International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 6, June-2018

Ester Oil Characteristics, Hot Spot and Overloading Capacity Analysis with Temperature Rise Test on Ester Oil filled Power Transformers

[1]Harsh Hirpara, [2]Prof. Mihir Bhatt, [3]Dr. Chirag Parekh

[1]Research Fellow, [2]Assistant Professor, [3]G. M. (Technical),
[1,2]M & V Patel, Dept. of Electrical Engineering,
Charotar University of Science and Technology. Changa, Gujarat, India.
[1]harsh.hirpara05@gmail.com, [2]mihirbhatt.ee@charusat.ac.in
[3]Atlanta Electricals Pvt. Ltd.
Vitthal Udyog Nagar, Anand, Gujarat, India.
[3]chirag.parekh@atlantaelectricals.com

Abstract— **Natural ester and Synthetic ester fluids may be used in new transformer units in order to improve their performance and reliability. Designing power transformers with natural ester and synthetic ester fluids requires, however, to account for a number of significant differences in properties, characteristics, and material parameters between natural ester fluids and mineral oil in order to obtain the desired performance. In this paper hot spot and overloading capacity of ester oil filled power transformers are discussed with the temperature rise test on power transformers. Currently mineral oil filled power transformers are used commonly but it can be replaced with ester oil filled power transformers. Ester oils (Natural ester oil and synthetic ester oil) have a high viscosity as compared to mineral oil so temperature rise test results need to be analyze because its directly affect on life of power transformer. Overloading capacity also discussed in this paper with results analysis.**

Keywords-Ester oils, hot Spot, overloading, temprature Rise,design improvement

I. INTRODUCTION

Power transformers are most important components of the power system. Transformers are used in power system for step up and step down the level of voltage, for energy saving. Efficient transformers are very important for power system to reduce the transmission losses. The life of a power transformer is also important for reliability and stability of the power system.

Due to internal losses of transformer like load loss, iron loss, eddy current loss, stray loss transformer gets heat up during loading condition.

Due to generation of heat, cooling of transformer is important. According to rating of transformer cooling systems are provided to transformer. For example, Oil Natural Air Natural (ONAN), Oil Forced Air Forced (OFAF) etc.

Transformer oil is used in transformer for mainly two purpose, as an insulating material and as a cooling medium. By providing transformer oil heat exchange to the environment is possible, by this transformer can work more efficiently.

Different types of oils are used in power transformers for cooling purpose. Mostly mineral oils are used in power transformers due to its lover cost and availability. But mineral oils have some drawbacks also. Due to this currently a craze of ester oil is increased.

Basically, mineral oil is a mixture of different hydrocarbon compounds like naphthenic CnH2n, such as cyclohexane C_6H_{12}, paraffin CnH2n+2, such as hexane C_6H_{14}, and aromatic CnHn, such as benzene C_6H_6. The proportions of the contents of the individual components depend on the composition of the petroleum and, for example, most prized naphthenic transformer oils can be obtained only with the certain types of petroleum. Therefore, in the case of spillage of oil to the environment, the oil is not a neutral for it. So basically, mineral oil is hazardous material which can directly affect on soil and water.

Mainly transformer oil used in transformer due to two reasons, one is for cooling purpose and second is for insulating purpose. Mineral oils are highly non-biodegradable so they are highly hazarders for environment. Even miner oils have low fire point and flash points compared to ester oils.

With some advantages like high biodegradability, high fire and flash points, environment friendly ester oils have some disadvantage also, like high resistivity and high viscosity.

Due to high viscosity ester oil filled power transformers have a high winding temperature rise and a high oil temperature rise, which can be directly affected on power transformer. In this paper some practical analysis for temperature rise with mineral oil and ester oils are explained.

II. EXPERIMENT PROCEDURE

A. Mineral and ester oils samples testings.

Ester oils have a different electrical and physical characteristic than mineral oil. To analyze that three samples are taken of oils and tested at ERDA (Electrical Research and Development Association, Vadodara, Gujarat, India). The comparative results are discussed in this paper. Samples taken are as below.

Sample I: Mineral oil sample

Sample II: Natural ester oil sample

Sample III: Synthetic ester oil sample

The comparative results are discussed in this paper

B. Temprature rise test.

First, temperature rise test is carried out for mineral oil filled power transformer. Temperature rise test is carried out with test procedure as per IS 2026, PART 2. Rating for a power transformer is 15 MVA, 66/11.55 kV.

Fig. 1. Temperature rise test setup.

By performing this test oil rise, high voltage winding temperature rise and low voltage winding temperature rise are observed and calculated.

After that, with the same design of transformer mineral oil is replaced with natural ester and synthetic ester oil and temperature rise test is carried out.

Following experiments are conducted on transformer.

Experiment I: Temperature rise test on mineral oil filled power transformer.

Experiment II: Temperature rise test on natural ester oil filled power transformer without changing the design.

Experiment III: Temperature rise test on synthetic ester oil filled power transformer without changing the design.

After design improvement (change in radiator fines and change in cooling ducts) again, temperature rise test are taken with natural and synthetic ester oil filled power transformer.

Experiment IV: Temperature rise test on natural ester oil filled power transformer with improved design.

Experiment V: Temperature rise test on synthetic ester oil filled power transformer with improved design.

C. Design improvement steps in ester oil filled power transformer for temperature rise test.

For cooling capacity improvement in ester oil filled power transformr two steps are taken for improvement in design.

1) Increasing in radiator fines.

Radiators are using for cooling of transformer at a loading conditions. With increasing radiator cooling duct heat transfer rate can be increased.

2) Increasing in cooling ducts.

Transformer windings have a cooling ductus between core to low voltage winding and low voltage winding to high voltage winding. These cooling ducts are providing space for oil to circulate from winding and providing clearance for voltages. These cooling ducts have a major role in oil circulation for heat transferring. By increasing thickness of cooling ducts heat transfer rate can be increased.

Both of these steps are taken for improving cooling in ester oil filled power transformer because of its high viscosity.

TABLE I. IMPROVEMENT IN RADIATOR FINS.

Old radiator size	Improved radiator size
1600 x 520 x 20 x 10	1600 x 520 x 21 x 10

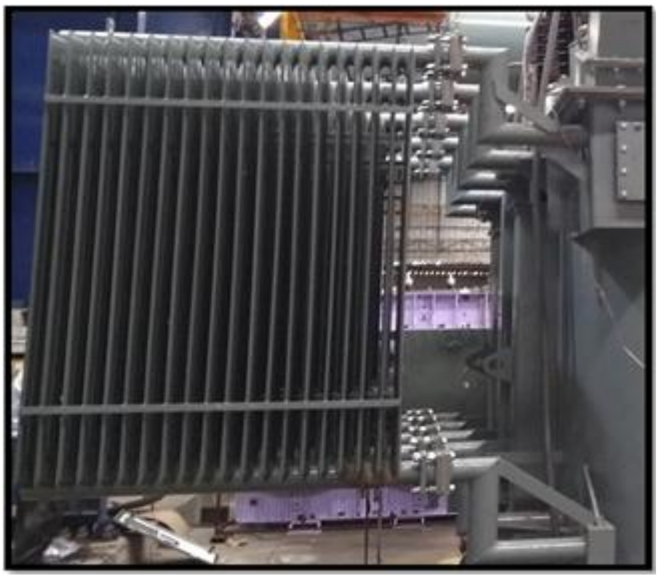

Fig. 2. Transformer radiator fines.

Here length of radiators are 1600 millimeters, width is 520 millimeters. Total numbers of fines are 20 which is increased in new design up to 21. Total number of radiators used per transformers are 10 numbers.

TABLE II. IMPROVEMENT IN COOLING DUCTS.

Ducts location in transformer	Old cooling ducts	Improved cooling ducts
Core to LV winding	8 mm	11 mm
LV to HV winding	12 mm	14 mm

Fig. 3. Transformer cooling ducts.

III. RESULTS AND DISCUSSION

The result comparison of oil samples is as bellow.

TABLE III. COMPARISON OF PRACTICAL DATA OF MINERAL, NATURAL ESTER AND SYNTACTIC ESTER OIL.

Test Particulars	Obtain Values for Mineral Oil (Sample I)	Obtain Values for Natural Ester Oil (Sample II)	Obtain Values for Synthetic Ester Oil (Sample III)
Electrical strength (BDV) (kV RMS)	83 (IS 6792) (60 Min)	81 (IEC 60156) (70 Min)	86 (IEC 60156) (70 Min)
Specific resistance at 90-degree C (Ω.cm)	$360x10^{12}$ (IS 6103) ($35x10^{12}$ Min)	$16x10^{12}$ ($10x10^{12}$ Min)	$19x10^{12}$ ($10x10^{12}$ Min)
Dielectric dissipation factor at 90-degree C	0.00045 (IS 6262) (0.002 Max)	0.0068 (IEC 60247) (0.03 Max)	0.027 (IEC 60247) (0.03 Max)
Water Content (ppm)	7 (IS 13567) (50 Max)	44 (IEC 60814) (50 Max)	47 (IEC 60814) (50 Max)
Neutralization Value (Total acidity), mg KOH/g of oil	0.00003 (IS 335) (0.4 Max)	0.02 (IEC 61125) (0.3 Max)	0.02 (IEC 61125) (0.06 Max)
Density at 20 ^oC (gm/cm3)	0.8270 (IS 1448) (0.89 Max)	0.9713 (ISO 3675) (1.0 Max)	0.9201 (ISO 3675) (1.0 Max)
Flash Point ^oC	140 (IS 1448) (140 Min)	268 (ISO 2719) (250 Min)	256 (ISO 2719) (250 Min)
Fire Point ^oC	160	320	354
Pour Point ^oC	-18 (IS1448) (-6 Max)	-48 (ISO 3016) (-45 Max)	-18 (ISO 3016) (-10 Max)
Kinetic Viscosity (mm^2/s)	14 at 27 ^oC (IS 1448) (27 Max)	33.5709 at 40 ^oC (ISO 3104) (35 Max)	35.3391 at 40 ^oC (ISO 3104) (50 Max)

Dielectric strength (BDV) is comparatively equal in all three types of oil. So natural and synthetic oil cause no effect on electrical break down strength in transformer.

Specific Resistance of natural and synthetic ester oil is lower than mineral oil, in other case Dielectric dissipation factor (Tan delta) of natural and synthetic ester oil is higher than mineral oil.

Both these properties indicate that natural and synthetic ester oil has comparatively higher contamination components then mineral oil.

Water Contain (PPM) and Neutralization value (Total acidity) both are comparatively higher in natural and synthetic ester oil then mineral oil. The higher ppm and acidity of transformer oil direct effect on the insulating material used in a power transformer. Degradation rate of insulating material increase with increasing ppm and acidity.

But, all these values are within limits as per specified standards. So, all these oils can be used in power transformers.

Flash point and Fire point of natural and synthetic ester oil are very high as compare to mineral oil. This is the main advantage of natural and synthetic oil over the mineral oil due to safety purpose.

Biodegradability of natural and synthetic ester oil is also very high as compare to mineral oil. That means both these ester oils are very less affect to the soil and water, which is good for environmental prospects. Which is the main reason to transformer trend turn with natural and synthetic ester oil.

Density and Viscosity both are comparatively higher in natural and synthetic ester oil then mineral oil.

Viscosity directly effect on the cooling of transformer. As ester oils have a high viscosity, they give comparatively low cooling to the transformer due to that temperature rise of transformer and transformer oil is comparatively higher in case of ester oils. Which is disadvantage of ester oil.

The results for temperature rise test with same design are as follows. (Experiment I, Experiment II and Experiment III)

TABLE IV. TEMPERATURE RISE TESTS RESULTS COMPARISON

	Mineral Oil	Natural Ester Oil	Synthetic Ester Oil
Oil temperature rise (Degree Celsius)	31.03	34.40	34.03
HV winding temperature rise (Degree Celsius)	33.13	37.76	37.49
LV winding temperature rise (Degree Celsius)	37.53	41.63	40.41

In table III comparison of experiment, I, II and III is shown. Temperature rise test is taken with reference of IS 2026, Part 2. Results shows that oil temperature rise and winding temperature rise of ester oils are higher than mineral oil.

As the viscosity of natural and synthetic ester oil is very high as compare to mineral oil, it's directly affect on temperature rise in power transformer. Oil temperature rise and winding temperature rise are high in ester oil filled power transformers with compare to the mineral oil filled power transformers which can reduce the life of power transformer.

These experiments are done with same designed transformer, only oils are changed for all three experiments.

As per mentioned above radiator size and cooling ducts are improved for better heat transferring.

The results for temperature rise test with increasing radiator fines and cooling ducts are as follows. (Experiment II and Experiment III)

TABLE V. TEMPERATURE RISE TESTS RESULTS COMPARISON WITH IMPROVED DESIGN

	Mineral Oil	Natural Ester Oil	Synthetic Ester Oil
Oil temperature rise (Degree Celsius)	31.03	31.37	31.73
HV winding temperature rise (Degree Celsius)	33.13	33.80	33.79
LV winding temperature rise (Degree Celsius)	37.53	37.19	37.21

By analyzing these results, oil temperature rise and winding temperature rise of ester oil filled transformers are reduced with improved design. Which can be improved life of transformers. So, with changing some conceptual design parameters, temperature rise of natural and synthetic ester oil filled power transformer can be controlled.

IV. TEMPERATURE RISE TEST WITH OVERLOADING OF ESTER OIL FILLED POWER TRANSFORMER

Overloading of power transformer can't be possible for long time period in case of mineral oil due to its low flash point (around 140 degrees Celsius). But, in case of natural and synthetic ester oil it can be possible due to their high flash points (268 degree Celsius for natural ester and 256 degrees Celsius for synthetic ester oil). Thermally upgraded paper need to be used for overloading. Temperature rise test is performed again with natural ester oil filled power transformer with improved design as per mentioned above with overloading of 30%. In this case transformer is overloaded with 30 % of rated current.

TABLE VI. TEMPERATURE RISE TESTS RESULTS COMPARISON

	Natural Ester Oil
Oil temperature rise (Degree Celsius)	45.37
HV winding temperature rise (Degree Celsius)	55.22
LV winding temperature rise (Degree Celsius)	61.11

From this test we observed that, overloading of power transformer filled with ester oils can be possible for longer period with compare to mineral oil. This is due to viscosity of ester oils are lower than mineral oil at temperature grater then 70 to 80 degrees Celsius. Thermally upgraded papers must needed for this.

V. CONCLUSION

Ester oils have a high flash point and fire points compared to the mineral oil, so ester oil filled power transformers are very safe with compare to the mineral oil filled power transformers. Combustion products of mineral oil being the result of its ignition occurred because of transformer failure, are considered to be dangerous and cause air pollution. With the high flash and fire points ester oil filled transformers can be used in public area or in middle of the city.

Ester oils are highly biodegradable with compare to mineral oil. Mineral oils have a very low biodegradability factor, because of that wastage or leakage of mineral oils form transformers are very harmful and hazardous for soil and water. Ester oils have a very high biodegradability factor, that's why they are easily decomposed in soil so, ester oils are environment friendly.

As discussed ester oil filled power transformers have high oil and winding temperature rise with compared to mineral oil filled power transformers. These phenomena are due to high viscosity of ester oils compared to mineral oil. But, cooling capacity for ester oil filled power filled transformer can be increased with some design improvement.

Ester oil filled power transformer can be overload up to 20 to 30% for longer period due to its high flash and fire points, which is not possible in case of mineral oil. So ester oil filled transformers can be used on partial overloading conditions.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of this research by Atlanta Electricals Pvt. Ltd. (Vitthal udyog nagar, Anand, Gujarat, India) for funding, including staff of testing laboratory of Atlanta Electricals Pvt. Ltd.

REFERENCES

[1] AEPL reference standards and documents.

[2] Oil samples test results obtained from ERDA (Electrical Research and Development Association)

[3] Test certificates from AEPL.

[4] Test certificates of M and I materials, Cargill India Pvt. Ltd.,

[5] Apar Industries Ltd. And Savita Oil Technologies Ltd.

[6] Pawel Rozga, Dr., PhD Eng. “Properties of new environmentally friendly biodegradable insulating fluids for power transformers” in 1st Annual International Interdisciplinary Conference, AIIC 2013, 24-26 April, Azores, Portugal.

[7] V. Mentlík, R. Polanský, P. Prosr, J. Pihera and P. Trnka “Synthetic ester-based oils and their application in power industry international conference on renewable energies and power” in Quality (ICREPQ’09).

[8] Roberto Asano, Jr., Member, IEEE, and Stephane A. Page “Reducing environmental impact and improving safety and performance of power transformers with natural ester dielectric insulating fluids.” In IEEE Transactions On Industry Applications, Vol. 50, No. 1, January/February 2014.

[9] Grzegorz Dombek1, Przemyslaw Goscinski1, and Zbigniew Nadolny “Comparison of mineral oil and esters as cooling liquids in high voltage transformer in aspect of environment protection.” In Poznan University of Technology, 60965 Poznan, Poland.

[10] K.J. Rapp, G.A. Gauger, J. Luksich “Behavior of ester dielectric fluids near the pour point presented at the 1999 IEEE conference on electrical insulation and dielectric phenomena.” In October 17-20, 1999, Austin, TX.

[11] Jian Hao, Ruijin Liao, George Chen, Zhiqin Ma and LijunYang “Quantitative analysis ageing status of natural ester-paper insulation and mineral oil-paper insulation by polarization/depolarization current” in School of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, UK.