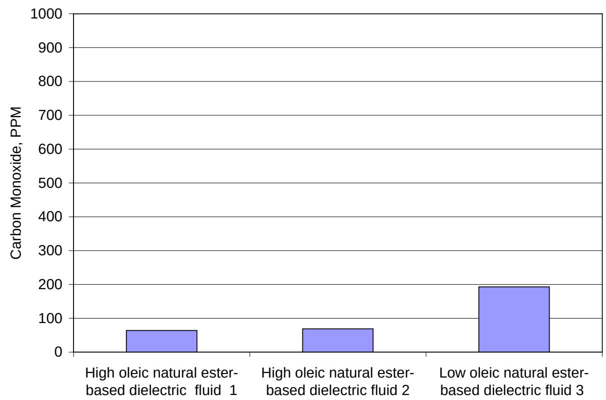

Figure 3 Carbon monoxide generation in transformer oils

Retention of Tensile Strength of Paper Insulation

It is well known that thermal or hydrolytic degradation of cellulose insulation paper is due to the scission of the cellulose polymer chains in terms of the number of the β-glucose bonds being broken [8] [9] [10]. In general, the paper insulation in all of the natural ester-based dielectric fluids retained its tensile strength by more than 50 percent in the aging conditions. The cellulose insulation in mineral oil would retain 50 percent of its tensile strength at the equivalent thermal aging conditions of 150 °C, 160 °C, and 170 °C as minimum life expectancy. The 50 percent retention of tensile strength represents "end of life" of the paper insulation. The retained tensile strength of paper insulation in natural ester-based dielectric fluid 1 and natural ester-based dielectric fluid 2 is higher than that in low oleic natural ester-based dielectric fluid 3 as shown in Figure 4.

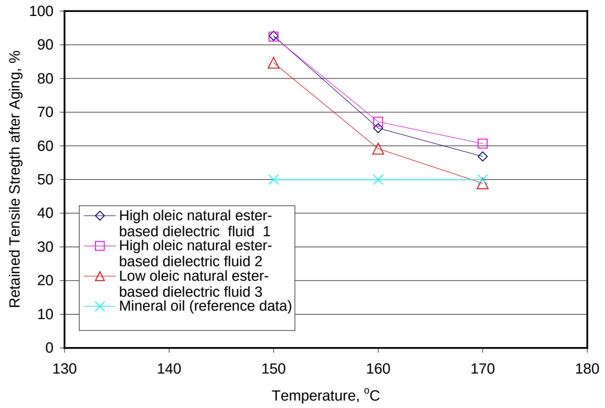

Figure 4 Retained tensile strength of thermally upgraded paper in transformer oils after accelerated thermal aging

CONCLUSIONS

The high oleic natural ester-based dielectric fluids are more stable than the low oleic natural ester-based dielectric fluid according to stray gassing characteristics at 120 °C. The high oleic natural ester-base dielectric fluid 1 and the high oleic natural ester-based dielectric fluid 2 demonstrated less propensity of CO and CO_2 generation in comparison to the low oleic natural ester-based dielectric fluid 3. All natural ester-based dielectric fluids aged the paper insulation slower than the reference mineral oil data at the equivalent accelerated thermal aging condition. Paper insulation aged in the high oleic natural ester-based dielectric fluids are expected to maintain their performance longer in the accelerated thermal aging condition than the low oleic natural ester-based dielectric fluid 1 in terms of retention of tensile strength of cellulose insulation.

REFERENCES

[1] T. V. Oommen, 2002, "Vegetable Oils for Liquid-Filled Transformers", IEEE Electrical Insulation Mag., Vol1, No.1, 6-11.

[2] I. U. Khan, Z. Wang, I. Cotton, S. Northcote, 2007 "Dissolved Gas Analysis of Alternative Fluid for Power Transformers", IEEE Electrical Insulation Mag., Vol. 23, No. 5, 5-14.

[3] K. Rapp, C. McShane, J. Luksich, 2005, "Interaction Mechanisms of Natural Ester Dielectric Fluid and Kraft Paper," Proc. IEEE Int. Conf. Dielect. Liquids, 393-396.

[4] X. Zhang, E. Gockenbach, 2008, "Asset-Management of Transformers Based on condition Monitoring and Standards Diagnosis", IEEE Electrical Insulation Mag., Vol. 24, No. 4, 26-40.

[5] M. Duval, A. dePablo, 2001, "Interpretation of Gas-In-Oil Analysis Using New IEC Publication 60599 and IEC TC 10 Databases", IEEE Electrical Insulation Mag., Vol. 17, No. 2, 41-41.

[6] M. Duval, 1989, "Dissolved Gas Analysis: It Can Save Your Transformer", IEEE Electrical Insulation Mag., Vol. 24, No. 4, 22-27.

[7] I. Hohlein, 2006, "Unusual Cases of Gassing in Transformers in Service", IEEE Electrical Insulation Mag., Vol. 22, No. 1, 24-27.

[8] T. V. Oommen, T.A. Prevost, 2006, "Cellulose Insulation in Oil-Filled Power Transformer: Part II-Maintaining Insulation Integrity and Life", IEEE Electrical Insulation Mag., Vol. 22, No. 2, 5-13.

[9] M. A. G. Martins, 2010, "Vegetable Oils, an Alternative to Mineral Oil for Power Transformers- Experimental Study of Paper Aging in Vegetable Oil Versus Mineral Oil", IEEE Electrical Insulation Mag., Vol. 26, No. 6, 7-13.

[10] H. Z. Ding, Z. D. Wang, 2008, "On the Degradation Evolution Equations of Cellulose", Cellulose, Vol. 15, 205-224.