Suitable Investigation of Power Transformer Liquid Insulation using Antioxidants

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ABSTRACT

Now a day, the insulating fluids play a major role in transformer. Generally the transformers use mineral oil based fluids, it is non-decomposable and it takes place long time for disposing the aged mineral oil. Past few years, insulating fluids are used in the transformer as long as used. Due to the scarcity of mineral oil, world focus on alternative solution for current users – which is biodegradable (natural esters). There are some of the important favourable critical parameters such as higher breakdown voltage (BDV), lower viscosity (cSt), higher flash and fire point (oC) and lower pour point (oC) are characterized by these properties. The other properties also need for natural esters like sunflower oil (SFO), corn oil (CO), rice bran oil (RBO), rapeseed oil (RPO), soybean oil (SBO), Honge oil (HO), olive oil (OO) and mustard oil (MO) have good physical, chemical and dielectric properties. The thermal, dielectric and ageing tests are done by these natural esters and it shows some good literature for natural esters. One of the most useful agents like added nanoparticles, thermal properties of insulating fluids are enhanced and also increase the year of transformer. This paper investigates on improving the efficiency of transformer compare to transformer oil. The transformer oil shows good efficiency as well as some of the natural esters also shows good efficiency using antioxidants. Comparative analysis of transformer oil and natural ester without and with antioxidant of 0.5% and it is proved with the different tests under various load condition.

Index Terms - **transformer; vegetable oils; mineral oils; antioxidants; efficiency**

1. INTRODUCTION

INSULATING medium is one of the prime factors which determine the life of a transformer. Some of the commonly used insulating medium are solid (Press board and Kraft paper) and liquid (mineral and natural esters). They function effectively as insulation and cooling medium. Mineral oil is the most commonly used dielectric and cooling medium since post world war II. But mineral oil undergoes degradation through ageing, heating due to faults etc and affects its dielectric properties. Therefore the lifespan of mineral oil is 20 years. Further it is non bio degradable [1, 2]. Nowadays liquid dielectric research gives a number of new approaches to overcome drawbacks like oil leak, harmful disposal and explosion. Many literatures are available which deals with conventional methods and its harmful environmental effects [3,4]. The requirement of existing mineral oil and upcoming forecast of using vegetable oil indicates a non-equilibrium condition [5].

Transformers can be broadly classified into two types namely (high) voltage power transformer and (medium / low) voltage distribution transformers. In recent years these transformers have been successfully run with natural esters as insulating and cooling medium. It is a sustainable alternative source of mineral oil and is environmental friendly. For existing transformers aged mineral oil can be replaced with natural esters, but has certain limitations due to properties like high kinematic viscosity, dielectric loss and acid values. Power transformers used in the transmission and distribution system have different voltage levels. On loaded conditions these transformers give very high efficiency up to 99%. The different kinds of losses like core and copper loss contribute to the remaining 1%. By reducing these losses the ideal state could be reached.

Few years ago research was carried out on the usage of alternative insulating and cooling fluids which are eco friendly and have good thermal and insulating properties. There were two main reasons to go for alternative insulating fluids in transformers. One was mineral oil has low biodegradability and its serious spills could contaminate the soil and ground water. It largely affects the humans and the ecosystem and has a long recovery period. Another reason to abandon the use of mineral oil is due to its dependency on petroleum products and the depletion of petroleum resources. The replacement of mineral oil with natural esters (processed from renewable natural sources like vegetable and animal products) and synthetic esters act as alternate solution to mineral oil suggested by research developers. The researcher's ideas vary with respect to types of natural esters used and its applications. By adding conducting or semiconducting nano particles with the base fluid the voltage withstanding capacity can be increased [8 -10].

T.V. Oommen from ABB Power Inc. Ltd., suggested that mineral oil could be replaced with vegetable oil and treated vegetable oil in distribution and power transformers for improving stability and other factors. BIOTEMPTM named after vegetable oil has favorable properties and act as an insulating medium[11].

Inmaculada Fernández et al presented a review paper on comparative evaluation of alternate fluids for power transformer. The authors elaborate properties such as physical, chemical and dielectric properties of qualitative equivalence of vegetable oils and their behavior for aged oils. Based on the results, favorable properties of the sunflower oil, rapeseed, canola and soybean oil act as insulating oil suggested by authors [12].

Lijun Yang et al suggested that accelerated thermal aging tests span of transformer paper (Kraft paper) with the result of vegetable oils. The span of solid insulation was prolonged by using natural esters through various tests. [13].

A. Raymon et al presented comparison of nano ester based insulating fluids namely sunflower oil, soybean oil, rapeseed oil, rice bran oil, coconut oil and cotton seed oil in this paper. The various concentrations of several types of conducting, semi conducting and non-conducting nano particles were impart in these oils. Experimental results show that the breakdown voltage was enhanced in the natural esters compared to mineral oil at higher temperature (above 45oC). The viscosity have a value ranging from 3 to 23% (downward side), implies the addition of nano particles [14].

The physiochemical and dielectric properties of vegetable oils make it an alternate source for cooling and insulation and have been experimented and tested by few methods for finding the transformer efficiency. Still most of the vegetable oils have not been identified as insulating fluids in transformer. The life and quality of oil can be analyzed by the oxidation stability. In many research works, antioxidants are used as free radical reducing agents. Antioxidant plays a vital role in the oil to increase the oxidation stability [15].

As per standards, the physiochemical and dielectric properties of the vegetable oil based nano fluids are used. Present work contributes to the breakdown strength, viscosity, flash and fire point of various vegetable oils with and without (BHT) antioxidant and is discussed by experimental methods.

2. PRESENT SCENARIO

Distribution transformers have losses of about 0.5% for larger units; it has very high efficiency and good performance. Smaller unit transformers have efficiency more than 97%. From this estimation, the entire electric power generated can exceed 3% of power distribution network. Day by day, the electrical power consumption is increasing gradually with total usage of about 500 billion kWhr per year. Efficiency of transformers will be increase by reducing the losses. The complete solution for finding and improving the transformer efficiency is the alternate insulating fluids especially natural esters (Vegetable Oil).

3. SYNTHETIC ANTIOXIDANTS

Synthetic antioxidants include phenolic compounds such as, Butylated HydroxyToluene (BHT), Tertiary-Butyl HydroQuinone (TBHQ) and Butylated HydroxyAnisole (BHA) and non-phenolics such as erythorbic acid, ascorbyl palmitate and ascorbic acid (Lee et al., 1997). Natural antioxidants include amino acids, ascorbic, carotenoids and dipeptides, protein hydrolysates, phospholipids; tocopherol into aldehydes and other volatile oxidation products is prevented. Antioxidants can decelerate or suppress lipid oxidation. Antioxidant which could be classified as primary or secondary prevents oxidation process. Multiple-function antioxidants are mentioned as quite one depending on the mechanism of action. The chain-breaking antioxidants are also called as primary antioxidant, which are ready to react free radicals directly and change over to more stable, non-radical products. Antioxidants respond with lipid, peroxyl and alkoxyl radicals, free radicals are decomposed by further process.

The cheaper antioxidants are EDTA and BHT, which could be processed much easier than natural antioxidants. The uses of synthetic antioxidants are restricted to enforce their health risks and toxicity but the semiconducting nanoparticles and antioxidants (performance of additives) are effective and economic [16, 17]. The role of various natural and synthetic antioxidants like Butylated Hydroxy Anisole (BHA), Butylated Hydroxy Toluene (BHT), Propyl Gallate (PG), Ascorbic Acid (AA), Citric Acid (CA), Alpha Tocopherol (α-T) are effective when used singly or in combination [18, 19].

4. EXPERIMENTAL DETAILS

1 KVA, 440 / 220 V three phase step down transformer is used for experimental setup. The different load condition in transformer such as quarter, half, half-quarter and full load are applied with resistive load and the relevant readings are noted [20]. Each set of loading is completed with particular mineral oil as well as with natural ester. The same experiment is repeated with other natural esters. The performance of transformer efficiency is calculated by doing open circuit (OC) test and short circuit (SC) tests. Here, the work deals with the transformer performance with mineral oil and natural esters.

4.1 EFFICIENCY

The commercial and industrial purposes are effectively ruined by the important electrical apparatus as transformers. The efficiency of full load about 95% to 98.5% occurred and the ratings from 1 KVA to 1000 KVA, sizes depend upon the rating of transformer. The losses of transformer such as core and copper loss, winding (resistance of the wire) includes the copper loss. The losses will occur in the form of heat, while the current passing through a conductor. Generally, the conductors are made up of copper act as a good conductor. Similarly, the constant load transformer has a aluminum conductor (best commercial metals for conducting electricity – offers low resistance), it's cheaper (low quality) and degrade the life span of transformer. Therefore, the windings are the important act in the transformer, quantity of energy lost in the form of heat. Losses may occur up to 20% of full-load rating. The variation is depending on the reciprocally as square of the load.

4.2 OC AND SC TEST

Two types of tests are carried out in transformers namely open circuit (OC) and short test (SC) for calculating the losses in the transformer. Figure 1 represents the connection for OC test. From the figure, the low voltage (LV) side of transformer is connected with three measuring instruments (Ammeter, Voltmeter and Wattmeter) at the required rating. By using the single phase auto transformer (variac), the rated voltage is applied to LV side of the transformer. The high voltage (HV) side of the transformer is kept open for OC test. By using auto transformer, LV side gets the rated voltage and the particular rated voltage is obtained in HV side. After the applied voltage, the readings are observed and calculated. The core loss in the transformer is determined by this test.

Another loss in the transformer is copper loss. This loss has a major impact in the transformer performance and to calculate this loss SC test is conducted as shown in figure 2. Here the transformer from HV side is connected with three measuring instruments (Ammeter, Voltmeter and Wattmeter) and LV side is kept closed and it is short circuited. By adjusting the auto transformer at rated current, readings are observed and copper loss is calculated [21].

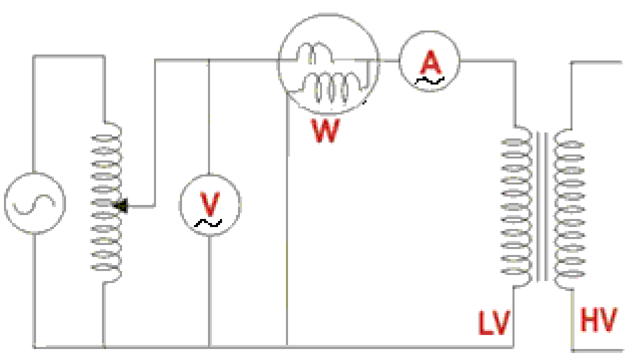

Figure 1. Circuit diagram for O.C test.

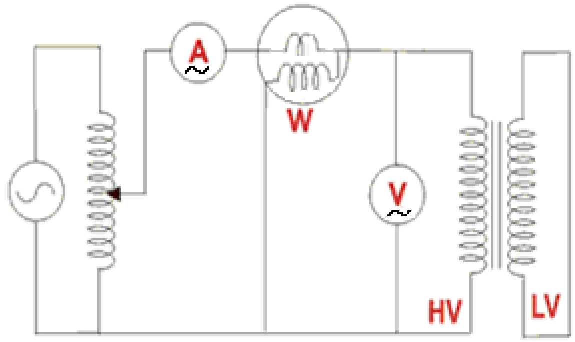

Figure 2. Circuit diagram for S.C test

5. INSULATING FLUIDS

In transformers different insulating fluids are used, like natural ester and mineral fluids. Moreover, the transformers used mineral fluids; it comes from the petroleum bi-products [22]. In recent years, the petroleum product is used frequently in the transformer and also reduces the availability of source. Therefore there is a need to look for alternative sources like natural esters.

5.1 SYNTHETIC FLUIDS

The synthetic fluids are of two types, one is naphtha and other is paraffin. Paraffin oil is not easily oxidized compared to naphtha. Sludge is one of the oxidation products in paraffin oil, which is less soluble than naphtha oil. Therefore bottom of the transformer is clean and it not deposited by sludge, while using naphtha oil. So, the cooling system in transformer does not get agitated and it does not disturb the convention of oil circulation. Instead if paraffin oil is used in the transformer, sludge and more oxidation affects the transformer tank as well as the cooling system. However, due to its easy availability paraffin oil is used in our country; which leads to the above mentioned drawbacks. Paraffin oil is suitable for Indian climatic condition and has high pour point and wax [23]. Transformer oil is used to reduce the heat losses in the transformer and act as a cooling medium. The characteristics of the transformer oil are colorless, low density and low viscosity, and are extracted from crude oil.

5.2. NATURAL FLUIDS

The demand for eco-friendly insulating fluids is increasing day by day, because the conventional fluids have harmful impact on the environment [24]. The commercially available vegetable oil based insulating fluids can replace mineral oil. Natural esters have some of the advantages like non hazardous, higher flash and fire point, east biodegradability and low thermal expansion coefficient. Compared to mineral oil, natural ester have strong benefits to be used in transformers considering the physical, chemical characteristics [25]. The presence of oxygen degrades the insulating fluid and the dielectric properties which degrades operational lifetime of transformers.

6. TESTING METHODOLOGY

6.1 TESTING

The methodology of testing is shown in figure 3. Transformers are tested under various load condition such as quarter, half, half-quarter and full load with resistive loads. Before on condition, the insulating fluids are tested by basic preliminary tests such as BDV, kinematic viscosity, flash and fire point. The transformer was loaded under various load condition at a time period of 24 hrs. The readings are noted and calculated by different insulating fluids like SFO, RBO and CO at different load condition.

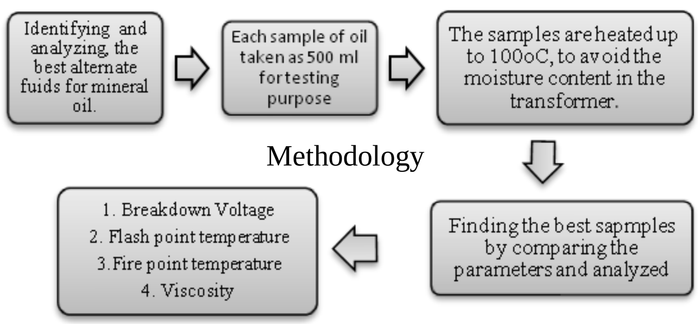

Figure 3. Methodology of liquid analysis

6.2 PROCEDURE

This work deals with the transformer efficiency and the efficiency is calculated by using different insulating fluids at various load condition. The insulating fluids are heated up to maximum level and it is poured into the transformer, to avoid the moisture content in the transformer. Inside the transformer, winding is completely immersed into the fluids. After checking these parts, power supply is given to the transformer at rated voltage and frequency under resistive load. The different load conditions are applied to the transformer and the observed readings are noted for calculation. In the same way, other insulating fluids are used and the above experiment is repeated.

7. RESULTS AND DISCUSSION

7.1 PRE-TEST RESULTS

Various insulating fluids are checked by their critical parameters as a measurable requirement for customer satisfaction. The Table1 represents the parameters of TFO, SFO and Table 2 represents the parameters of RBO and CO (with and without antioxidant). The pretest results are obtained for the above mentioned insulating fluids. The mineral oil (TFO) and natural esters (SFO, RBO and CO) are compared by the basic parameters such as BDV, kinematic viscosity, flash and fire point. Here, the SFO with 0.5% of antioxidant is the best alternate for TFO by comparing all parameters.

Antioxidants are mixed with the ratio of 0.5 g (1:1) for 0.25% and the ratio of 1 g (1:1) for 0.5% is taken. The fluids show high performance and less oxidized by adding these agent. Natural esters are mixed with the above mentioned composition and the critical parameters are measured [26].

Table 1. Pre-Test results of TFO and SFO (With and Without Antioxidant)

Parameters	TFO	SFO		
		PURE	0.25%	0.5%
BDV(kV)	28	38	40	the45
Viscosity a) Room Temp	25.38	56.15	50.2	48.25
b) 60ºC	12.73	34.55	25.66	20.07
c) 90ºC	8.56	14.25	12.11	11.80
Flash Point (ºC)	190	270	282	292
Fire Point (ºC)	212	290	306	314

Table 2. Pre-Test results of RBO and CO (With and Without Antioxidant

Parameters	RBO			CO		
	PURE	0.25%	0.5%	PURE	0.25%	0.5%
BDV(kV)	32	38	42	27	32	40
Viscosity a) Room Temp	113	81.4	67.8	78.7	70.2	64.5
b) 60ºC	53	35.6	24.28	45.8	39.5	34.2
c) 90ºC	16	14.3	13.95	21.4	17.4	14.6
Flash Point (ºC)	274	288	286	280	284	286
Fire Point (ºC)	296	308	310	290	300	304

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7.2 APPLIED LOAD

Transformers are loaded under various conditions by using resistive load. It is a type of load that draws current in phase with the applied voltage. Here the energy is dissipated in the form of heat. Resistive load by using TFO, SFO, RBO and CO (with and without antioxidant) is presented in Table 3 to 12

Table 3. Results from TFO by Resistive Load

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	420	415	410	398
	Current (A)	0.03	0.39	0.56	1.18	1.64
	Power(W)	13.2	52	96	172	210

Output	Voltage (V)	220	210	198	192	188
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	0	28	60	128	178
Efficiency %		0	53.8	62.5	74.4	84.7

Table 4. Results from Resistive Load Using SFO (Without Antioxidant)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	436	430	420	415
	Current (A)	0.03	0.36	0.5	0.8	1.2
	Power(W)	13.2	56	110	148	220
Output	Voltage (V)	220	218	210	205	200
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	0	20	60	96	156
Efficiency %		0	36	55	65	71

Table 5. Results from Resistive Load Using SFO (With Antioxidant – 0.25%)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	430	420	415	400
	Current (A)	0.03	0.39	0.68	0.96	1.7
	Power(W)	13.2	52	114	148	244
Output	Voltage (V)	220	212	210	200	186
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	0	30	76	118	200
Efficiency %		0	57.6	66.6	79.7	82

Table 6. Results from Resistive Load Using SFO (With Antioxidant – 0.5%)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	432	424	418	410
	Current (A)	0.03	0.38	0.68	1.2	1.64
	Power(W)	13.2	48	100	184	240
Output	Voltage (V)	220	212	208	200	190
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	0	32	68	132	184
Efficiency %		0	66.6	68	71.7	76.6

Table 7. Results from Resistive Load Using RBO (Without Antioxidant)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	432	424	418	410
	Current (A)	0.03	0.36	0.68	0.98	1.5
	Power(W)	0	46	88	168	216
Output	Voltage (V)	220	210	204	198	192
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	6.27	18	46	118	170
Efficiency %		0	39	52.2	70.2	78.7

Table 8. Results from Resistive Load Using RBO (With Antioxidant – 0.25%)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	432	426	420	412
	Current (A)	0.03	0.46	0.70	1	1.8
	Power(W)	0	48	96	172	228
Output	Voltage (V)	220	218	210	208	192
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	6.27	24	60	136	196
Efficiency %		0	50	63	79	86

Table 9. Results from Resistive Load Using RBO (With Antioxidant – 0.5%)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	434	422	418	408
	Current (A)	0.03	0.4	0.72	1.2	1.54
	Power(W)	0	60	120	168	244
Output	Voltage (V)	220	216	212	206	196
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	6.27	36	80	124	196
Efficiency %		0	60	66.6	73.8	80.3

Table 10. Results from Resistive Load Using CO (Without Antioxidant)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	432	424	418	414
	Current (A)	0.03	0.30	0.52	1	1.32
	Power(W)	0	42	120	176	224

Output	Voltage (V)	220	210	204	198	194
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	6.27	22	68	114	152
Efficiency %		0	52.3	56.6	64.7	67.8

Table 11. Results from Resistive Load Using CO (With Antioxidant – 0.25%)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	432	426	420	412
	Current (A)	0.03	0.32	0.54	1.14	1.38
	Power(W)	0	54	108	184	220
Output	Voltage (V)	220	218	210	208	192
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	6.27	36	84	152	192
Efficiency %		0	66.6	77.7	82.6	87.2

Table 12. Results from Resistive Load Using CO (With Antioxidant – 0.5%)

Parameters		Zero Load	One-fourth Load	One-Half Load	Three-fourth Load	Full Load
Input	Voltage (V)	440	432	428	420	416
	Current (A)	0.03	0.36	0.64	1.14	1.38
	Power(W)	0	44	100	184	224
Output	Voltage (V)	220	216	212	208	198
	Current (A)	0	0.65	1.3	2	2.6
	Power(W)	6.27	24	72	152	200
Efficiency %		0	54.5	72	82.6	89.2

Using TFO, SFO, RBO and CO with and without antioxidant in resistive load gives different results. Comparing the efficiency, corn oil with 0.5% of antioxidant gives high efficiency than transformer oil. Figure 4,5 and 6 shows the graphical representation of the above results.

Table 13. Overall Observation from Resistive Load

Insulating Fluids		Efficiency %			
		One-fourth Load	One-Half Load	Three-fourth Load	Full Load
TFO		53.8	62.5	74.4	84.7
SFO	PURE	36	55	65	71
	0.25%	57.6	66.6	79.7	82
	0.5%	66.6	68	71.7	76.6
RBO	PURE	39	52	70.2	78.7
	0.25%	50	63	79	86
	0.5%	60	66.6	73.8	80.3
CO	PURE	52.3	56.6	64.7	67.8
	0.25%	66.6	77.7	82.6	87.2
	0.5%	54.5	72	82.6	**89.2**

The performance of SFO, RBO and CO as shown in figure 4, 5 and 6 mentioned with One-fourth load as Quarter load, one-half load as half load, three-fourth load as half-quarter load and full load. When the heat (temperature) of the transformer is reduced, automatically transformer efficiency goes high. The loading of transformer can be extended to 20%.

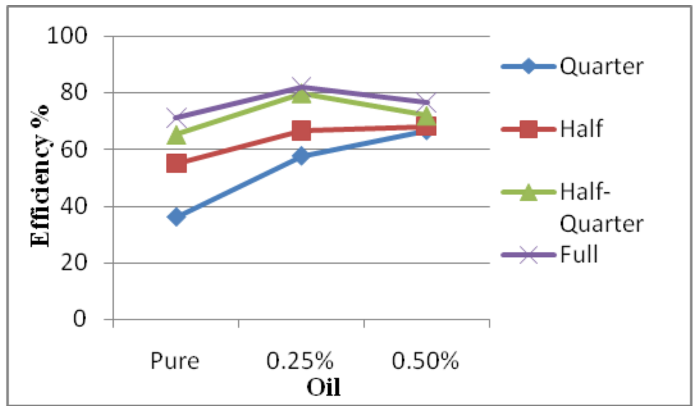

Figure 4. Sunflower Oil Performance

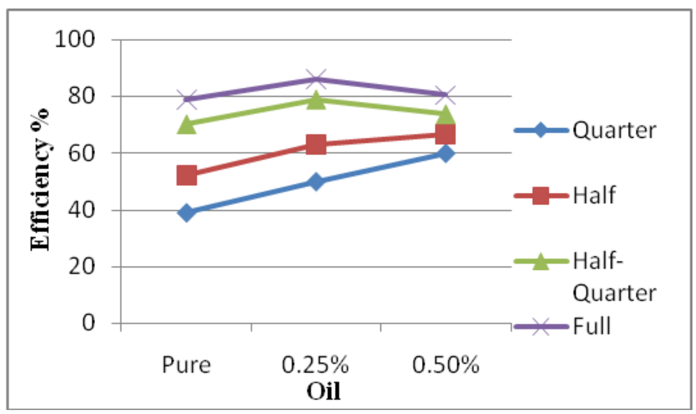

Figure 5. Ricebran Oil Performance

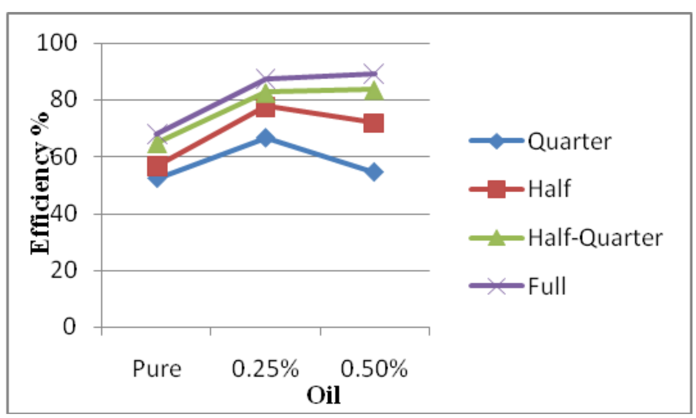

Figure 6. Corn Oil Performance

The oil which shows their performance under various load condition with (pure) and without antioxidant (0.25%, 0.5%) as figure 4 represents the SFO, figure 5 represents the RBO and figure 6 represents the CO.

By comparing the efficiency of TFO, SFO, RBO and CO (with and without antioxidant BHT) under quarter, half, half-quarter and full load conditions. The efficiency is high in corn oil with 0.5% antioxidant BHT under full load condition. The Figure 7 shows the comparison via bar chart.

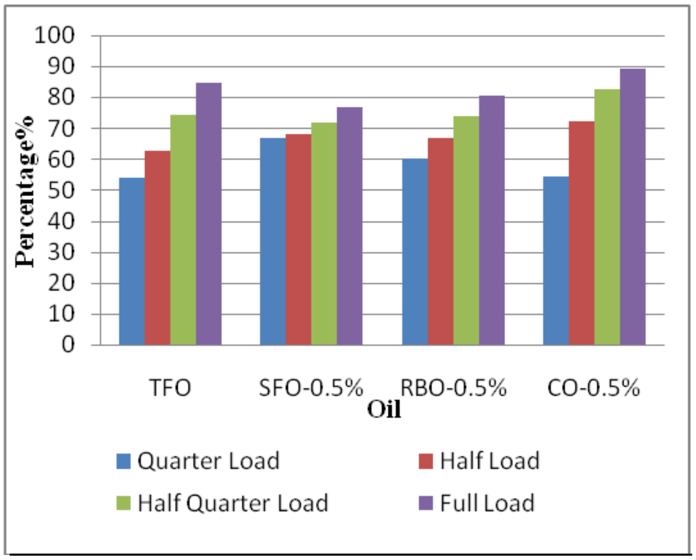

Figure 7. By Comparing the efficiency under various load condition in transformer with TFO and SFO, RBO &CO with and without antioxidant via bar chart

8. CONCLUSIONS

This paper deals with the complete analysis of efficiency of transformer with mineral and natural esters with and without antioxidant. Moreover there are several natural esters available in the world, but few of them are used for research purpose. Among them SFO, RBO and CO are having good dielectric properties.

The experimentation results were carried out on TFO, SFO, RBO and CO with and without antioxidant, to find out the critical parameters, such as BDV, kinematic viscosity, flash and fire point. The transformer was experimented by different load condition using mineral oil and natural esters. During experimentation, the result shows that the sunflower oil with 0.5% of antioxidant has high withstand voltage (BDV), high flash and fire point. Oil for transformer should have high dielectric strength, and it is capable of high flash and fire point. Good oil should have low viscosity so that it offers less resistance to conventional flow of oil thereby not affecting the cooling of the transformer. The kinematic viscosity depends upon the temperature, but the viscosity is high for sunflower oil. The efficiency of the transformer was evaluated with mineral oil and different natural fluids.

By Comparing the efficiencies, with transformer oil and natural fluids with and without antioxidant, the efficiency is high under full load condition with corn oil having 0.5% of antioxidant.

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