Real Life Assesment of Natural Ester Filled

Rajaram Shinde
Cargill

TLM Bangkok

Real life assessment of Natural Ester Filled (Envirotemp™ FR3™ Dielectric fluid) Transformers.

Mr. Rajaram Shinde
Global Technical Adviser
Cargill Inc.
Rajaram_shinde@cargill.com

Abstract: *Dielectrics fluid and Electrical Insulation paper are dedicated to transformer insulation. The transformer is a very essential apparatus in an electric power system and its reliability is of utmost importance as transformer failure results in a very costly and difficult to predict interruption of energy delivery. Transformer's performance depends heavily on its insulation system; therefore, the insulation is perhaps the most critical transformer part. The prime function transformer oil of transformer has always been to insulate and cool the system. In the present times, its role has been expanded far beyond these two important functions. [1]*

As Per IEC 60076:2013 Part 14, table C.2 Natural ester dielectric fluid is high thermal class insulation, provides fire safety as well as prevent thermal ageing. It helps to improve the load capacity without changing design of transformer. Today the Natural esters are the most accurate diagnostic media amongst available alternate fluids to monitor and assess the overall health of the power transformers IEEE C57.155 (DGA Guide).

safety, firewalls, deluge systems, and fluid containment are some of the fire protection requirements, users should address while installing mineral oil filled transformers. Aging substation infrastructure, environmental protection, and resource sustainability are other growing issues. Ester based alternate fluids are now available in market viz. Natural Esters which take over the limitations of conventional mineral oil in terms of partial biodegradability, low fire point and consequent safety issues with transformer explosions and fires that can cause catastrophic damages.

however, a good number of distribution transformers up to 33 kV have been retro filled with ester liquids. In case of power transformers, GETCO has taken lead and used natural ester liquids in 2 Nos. 66 kV class 15 MVA transformers to have first-hand experience. Also, Siemens 420 KV/ 400KVA transformer. In this paper, we are discussing about the integral role of Natural ester EnvirotempTM FR3TM dielectric fluids in the life management of transformers

Keywords: Transformer, Fire safety, Ester Fluid, Natural Ester, Life assessment.

Real Life Assesment of Natural Ester Filled

INTRODUCTION

Insulation system plays vital role in the transformer. Its primarily function as di-electric insulating and cooling medium in the transformer. The operational stress inside the equipment in service and chemical reaction cause generation of moisture, acids and gases. Excessive presence of the decay products will lead to accelerated deterioration in the dielectric strength of the fluid apart from damaging the insulation paper (Typically in case of mineral oil). This will call for timely detailed analysis of dielectric fluid to determine whether re-conditioning will be sufficient or replacement is the solution for prevention of transformer failure.

1. Effect of Moisture Contamination in the System:

Entry of moisture from atmosphere via breather, structural components inside the transformer one of them is source of moisture. The presence of oxygen coupled with moisture and high temperature will causes serious hazard to the insulation system. Even trace of moisture is harmful to power transformer. As per experts, oxygen levels more than 2,000 ppm in dielectric fluid greatly accelerate insulation paper deterioration. It is recommended that if oxygen reaches 10,000 ppm in the (Dissolved Gas Analysis) DGA, the oil should be de-gassed and new oxygen inhibitor installed in typically mineral oil filled transformers. Unless it will result into major failure in the transformer.

2. Effect of Particulate Contamination in the System:

Presences of Particles in insulating oil in transformers area major concern in the life management of the asset. Particle such as Cellulose fiber, iron, aluminum, copper, zinc and carbon particles are generated at the manufacturing stage and due to operational wear and ageing. Carbon particle contaminate the vital part of the transformer. Which block the flow of Insulation oil or slow down it, which will affect the cooling process in mineral oil filled transformers. Continues monitoring is needed. [2]

3. Ageing Effect of Insulation (Oil and Paper) System:

Ageing of insulation system is an unavoidable phenomenon during the service life of transformer. Ageing of insulation (Oil and Paper) is mainly due to polymerization and oxidation. Temperature, moisture and oxygen are the main agents like cancer of cellulose and oil decomposition. Polymerization leading to continuous decomposition of insulation even at110-120°C temperatures. The ageing process of insulation is initiated by moisture & oxygen in presence of acid catalysts from the oxidized oil. Acids generated in mineral oil are highly corrosive & reactive in nature. Ageing process can be slow down if timely preventive actions are introduced to remove water, oxygen, acids and keeping the system cool in mineral oil filled transformers. The transformer mineral oil insulation also several other abnormalities developing inside transformers in service such as,

- Conductive particles– reduction in dielectric strength.
- Dissolved water – reduction in dielectric safety.
- Bubble formation – partial discharge-PD, reduction in interfacial tension- IFT
- Sludge formation – increase in viscosity, increase in acidity of the oil

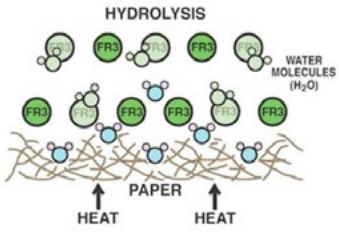
To resolve all the above problems and improve the life of the power transformer natural ester Envirotemp™ FR3™ Dielectric fluid is a proven solution. With its unique electrical properties of high thermal Capability, higher fire point & hydrolysis help to improve the life of insulation paper. FR3 fluid directly enhances the life of insulation system & Transformer.

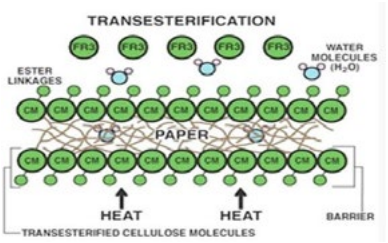
Real Life Assesment of Natural Ester Filled

ENVIROTEMP FR3 DIELECTRIC FLUID

1. Slow down Thermal Ageing:

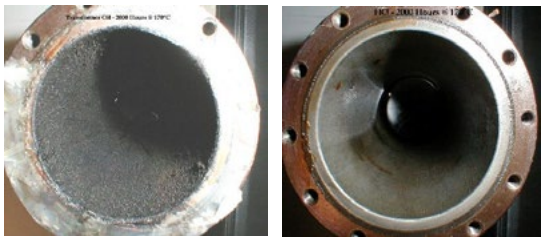
Typically, operating temperatures for power transformers lie between 65°C to 90°C. At these temperatures, the insulation materials undergo slow ageing with concurrent loss in electrical and mechanical properties. The insulation properties can also degrade due to the presence of moisture. Within a transformer when the insulating paper ages, water molecules are released from the insulation which accelerate further degradation of the cellulose due to hydrolysis leads to corrosive reaction in mineral oil. [3] However, with FR3 fluid, a hydrolysis reaction occurs whereby a molecule of water is converted to a non-reactive, long chain, free fatty acid thus absorbing the water molecule into the carbonyl structure of the natural ester. These fatty acids have no negative impact on the performance of the fluid or transformer. Also, they are non-corrosive & non-reactive as compared to acids generated with mineral oil shown in fig. (2)





(Figure 1. a) (Figure 1.b)

Figure 1: Hydrolysis process with Natural ester FR3 dielectric fluid.



Result with (2.a) Mineral oil (2.b) FR3 dielectric fluid.

Figure 2: comparison of Corrosive effect with mineral oil and Natural Ester FR3 dielectric fluid

In figure (1.a.) Shows that in hydrolysis process Natural ester FR3 dielectric fluid consumes water molecules creates fatty acids. In this way, it will remove dissolved water (Moisture).In figure (1.b.) Shows combination natural ester attached to the weak point of the cellulose. During hydrolysis, fatty acids form attached to cellulose and strengthening the insulation paper.

With a FR3 fluid-filled transformer, the water volume (ppm) allowed before reaching saturation and acid counts will be higher. That's not a bad thing – that's normal for FR3 fluid compared to a mineral oil

transformer. By being able to absorb the extra water produced as part of the thermal aging process and having a higher water saturation point, FR3 fluid protects the insulation paper (essentially 'self-drying') thus extending the asset life and helping improve the grid reliability. FR3 fluid can extend the insulation life of new transformers or the residual insulation life in a retro-filled transformer.

2. Impact on transformer life extension

Envirotemp™ FR3™ fluid extends insulation life by a factor of as much as 5-8 times because it has the unique ability to draw out retained moisture and absorb water driven off by aging paper. It also helps prevent paper molecules from severing when exposed to heat. These properties can result in an increase of overloadability and/or longer transformer insulation life, resulting in both lower life cycle cost and delayed asset replacement.

Figure 3: Sealed test on insulation paper with Mineral oil and with FR3 Fluid

In Figure 3. We can find that in seal tube test after 80 years of service life of transformer insulation paper still with working state as compare to mineral oil. Conclude that natural ester Envirotemp FR3 dielectric fluid accelerate the life of asset by improving the life of insulation system.

As per IEC 60076-14 brings the following table 1.3.1 in Annex C.2, It is clearly stated that when paper is impregnated with Natural Esters it will increase of the thermal class of paper

Table 1. Annex - C.2-C amparing of ageing result

	Constant a	Temperature T °C	Thermal index	Thermal class
IEEE mineral oil/thermally upgraded paper	$9{,}80 \times 10^{-18}$	110,0	110	120
Natural ester liquid/thermally upgraded paper	$7{,}25 \times 10^{-17}$	130,6	130	140
IEEE mineral oil/kraft paper	$2{,}00 \times 10^{-18}$	95,1	95	105
Natural ester liquid/kraft paper	$1{,}06 \times 10^{-17}$	110,8	110	120

Real Life Assesment of Natural Ester Filled

CASE STUDY

A. GETCO Retro-fill: The transformers were manufactured for Gujarat Energy Transmission Corporation Limited (GETCO), the state transmission utility in Gujarat. This is a two-winding transformer containing 7.4 tons of natural ester fluid, which was successfully tested by the company in May 2015 in the presence of customer's representatives. Ester based insulating fluids provide an alternative to mineral oil and are favored for their fire safety, full biodegradability and Life extension.

Figure 4: T&R India Ltd has manufactured two 66 kV, 15 MVA, three phase power transformers filled with Envirotemp FR3 natural ester fluid supplied by Cargill.

Commissioning of both the transformers was done one by one by GETCO under supervision of T&R representative. All the required precautions were taken such that there would not be direct contact of NE with air. The pre-commissioning checks and tests were carried out. The transformer was charged on 09.11.2015. Over nine months in service, both the transformers have undergone periodic dissolved gas monitoring and other natural ester properties.

Dissolved gas analysis was used to study the types of gases produced inside the transformer during its time in operation. Graphical representation of key gases for both transformers with respect to loading conditions during this period is given in figure (5). There was no generation of Acetylene (C2H2). As the loading conditions during the period under review were minimal, the maximum oil and winding temperature were of the order of 58 °C.

Real Life Assesment of Natural Ester Filled

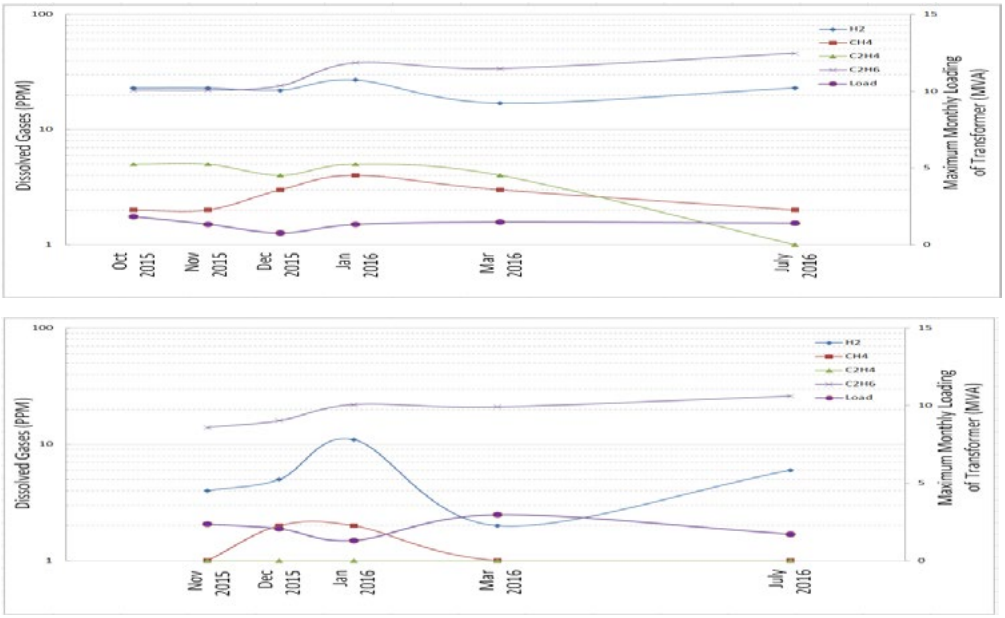


Figure 5. Graphical representations of periodic Oil DGA test results

From figure 5. GETCO found that Non-mineral oils appear to be more stray gassing type than mineral oils. Gassing data from many transformers retro filled with Envirotemp FR3 liquids since 2001 have indicated significant difference with stray gassing in ester liquid as compared to mineral oil. Ethane (C2H6) gas formation can be attributed to the stray gassing of FR3, which is the unexpected gas formation from mineral oils at relatively low temperatures in the 80 to 250°C range2,3. These are not considered a fault or a concern with the transformer and such experiences are presented in various platforms to distinguish this stray gassing from more serious faults in service.

Experience with use of Natural Ester (FR3) in 15 MVA 66 kV class transformers has been satisfactory. At works testing, in dielectric high voltage tests, transformer filled with this liquids with same design as for mineral oil filled type, did not give any problem. However, same temperature rises require about 10% increase in cooling radiators. Up to 66 kV, it is a kind of retro filling experience. Globally, transformers upto 420 kV class have been built using ester liquids. Environmental demands and fire safety need more and more use of such liquids.

Real Life Assesment of Natural Ester Filled

B. Transnet BW, Germany: The transmission network of TranetBW, Germany needed innovative technologies for the future of energy. It is particularly important for them that the natural ester fluid filled transformer is not only for technological progress and performance, but also for the protection of human beings and the environment. The new 400kV 300MVA natural ester fluid filled transformer is an essential component in establishing a sustainable network infrastructure that will ensure long-term power supply to the region.

Figure 6. The 300MVA, 420-kV natural ester FR3 filled Power Transformer in the test bay and during delivery.

Experiences from the field:

Over the past four years it is in service, the transformer has undergone many tests and measurements. These included gas analysis, as well as water content, breakdown voltage and tan delta analyses of natural ester samples, and more.

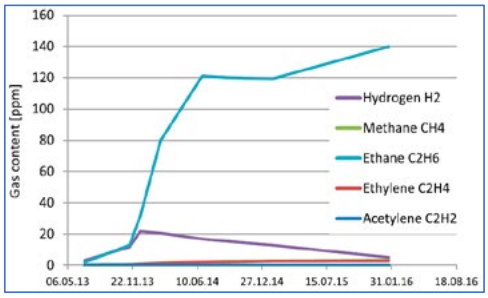


Figure 7. Concentrations of gases dissolved in natural ester

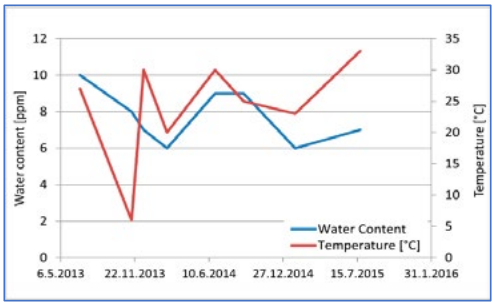


Figure 8. Water content in natural ester samples

Dissolved gas analysis (Figure 7) was used to reveal the types of gas produced inside the transformer during its time in operation. Notably, the presence of ethane increased over the four years in service. In comparison to the transformers using mineral oil, ethane is generated by different natural decomposition processes taking place inside the transformer with an insulation system which is a combination of natural ester and cellulose. These differences between the two insulation systems are based on the chemical structure of the various liquids, and they are explained in detail in the IEEE DGA guide [6]. Another distinction lies in a different solubility of gases in mineral oil and natural esters. Consequently, many, but not all, normally operating transformers filled with FR3 fluid have a higher ethane content than their mineral oil counterparts. Other hydrocarbon gases remained low [7].

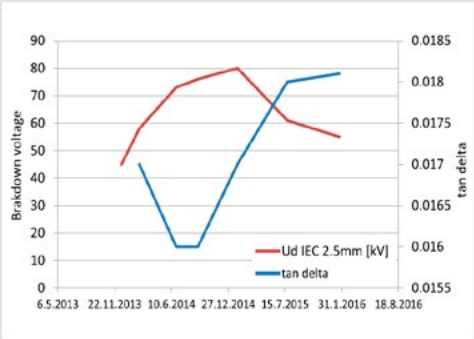


Figure 8. Breakdown voltage and tan delta of FR3 natural ester samples

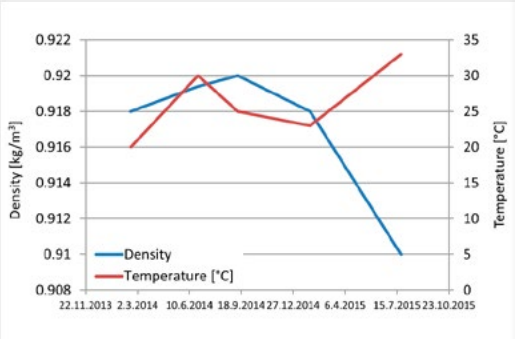


Figure 9. Density of natural ester sample

The analysis of the moisture in the transformer oil (Figure 8) was based on the oil samples which were taken from the transformer at quarterly intervals in order to evaluate the transformer condition. Breakdown voltage and tan delta of natural ester samples were also regularly measured and showed no significant changes with respect to the required values (Figure 8).

Other parameters, such as the density of natural ester sample (Figure 9) and oil viscosity, were also measured to further check the condition of the transformer. While some of these measurements are done on every third sample, all of these parameters help us establish that the transformer is in good condition and that the condition of the natural ester itself has no influence on its performance. The performed measurements and their results show that there have been no abnormalities in the operation of the transformer and that its performance has been perfect and according to all standard expectation.

CONCLUSION

In the early days, there were certain concerns about building a large power transformer with the use of natural ester FR3 fluids. However, all of the findings collected from monitoring data of the world's largest transformer of this type demonstrate that this is a transformer with a perfectly normal behavior, causing absolutely no concern and operating according to all expectations and standards prescribed by the IEEE reference guide. Any differences in the values are acceptable according to the IEEE guide.

The water content, dielectric strength and tan delta results indicate that this is a well prepared and a perfectly normally operating transformer – and the DGA results support this. All these findings suggest that this solution is the future for power transformers, serving not only as an alternative to mineral oil

now, but also as its replacement in the future. With this in view, applying these solutions now is becoming increasingly important in order to gain experience with the alternative liquids that seem to be a perfectly suitable replacement for mineral oil.

Bibliography:

[1] Ronny Fritsche, *Transformers: Natural Esters Replace Mineral Oil – Greener than ever,* Electrical Monitor, April 2015.
[2] Ronny Fritsche, Uwe Rimmele, Frank Trautmann, Michael Schäfer, *Prototype 420 kV Power Transformer Using Natural Ester Dielectric Fluid*
[3] Ronny Fritsche, Ivanka Atanasova-Höhlein, Karsten Loppach, Frank Trautmann, Uwe Rimmele, Michael Schäfer, Gernot Adamietz, *Large Power Transformers using Natural Insulation Liquids – aspects of design and first service results*
[4] Ronny Fritsche, *Nachhaltige Elektrische Isolierung Dank Pflanzenölen,* Automatisierungs- & Elektrotechnik, 2015
[5] Ronny Fritsche, *Großtransformatoren mit natürlichen Isoliermitteln, VDE Diagnostik Tagung;* November 2014
[6] C57.155-2014 - IEEE Guide for Interpretation of Gases Generated in Natural Ester and Synthetic Ester-Immersed Transformers, IEEE; 2014
[7] R2070_FR3_Dissolved_Gas_Guide v5 August 2006