International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Special Issue 39 (KCCEMSR) (March 2016), PP. 20-23

INSULATING FLUIDS FOR POWER TRANSFORMERS PROPERTIES

Chhapra Abdur Rehman , Tiwari Vivek , Patel Iftekar , Syed Kaleem
Anjuman-I-Islam's Kalsekar Technical Campus
New Panvel , India

***Abstract*— Since independence in India there has always been shortage of electricity and at no point of time we have been able to meet the peak demand. The gap between the demand and generation can be minimized by either improving the installed capacity or reducing the consumer demand. The gap between availability & demand is of order 6% as on date. If we take into account the issues like environment pollution and global warming, the preferred option is to increase the energy efficiency or minimize the consumer demand, as in the other alternative particularly in India where thermal generation dominates increased environmental pollution is inevitable.**

The problem of using the new environmentally friendly insulating liquids like synthetic and natural esters for power transformers is presented in this article. The positive and negative properties of the esters are described on the basis of a comparison with the most popular insulating liquid like mineral oil. The results of the experimental studies were taken into account as well as the results of works presented in the world literature. Conclusions from the analysis will indicate that the wide knowledge about ester properties is necessary to correct design process and to proper exploitation of the power transformers filled in esters.

***Key Words*— Power transformers, insulating fluids, environmental protection, high voltages.**

INTRODUCTION

Generation of electrical power in low voltage level is very much cost effective. Therefore electrical power is generated in low voltage level. Theoretically, this low voltage level power can be transmitted to the receiving end. But if the voltage level of a power is increased, the current of the power is reduced which causes reduction in ohmic or I^2R losses in the system, reduction in cross sectional area of the conductor i.e. reduction in capital cost of the system and it also improves the voltage regulation of the system. Because of these, low level power must be stepped up for efficient electrical power transmission. This is done by stepping up transformer at the sending side of the power system network. As this high voltage power may not be distributed to the consumers directly, this must be stepped down to the desired level at the receiving end with the help of step down transformer. These are the uses of electrical power transformer in the electrical power system.

The transformers are not the devices that generate particularly environmental problems. . A significant majority of the total number of transformers, produced in all ranges of voltage and power, are the oil power transformers. The so-called dry transformers are the margin of exploited units. Therefore, in the assessment of environmental risks connected with the transformer in service, the mineral oil is the most important element to be taken into consideration. Of course, the aspects such as the risk of electric shock, noise and vibration as well as energy and power losses are also important, but taking into account the effects for the environment from these types of interactions, these, connected with mineral oil, seem to be the most dangerous [9].

In oil type transformers insulating oil is used for cooling of transformers . Insulating oil in an electrical power transformer is commonly known as transformer oil. It is normally obtained by fractional distillation and subsequent treatment of crude petroleum. That is why this oil is also known as mineral insulating oil. Transformer oil serves mainly two purposes one it is liquid insulation in electrical power transformer and two it dissipates heat of the transformer e.i. acts as coolant. In addition to these, this oil serves other two purposes, it helps to preserve the core and winding as these are fully immersed inside oil and another important purpose of this oil is, it prevents direct contact of atmospheric oxygen with cellulose made paper insulation of windings, which is susceptible to oxidation [5].

Mineral oil is a mixture of different kinds of hydrocarbon compounds (naphtenic C_nH_{2n}, such as, paraffin CnH_{2n+2}, hexane C_6H_{14}, and aromatic C_nH_n, such as benzene C_6H_6). The proportions of the contents of the individual components depend on the composition of the starting petroleum , for example, 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..For example, 1 kg of the waste oil that has leaked from the transformer to the water reservoir makes it unfits to drink in the volume of 5 million liters [8].

Thus, the failures concerning the oil leakage are undoubtly harmful to the environment (air, water, soil), and the costs of removing their effects are usually very large. Prevent them or limitation their effects, although expensive, has an importance meaning for the environment. It is believed that this role is fulfilled by the special place with the pans for leaking oil, by the systems of oil and water separation, and by the monitoring of the transformer and its equipment [3]. The example of the oil pan installation is shown in Fig. 1.

The volume of designed and built oil pans should be enough large to bring all of the oil contained in the transformer.

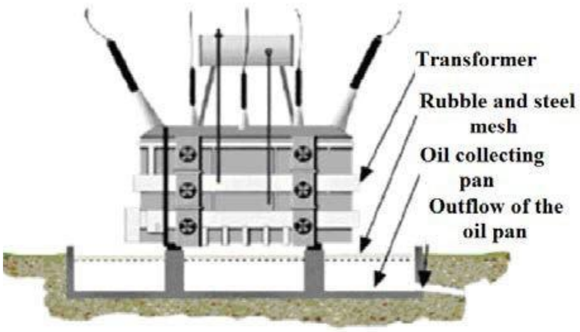

Fig. 1. Example of the oil pan installation.

Another problem of environmental nature is the combustibility of fluids like mineral oil because of their relatively low flash point. Combustion products of mineral oil being the result of its ignition occurred because of transformer failure (e.g. short circuit), are considered to be dangerous and cause air pollution. Around 1000 kg of burnt, under unfavorable conditions, mineral oil emits circa 10 kg of harmful substances to the atmosphere. Additionally, the side product accompanying the mineral oil combustion is the dense and very black smoke (Fig. 2).

Fig. 2. Example of transformer failure with fire

Insulating Fluids - The insulating liquid most commonly used in power transformers is based on mineral oil. It has been used for decades in electrical equipment for insulation and cooling purposes because the technical parameters, as well as the physical behavior of mineral-based oil, are well known. Mineral oil is a non-renewable fossil resource that may be exhausted in the upcoming decades [15] .

Consequently, there is a strong demand to replace that kind of insulation liquid with any kind of alternative solution that enables a higher degree of sustainability. Several types of alternative liquids are available for the market of electrical equipment. The alternative liquids can be divided into three basic types: natural ester-based liquid, synthetic ester-based liquid, and silicone oil. Because the properties of these types of alternative liquids are different from those of mineral oil, as well as among themselves, it has to be clearly investigated for which purpose these liquids will be used.

A study by Hartford Steam Boiler over a period of 20 years indicates that 13% of all transformer failures were caused by inadequate maintenance. This number is significant, considering the study found that the average age of a transformer at the time of failure was only slightly more than 11 years; transformers are expected to last 25 to 30 years [16].

Mineral Oil - Conventionally applied transformer oil consists mainly of carbon and hydrogen in molecules of different structures. There are three basic transformer oil structures: paraffinic, naphthenic, and aromatic .Paraffinic molecules have lower thermal stability than naphthenic molecules [15] .

The Most important group is the aromatic structure group, which has a major influence on the grade of the oil. While monoaromatics are always alkalized and generally have good electrical properties, polyaromatics exist naturally in the mineral oil and may have a negative impact on electrical properties (e.g., charging tendency and impulse breakdown withstand strength).Additional molecules, such as nitrogen, oxygen, and sulfur, also naturally exist in mineral oil.

For mineral oil, the biodegradability factor is very low, and in accordance to the standard, is only 10%. It means that after 28 days from the entering the oil to the environment, only such small part of this fluid surrenders to self-degradation.

There are a lot of parameters, investigation results and design rules that enable the insulation design of mineral oil filled electrical equipment. Also , the cooling characteristics and behavior of flowing fluid have been investigated in several rules and standards.

Ester Fluids - In regard to the requirements for increased biodegradability and sustainability, the most important alternative liquids are ester based. These liquids are the only alternative liquids that are classified to be fully biodegradable. Of course, this is still dependent on the composition of the esters, the volume of the disposed liquid, and the time allowed for biodegradation.

Esters are divided into two main classes: synthetic and natural.

Synthetic esters are derived from crude oil-based chemicals. These esters are usually the product of a polyol combined with synthetic or natural carboxylic acids to create structures where several acid groups are bonded to a central polyol structure. Polyol is a molecule with more than one alcohol functional group. The properties of synthetic esters lead to benefits for transformer insulation, especially with respect to the thermal and environmental behavior of the equipment[15].

Natural esters are derived from vegetable oils. Consequently, they are the only kinds of liquids that are primarily derived from renewable sources. Natural ester fluids are based on saturated as well as single, double, and triple unsaturated fatty-acids. Saturated fatty acids are chemically stable but have a high viscosity. Triple unsaturated fatty-acids have a lower viscosity but are very unstable in oxidation. To reach an acceptable value of oxidation stability for natural esters, it is necessary to add suitable antioxidants.

In the Table 1, the basic physico-chemical and dielectric parameters for both esters and mineral oil are summarized . These parameters concern the fresh fluids as received by the manufacturers, without the use of any treatment.

Table 1. Basic parameters of synthetic ester, natural ester and mineral oil .

Parameters	Units	Synthetic ester	Natural ester	Mineral oil
Physico-chemical properties				
Density	kg / dm^3	0.95	0.9	0.81
Specific Heat at 25^{O}C	J / kg K	1873	1848	1820
Thermal Conductivity	W / m K	0.14	0.17	0.11
Kinematic Viscosity at 25^{O}C	mm^2 / s	69	82	25
Pour Point	^{O}C	-57	-21	-50
Fire Point	^{O}C	320	360	165
Flash Point	^{O}C	260	310	152
Biodegradability	%	90	96	10

Dielectric Properties				
Breakdown voltage	kV	>80	>80	70
Permeability at 20^{O}C	-	3.15	3.08	2.2

The physico-chemical properties of the esters, particular meaning, from the side of ecological aspect, has two of them: biodegradability and flash point.

For both of esters, their biodegradability is significantly higher than mineral oil, what confirms the better ecological properties of these liquids. Taking into account that after 28 days both of esters decay in above 60%, they can be admitted as a biodegradable. Thus, using esters in the places having restricted environmental regulations is not a problem. It is important to notice, that in the case of esters it is not necessary to use the oil pans, what finally reduces the costs of installation of the transformers.

The second of the mentioned parameters – flash point – also specifies the esters as the environmentally friendly liquids. Performed for the all three insulating fluids the test of "open burner" indicates on the flash temperatures identical as determined by the manufacturers in the data sheets. For the mineral oil the temperature, after delivered the open fire from the acetyl burner, rose violently and after 4 minutes the ignition of mineral oil took place in the temperature of about 130 ^{o}C.. Then the oil burned without the open fire and during the combustion process emitted the dense black smoke. Whereas in the case of ester fluids the temperature rose slower and after the 70 minutes the process was stopped because the ignition did not occur and the temperature reached nearly 280 ^{o}C.

From the insulating properties point of view the most important parameter is breakdown voltage. This voltage, standard, is determined by the introduction of the liquid sample to the special apparatus with profiled metal electrodes creating the uniform electrical field distribution and then subject to the rising electrical field resulting from the AC voltage increasing. The average value of six breakdowns occurring in the specified conditions is taken as an AC breakdown voltage. Of course, the value of breakdown voltage depends on the quality of tested liquid (water and impurities content), so in order to compare the values of breakdown voltages of different dielectric liquids, they should have the similar quality [11] . In the Fig. 3, the results of the measurements of AC breakdown voltage are presented. These results confirm identical properties connected with the electrical strength of synthetic ester, natural ester and mineral oil [10] .

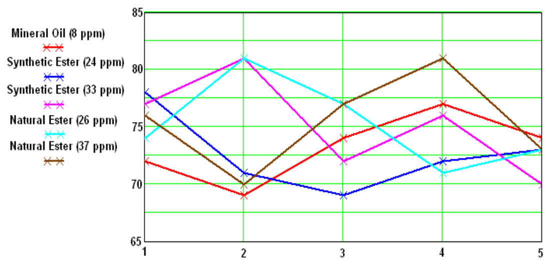

Fig. 3. AC breakdown voltage for different types of insulating liquids measured according to the IEC 60156 standard.

Looking at the influence of moisture content on the electrical strength, the esters behave more favourable. It is because the esters are characterized by the constant value of breakdown voltage apart from the moisture content up to 575 ppm [2] . For the mineral oil, its strength goes down even at the small increasing of moisture (at 20 ppm the breakdown voltage is only 42 kV while for good conditioned oil this value is in the range of 65-78 kV).Similarly other parameter characterizing the dielectric properties of the liquids, that is the electrical permittivity, also indicates on the possibility of better using the esters in the insulating systems of power transformers.

CONCLUSION

Biodegradable synthetic and natural esters are the good alternative for mineral oil, especially in the situations when the power transformer has to be installed in the places for which the restricted environmental regulations are specified. Next to the many positive aspects like the higher biodegradability, high flash point and good properties concerning the AC electrical strength, esters have also negative features, which should be taken into account in the design phase and during the exploitation of the transformer with esters. The parameters of the designed transformer must be based on the knowledge about these negative features. Designer should know that the esters are susceptible to the action of a concentrated heat flux, have the worse cooling properties than mineral oil, and lower lightning strength. The final product – power transformer filled by ester – will be in effect the more expensive device, but taking into consideration the pro-ecological tendencies reigned on the transformer market and still increasing demand for new environmentally friendly products, in the feature the cost will be certainly lower.

REFERENCES

[1] Fritsche Ronny, Pukel Georg, Siemens AG; “The Green Machine: Renewable materials for transformers,” 2014, Electricity Today, India, January 2014.
[2] Martins 2010, Dang Viet-Nung, Beroual A., Perrier C. 2011.
[3] Mosinski F. 2009, Rozga P., Skowron A., 2012.
[4] Borsi H., Gockenbach E., Properties of ester liquid Midel 7131 as an alternative liquid to mineral oil for transformers. IEEE Intern. Conf. on Diel. Liquids, 2005.
[5] http://www.electrical4u.com/transformer-insulating-oil-and-types-of-transformer-oil/
[6] Hulshorst W.T.J., Groeman J.F., Energy saving in industrial distribution transformers. KEMA report reference 40130017-TDC 02-24226A, 2002.
[7] Kaminska A., Very dangerous waste – PCB in oil (in Polish). Ekologia, No 2, 2007.
[8] Kucharska A., Polityka Energetyczna, Rewiev of water-soil protection systems from electro insulating oil leaks from electrical power transformers in law aspects (in Polish), T. 2, 2007.
[9] Kycior K., Environmental protection against the oil leakage (in Polish).Ekologia, No 1, 2007.
[10] http://eujournal.org/index.php/esj/article/download/1470/1479
[11] Li J., Grzybowski S., Sun Y., Chen X., Dielectric properties of rapeseed oil paper insulation. Annual Report Conf. on Electr. Insul. and Diel. Phenom., 2007.
[12] Liu Q., Wang Z. D., Streamer characteristic and breakdown in synthetic and natural ester transformer liquids under standard lightning impulse. IEEE Trans. Diel. Electr. Insul., No 1, 2011.
[13] Martins M. A. G., Vegetable oils, an alternative to mineral oil for power transformers – Experimental study of paper aging in vegetable oil versus mineral oil. IEEE Electr. Insul. Mag., No 6, 2010.
[14] Midel 7131 - Comparison to Alternative Technologies, 2010.
[15] http://www.energy.siemens.com/hq/en/power-transmission/transformers/assets/pdf/siemens-transformers-prototype-420kv-power-transformer.pdf
[16] http://ecmweb.com/content/analyzing-transformer-insulating-fluid