INVESTIGATION OF ANTIOXIDANTS POTENTIAL AGAINST 2FAL IN NATURAL ESTERS USING UV SPECTROPHOTOMETRY AND HPLC METHODS

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Abstract: *In this investigation Natural Esters (NE) like Punga Oil (PO), Coconut Oil (CCO) and Corn Oil (CO) are chosen for based on the wide market availability in India. These natural esters are blended with furan like 2-Furaldehyde (2FAL), which is considered as the principal derivative due to incipient fault in power transformer. These natural esters with 2FAL are blended in 1 g/L proportion to understand the impact of furan on the critical properties of natural esters. The prepared samples are therefore amalgamated with natural and synthetic type antioxidants (AO), which are chosen after carefully investigating the mechanisms of antioxidant. The analysis is done using UltraViolet Spectrophotometry (UVSPEC) and High-Performance Liquid Chromatography (HPLC) through columns to estimate the peak absorbance wavelength and retention time according to IEC standard. Thus antioxidant BHA is appropriate additives to reclaim 180 % of insulating property of natural esters depreciated by furans and deflate furan concentration from 60 % (1000 ppm to 632 ppm) to 1 % (1000 ppm to 9.8 ppm). All the natural esters show good retention time when amalgamated with antioxidants, but BHA is highly stable with Punga Oil (PO).*

Key Words: *power transformer, natural esters, antioxidants, nanoparticles, furans, peak absorbance.*

1. Introduction

Power transformers use solid and liquid insulation for providing mechanical strength, cooling and insulation. The relentless operation of the power transformer depends on the strength of solid and liquid insulation in practice [1]. Mineral oil is the most commonly used fluids for electrical insulation and heat transfer in transformers. The major problem faced with mineral oil is that it is poorly biodegradable and could cause severe pollution of soil and waterways if spillages occur. Mineral-oil-filled transformer explosions and fires causing heavy collateral damage have raised major safety concerns. There have also been major environmental concerns over the toxic effects of uncontained mineral oil spills [2]. The power transformer is often affected by incipient faults, which create furan derivatives in the liquid insulation. Thus the insulating property of liquid insulation is depreciated and deteriorates the strength of solid insulation and lead to ageing. The thermal ageing and other reasons like moisture, oxidation and faults degrade the solid insulation paper. This thermal ageing produces furanic derivatives which are dissolved along with transformer oil. It reduces the ageing stability and leads to low insulation capacity, corrosion, impairment of heat transfer and deterioration of electrical properties [3]. Losses due to the repair and installation and also the interruption of production and services the cost associated with site restoration may exceed millions of dollars for major oil spills associated with transformer failures. Hence the working of the transformer is interfered by overheating, short-circuiting and even burnout [4]. Furans are the main chemical compounds that are produced as the cause of ageing and degradation of paper insulation due to thermal and electrical stresses experience by transformer during operation. In oil immersed transformer the paper insulation is a critical component. The life of the transformer is equal to the solid dielectric ageing [5]. The thermal degradation of cellulosic insulation material within paper insulation results in 5 furan compounds namely; 2furaldehyde,5-hydroxymethyl-2-furaldehyde, 2-acetylfuran, 5-methyl-2-furaldehyde and 2-furfurol. The presence of thermal

fault indicated by the high concentration of furanic derivatives. The tensile strength of insulation can also be determined. The faults can be avoided in transformer oil making continuous monitoring [6].

The absorbance wavelength is used to identify the kind of furan present in liquid insulation [7]. Mineral oil used as liquid insulation age rapidly due to the presence of furans and not biodegradable. Such scams cause harm to the environment during its disposition and spillage. Therefore the need to find alternative insulating fluid of natural origin is necessary to tackle the scams in properties of mineral oil. Unlike mineral oil, natural ester does not contain halogens, polynuclear aromatics, volatile or semi-volatile organics but fatty acid components which behaves unstable against oxidative stresses. In recent years successful alternations of mineral oil were successful by selection of natural ester (NE) (called as vegetable oil) fatty acid profile. As the fact that the natural esters, when subjected to laboratory condition, could greatly affect the critical properties of natural esters due to repeated testing. This causes instability issues in using natural esters. Such negativism is out-ruled by adding antioxidants and nanoparticles. Additives like antioxidants and nanoparticles greatly influence the critical characteristics of natural esters. In recent years addition of different types of natural and synthetic antioxidants in combinatorial addition prove to be a useful technique in improving the critical characteristics of liquid insulation (mineral oil and natural esters). The result shows that the antioxidant potential is vibrant and sound in natural esters when compared to mineral oil. Although the addition of nanoparticles improves the properties of mineral oil to near permissible level, it will agglomerate at the bottom after certain time causing thermal stress in the oil due to poor heat convection.

Therefore based on above autopsy, natural esters like coconut oil is chosen based on high fatty acid content (slow to oxidize), corn oil is chosen based on high unsaturated fatty acid content (low cost and high smoke point) and punga oil is chosen based on unsaturated fatty acid content (low viscous and very high oxidative stability). The violent furanic derivative such as 2-furfural (2FAL) is amalgamated with chosen natural esters in different proportions to understand the changes in characteristics of natural esters. On the other hand, antioxidants being active in natural esters and exhibit parallel mechanisms when used in combinatorial phase, Butylated Hydroxy Anisole (BHA), Citric acid (CA) are blended with above samples (NE+2FAL). The changes in wavelength are recorded for samples containing natural ester containing 2FAL, antioxidant (NE + 2FAL + AO) using techniques like UVSPEC and HPLC. The recorded data is used to develop the standard equation based on the calibration curve to understand the concentration of furans clearly.

2. Impact of Furan

The transformer Furanic derivatives in transformer oil are correlated with spectral property. 2FAL is the major furanic derivative and the most stable compound of deterioration of insulation paper and 2FAL. A maximum concentration is available with the compound always. Less than 10% of other furnaic derivatives are available in the compound. So other compounds are not used for the investigation. UV–visible spectrophotometry and High-Performance Liquid Chromatography is used to overcome the difficulty for determining the furnace derivatives. Even though furanic compounds absorb light from 200 to 450 nm, the absorbance values are much higher than the instrument limit up to 350 nm, whereas the absorbance values are within instrument limit from 350 to 450 nm, and there are well-defined maxima in this range. The values are in the range between 350 to 450nm only used for further studies. Various concentrations of test samples are prepared by mixing the furanic derivative 2FAL individually with natural esters.

3. Antioxidants

Oxidation is any synthetic response in which a molecule of a component loses at least one of its electrons to a particle of an alternate component. Initially, the term was connected just to a response in which oxygen consolidates with another component or gathering of components to shape a compound called an oxide. A large portion of the vegetable oils are much unsaturated which makes it vulnerable to oxidation, and they need adequate oxidative steadiness.

Oxidation in oil happens when the transformer is invigorated, and warmth, metals or different impetuses cause the unsaturated particles to change over to free radicals. Free radicals are iotas with unpaired electrons, and it chases for extra to make themselves settled. These free radicals lock onto electrons from different cells which make a chain response as the oxidation advances, and it results in slop arrangement. The ooze gets stored in the transformer tank in this manner making block the cooling, and furthermore, it diminishes the breakdown voltage. To defeat this disadvantage of vegetable oils, cancer prevention agents are included, which can break up completely and keep away from hotspot inside the tank.

The chemical agents like Antioxidants that delays the process of oxidation. The main functions of antioxidants are interrupting the free radial

propagation. The free electron given by antioxidants makes free radicals — antioxidant acts like as deoxidising agents.

3.1 Nature of Antioxidants

There are several types of antioxidants which include natural and synthetic antioxidants. The fruits and vegetables are with more natural antioxidants. Citric Acid (CA), L-ascorbic acid, Vitamin C, Vitamin E etc., are few of the natural antioxidants and Butylated Hydroxy Anisole, Butylated Hydroxy Anisole (BHA), Propyl Gallate etc., are few of the synthetic antioxidants. The antioxidants like natural and synthetic are added in the proportion of individual combined. The level is in the range of 0.5 g each, thus utilizing the parallel mechanism of both the antioxidants.

3.2 Influence of Antioxidants

Antioxidants by making the free radicals stable avoid the movement of electrons between the neighbouring atoms, which thus decreases the conductivity of the fluid. Thus it paves the way for improving the breakdown voltage. The viscosity and thermal characteristics of the base fluids with antioxidants are greatly influenced by the degree of unsaturation. Antioxidant should be added in the lipid phase to form homogeneous colloidal solutions that attribute antioxidant activity at every coordinate of the oil so that they do not agglomerate or deposited at the bottom.

4. Quantification techniques

4.1 Ultra Violet Spectrophotometry (UVSPEC)

Spectrophotometric methods are utilized to gauge the convergence of solutes in an arrangement by estimating the measure of light that is consumed by the arrangement in a cuvette put in the spectrophotometer. The spectrophotometer can quantify the measure of light transmitted or consumed by the arrangement. The light source is gone through a monochromator and split into two shafts and looked over the example and the reference arrangements.

Portions of the occurrence wavelengths are transmitted through, or reflected from, the example and the reference. The resultant light strikes the photograph identifier gadget which looks at the overall power of the two shafts. Instruments will apply a logarithmic capacity to the straight transmission proportion to ascertain retentiveness of the example/convergence of substance being estimated.

For this test, several sets of natural oil samples whose furan contents were identified using BL-198 Bio spectrophotometer. It is observed that 2FAL is the most stable product of cellulosic ageing. 2FAL compound is always available with maximum concentrations; hence in this work, the 2FAL furanic derivative is mixed along with natural oil samples for various levels of concentrations (ppm). The base oils are then mixed with furanic derivative 2FAL in 10 ppm proportion. The high potent antioxidants like Butylated Hydroxy Anisole (BHA) and Citric Acid (CA) are blended with samples containing furans in 1 g/L for individual composition and 0.5 g/L + 0.5 g/L for combinatorial addition.Thus ensuring the best proportion for which the antioxidant can be effective in natural esters. The dielectric strength is measured and recorded for base samples, base oil with furans and base samples with furans and antioxidants using standard experimentations.

4.2 High-Performance Liquid Chromatography (HPLC)

The HPLC instrument is having a mobile phase, a pump and an injector with a separation column, detector. The heart of an HPLC system is the column, which contains the particles that contain the stationary phase (silica gel). Compounds are separated by injecting a sample mixture onto the column. The different component in the mixture passes through the column at differentiates due to differences in their partition behaviour between the mobile phase and the stationary phase. The mobile phase must be degassed to eliminate the formation of air bubbles.

For measurement, 2FAL is mixed with base samples in 1g/L composition and antioxidant in 1 g/L for individual composition and 0.5 g/L + 0.5 g/L for combinatorial addition. The HPLC analysis using standard D 5839-99 is done to estimate the concentration of furans before and after adding antioxidants. The standard for which the critical characteristic (like breakdown voltage) is measured, different modules of sample preparation and base values are given in Table 1, 2 for estimating and comparing the strength of base oil samples with furans and antioxidants in future.

4.3 Analytical Conditions

The following analytical conditions are satisfactory for direct injections of the oil.

- Mode : Reverse Phase
- Injection volume : 20-30 µL
- Mobile phase : ACN, Water
- Pump : Isocratic pump (constant mobile phase composition)
- Pressure : 93 kgf/cm2
- Flow rate : 0.4-1mL/min

- Column temperature: ambient to 30℃
- Column : C18 reverse phased
- Detector : UV detector
- UV range : 190 to 350 nm;
  : for 2FAL - 272 to 280nm

Preparation of extraction standards in the solvent was done by weight procedure. 0.5g of furan was weighed, and this portion is dissolved into 50 mL of acetonitrile (ACN). Now, 0.25mL of the dissolved solution is added with 24.75 mL of ACN. Hence the final concentration is 2000 µg/L. Similarly, 0.5 ml, 0.75 ml, 1ml, and 1.25 ml of dissolved solution is further added with 24.5 ml, 24.25 ml, 24 ml and 23.75 ml of ACN. Hence the final concentration of test standards was 4000 µg/L, 6000 µg/L, 8000 µg/L, 10000 µg/L and final volume of test standards obtained is 25 ml. The HPLC instrumentation is shown in Fig.1.

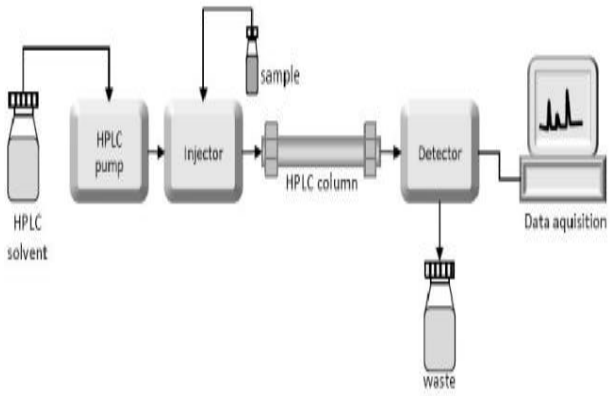

Fig. 1. HPLC Instrumentation

5. Preparation Samples

The natural esters like punga oil (PO), corn oil (CO) and coconut oil (CCO) are taken as base oil samples. These natural esters are tested for its breakdown voltage strength as per IEC 60156 before and after adding additives (2FAL and Antioxidants) shown in Table 1. The samples prepared are investigated using UVSPEC and HPLC methodologies. The peak absorbance values are used to identify the concentration of furan before and after adding antioxidants.

Table 1. Samples prepared using natural esters, furans and antioxidants

Sample No	Sample Composition
1	Punga Oil (1L) BASE FLUID
2	Punga Oil + 2FAL (10 ppm)
3	Punga Oil + 2FAL at 10 ppm + 1g CA
4	Punga Oil +2FAL at 10 ppm + 1g BHA
5	Punga Oil + 2FAL at 10 ppm + 0.5g CA + 0.5g BHA
6	Coconut Oil (1L BASE FLUID
7	Coconut Oil + 2FAL (10 ppm)
8	Coconut Oil + 2FAL at 10 ppm + 1gCA
9	Coconut Oil + 2FAL at 10 ppm + 1g BHA
10	Coconut Oil + 2FAL at 10 ppm + 0.5g CA + 0.5g BHA
11	Corn Oil (1L) BASE FLUID
12	Corn Oil + 2FAL (10 ppm)
13	Corn Oil + 2FAL at 10 ppm + 1g CA
14	Corn Oil + 2FAL at 10 ppm + 1g BHA
15	Corn Oil + 2FAL at 10 ppm + 0.5g CA + 0.5g BHA

6. Quantification Techniques

6.1 Measurement of Absorbance Wavelength using Ultra Violet Spectrometry (USPEC)

Even though furanic compounds absorb light from 200 to 450 nm, the absorbance values are much higher than the instrument limit up to 350 nm. Spectra of 2FAL solutions in transformer oil are recorded between 350 to 450 nm. Results show that more furan contents in transformer oil are related to higher bandwidth and peak absorbance in its spectral response. The Fig.2, Fig.6 and Fig.10 show the UV-Vis spectral response of base oils with furan content 10 ppm and the spectral response corresponding to peak absorbance is between 350 nm to 450 nm which proves the presence of 2FAL due to thermal faults, and as a result, it strongly indicates that the oil lost its insulation property. Whereas the spectral response of antioxidants added with samples containing furans is shown in Fig.3-Fig.5, Fig.7-Fig.9 and Fig.11-Fig.13 and it is observed that all the maximum peaks depreciate below the range of 280. This clearly shows the declination of concentration by 20 to 38 % of furans by potential strength of antioxidants in natural esters.

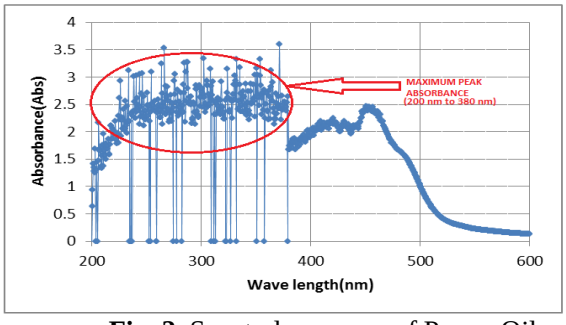

Fig. 2. Spectral response of Punga Oil containing 1 g/L of 2FAL

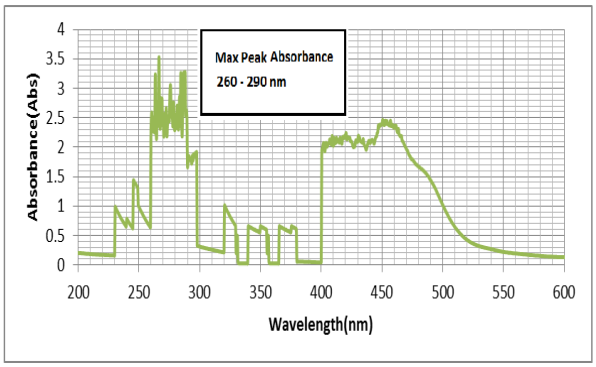

Fig. 3. Spectral response of Punga Oil containing 1 g/L of 2FAL+ 0.5 g Citric Acid + 0.5 g Butylated Hydroxy Anisole

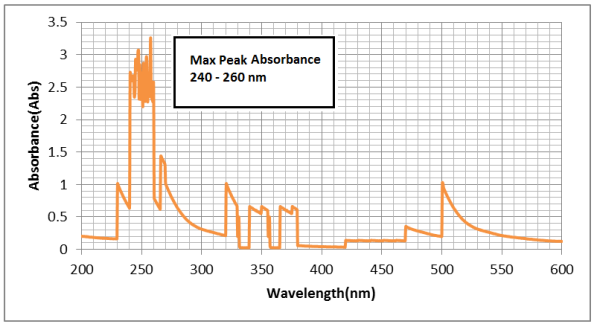

Fig. 4. Spectral response of Punga Oil containing 1 g/L of 2FAL + 1 g Citric Acid

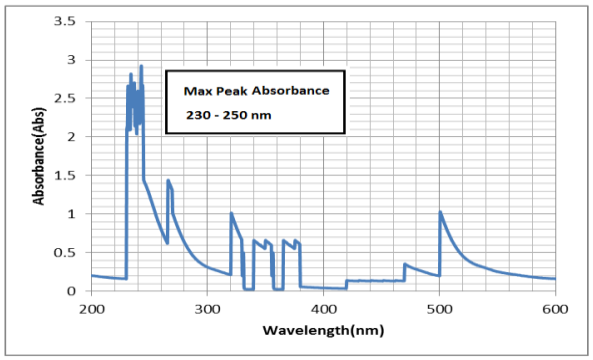

Fig. 5. Spectral response of Punga Oil having 1 g/L of 2FAL + 1 g Butylated Hydroxy Anisole

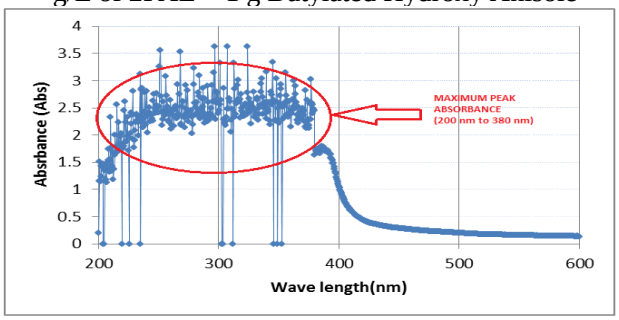

Fig. 6. Spectral response of Coconut Oil having 1 g/L of 2FAL

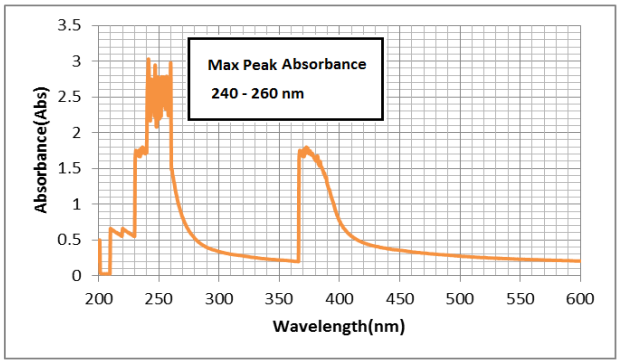

Fig. 7. Spectral response of Coconut Oil having 1 g/L of 2FAL + 1 g Citric Acid

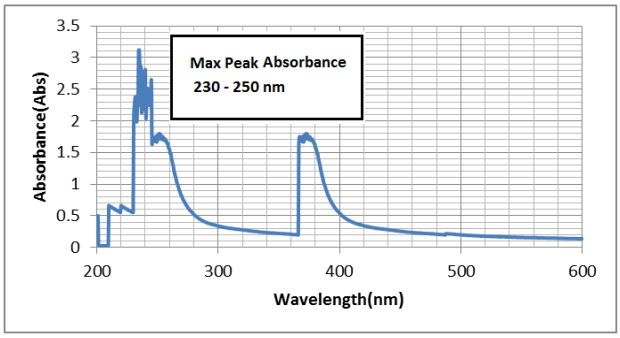

Fig. 8. Spectral response of Coconut Oil having 1 g/L of 2FAL + 1 g Butylated Hydroxy Anisole

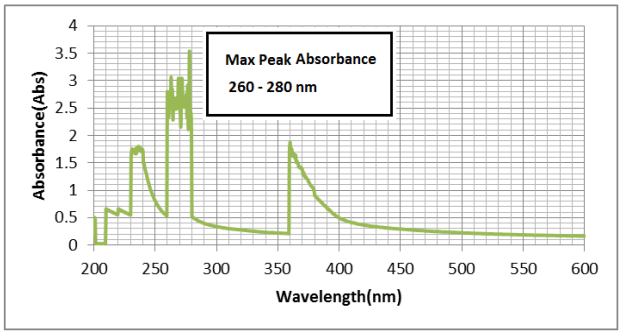

Fig. 9. Spectral response of Coconut Oil having 1 g/L of 2FAL+ 0.5 g Citric Acid + 0.5 g Butylated Hydroxy Anisole

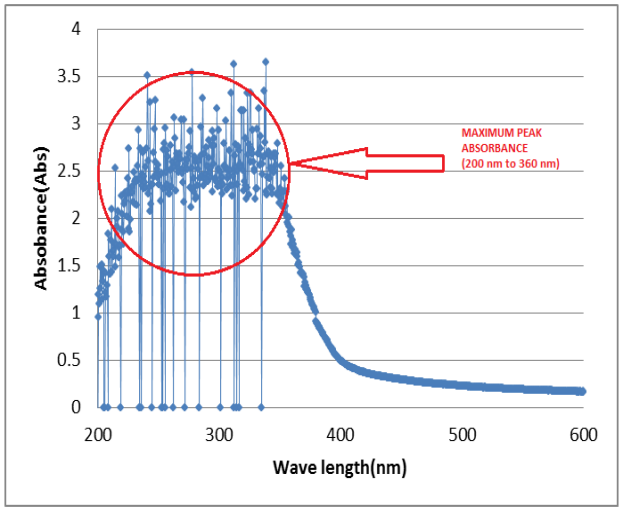

Fig. 10. Spectral response of Corn Oil having 1 g/L of 2FAL

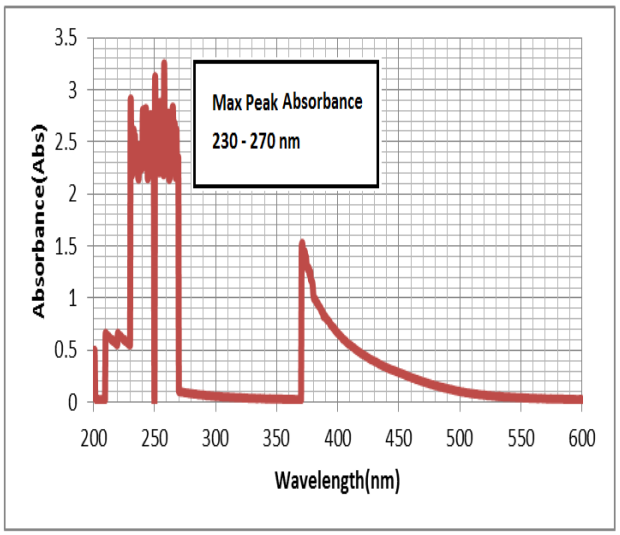

Fig. 11. Spectral response of Corn Oil having 1 g/L of 2FAL + 1 g Citric Acid

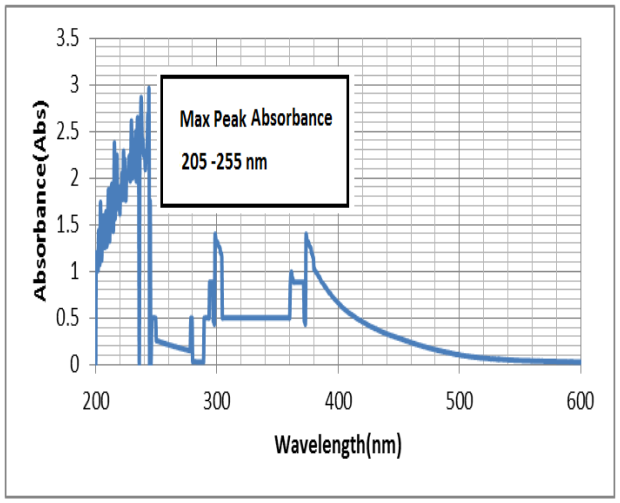

Fig. 12. Spectral response of Corn Oil having 1 g/L of 2FAL + 1 g Butylated Hydroxy Anisole

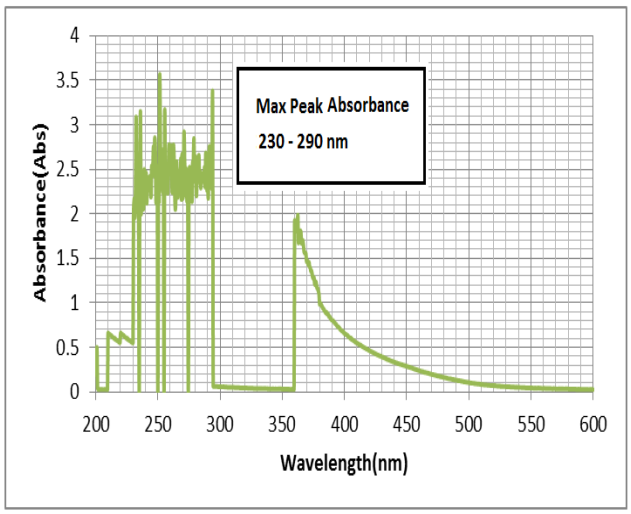

Fig. 13. Spectral response of Corn Oil having 1 g/L of 2FAL+ 0.5 g Citric Acid + 0.5 g Butylated Hydroxy Anisole

6.2 Measurement of Breakdown Voltage (BDV)

The breakdown strength is calculated from the average of five measurements according to IEC standard and recorded values are presented in Table 2. From Table 2, sample 1 containing punga oil deserves to have 26.4 kV as the dielectric strength and upon amalgamating 2FAL with punga oil (sample 2) which likely to reduce the insulating strength of oil by distributing more secondary ions responsible for ionization process and possess 17.8 kV as breakdown strength. Whereas the addition of natural and synthetic antioxidants likes Citric Acid (CA) and Butylated Hydroxy Anisole (BHA) scavenge the secondary ions, and singlet oxygen is hence resisting ionization process. The dielectric strength of sample 3 and 4 is 180 % higher than the base sample 2. On the other hand sample 5 containing CA and BHA in equal proportion and does not show constructive outcome than base sample used with either of CA and BHA separately.

Table 2. Measurement of the breakdown voltage of samples before and after adding Furans and Antioxidants

Sample Composition	BDV1 (kV)	DV2 (kV)	DV3 (kV)	BDV4 (kV)	DV5 (kV)	Average BDV (kV)	Holding Time before Break down
Punga Oil(1 L)	20	21	32	37	32	26.4	< 14 Sec
PungaOil +2FAL1 g/L	16	19	18	18	18	17.8	< 10 Sec
PungaOil +2FALat 1 g/L + 1 g CA	40	40	46	42	50	43.6	< 30 Sec
Punga Oil +2FALat 1 g/L + 1 gBHA	38	43	45	46	44	43.2	> 70 Sec
Punga Oil +2FAL at 1g/L + 0.5 gCA + 0.5 g BHA	34	38	40	41	42	39	< 30 Sec
CoconutOil (1 L)	32	35	39	40	38	36.8	< 10 Sec
CoconutOil +2FAL1 g/L	15	16	16.5	15	16	15.7	< 07 Sec
Coconut Oil + 2FAL at 1 g/L + 1 g CA	55	56	56	53	60	56	< 30 Sec
CoconutOil + 2FAL at 1 g/L+ 1 gBHA	46	44	50	48	50	47.6	> 60 Sec
CoconutOil +2FALat 1 g/L+ 0.5 gCA +0.5 g BHA	58	55	60	56	54	58.6	< 30 Sec
CornOil (1 L)	30	32	32	31	32	31.4	< 10 Sec
CornOil + 2FAL 1 g/L	16	19	17	18	18	17.6	< 09 Sec
CornOil +2FALat 1 g/L+ 1 g CA	40	37	36	36	37	37.2	< 30 Sec
Corn Oil + 2FALat 1 g/L+ 1 g BHA	50	46	44	48	49	47.4	> 60 Sec
Corn Oil + 2FAL at 1 g/L+ 0.5g CA + 0.5 gBHA	43	42	44	44	43	43.2	< 30 Sec

HPLC method has been developed for the analysis of furanic compound like 2FAL. The standard solutions are calibrated across the range of 2000 to 10000 µg/L on the column for five levels. The mobile phase for the analyze is roughly 40 to 45 ml and take time of 25 to 30 minutes. The retention time and peak area of the standards are shown in Table 3. The average coefficient of determination for a line of linear regression was 0.998. The calibration curve for extraction standards of solvents is shown in Fig.14 and presented in Table 3.

Table 3. Calibration test for finding optimum UV absorbance wavelength of 2FAL in HPLC

Calibration Level No.	Concentration ofFuran (µg/L)	Final Volume (ml)	Retention Time (min)	Peak Area (cm^2)
1	2000	25	3.456	105000
2	4000	25	3.488	300000
3	6000	25	3.496	400000
4	8000	25	3.488	500000
5	10000	25	3.501	600000

For standard calibration, the flow rate maintained is 0.45ml/min. Pump A pressure is 93 kgf/cm^2. The pressure of pump B is 0 kgf/cm^2. The detector optimum UV absorbance wavelength of furfural (2FAL) for five levels of the standard calibration was 277nm with the retention time of 3.4 min.

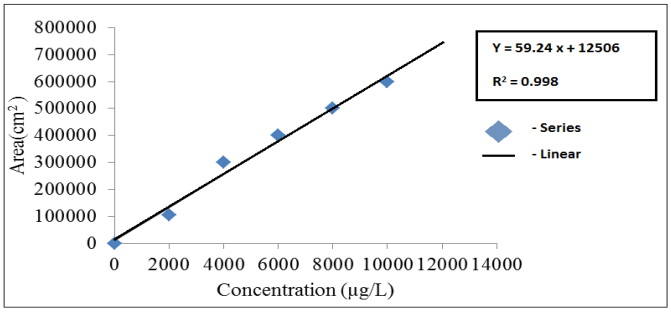

Fig. 14. Calibration Curve

Nine samples of natural oils were analyzed using the HPLC method developed here for the analysis of furanic compound, 2FAL. The prepared liquid extraction samples of Punga oil, Coconut oil and Corn oil are tested using HPLC for the analysis of furanic compound, 2FAL. Chromatography outputs for the oil samples are shown in Fig.2-Fig.13 and its retention time and peak area is presented in Table 4. The impact of antioxidants against furans in the samples are measured with respect to the concentration of furans

before and after adding antioxidants and presented in Table 5.

Table 4. Chromatography analysis of oil samples

Sample	Retention time (min)	Detector Wave length (nm)	Peak Area (cm^2)	Height (cm^2)
3	3.504	277	37489645	3999692
4	3.467	277	1686971	335523
5	3.646	277	23581043	3997798
8	3.464	277	6656607	1309597
9	3.466	277	597330	128379
10	3.496	277	31576201	3999781
13	3.468	277	11796570	2371695
14	3.475	277	10549903	2018378
15	3.504	277	35097359	3999821

Table 5. Furan concentration before and after adding antioxidants using the calibration curve

Sample	Furan Concentration Before adding antioxidants (ppm)	Furan concentration (g/L)	Furan concentration (ppm)
3	1000	0.632	632.63
4	1000	0.028	28.21
5	1000	0.397	397.84
8	1000	0.0112	112.15
9	1000	0.0098	9.87
10	1000	0.532	532.31
13	1000	0.198	198.92
14	1000	0.017	17.511
15	1000	0.532	592.24

Antioxidant with the minimum quantity is added to the base fluids. Because of the minimum quantity, it will not affect the performance of the base fluids. The Citric Acid (CA) and Butylated Hydroxy Anisole (BHA) with the quantities of 1g are added respectively to the base fluids of 1g/L 2FAL.1g/L is equivalent to 1000ppm. 1g/L of 2FAL in the natural oil samples was analyzed which is the equivalent of 1000ppm of 2FAL. From Fig.15-Fig.24 the chromatogram results show the peak in Y-axis and retention time in X-axis. Equation 1 obtained in the calibration curve is

$$Y = 59.24\,x + 12506 \quad (1)$$

For sample 3 (Punga Oil) the UV absorbance wavelength is 277nm where the peak is developed at the time of 3.504 min. The area of the peak is mentioned as 37489645 cm^2. Presence of furan in sample 3 was identified by comparing the retention time of standard and the sample. By substituting the peak area (Y) in the above equation, the furfural concentration (X) was found. The concentration of furan in sample 3 is 0.632 g/L which is equal to 632.63 ppm. Initially, the base oil sample contains 1000 ppm of furan. It is clear that the concentration was reduced to 632.63 ppm by adding the natural type of antioxidant like Citric Acid (CA) which could be seen from Fig.16. The remaining sample results are established in Table 5.The sample analysis results are shown in Table 5 below. From Table 5, it is inferred that the insulation property is enhanced with the addition of antioxidants. By comparing the Punga oil samples 3-5 in Table 2, 4 and five, it is found that the Punga oil with BHA is better than other combinations where the retention time of the peak is 3.467 min. The furan concentration was reduced from 1000 ppm to 28.21 ppm, and the detector wavelength is 277 nm.

For Coconut oil (sample 8-10), the performance of antioxidants BHA in individual proportion is better than the combined proportion (CA+BHA). Furan reduced from 1000 ppm to 9.87 ppm with the addition of synthetic antioxidant BHA. The absorption chromatogram indicates that the wavelength of peak absorbance at 277 nm with the retention time of 3.466 min. Similarly for Corn oil samples; BHA is superior to anything different mixes where the ingestion crest is in the locale of 277nm. The furan concentration was reduced from 1000ppm to 17.51ppm. And the retention time of peak is 3.475 min.

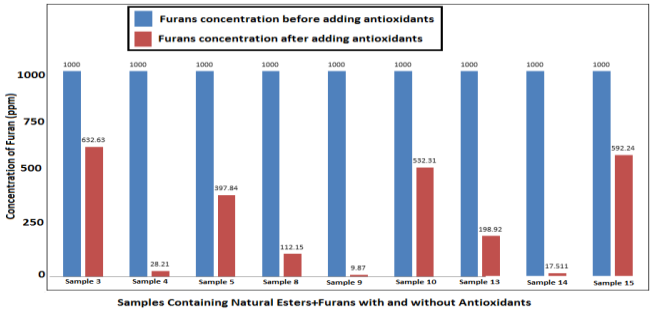

Fig. 15. Correlation between concentration of Furan before and after adding Antioxidants

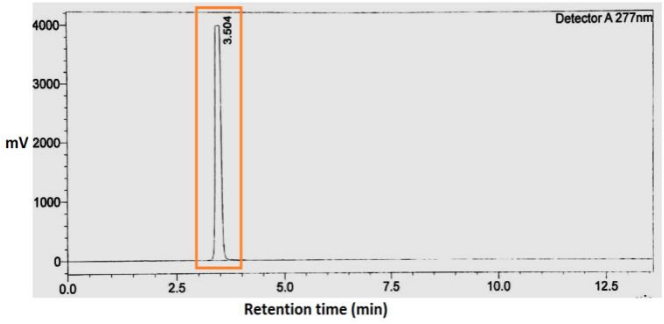

Fig. 16. Punga Oil having 1 g/L of 2FAL + 1 g CA with Retention Time 3.504 min

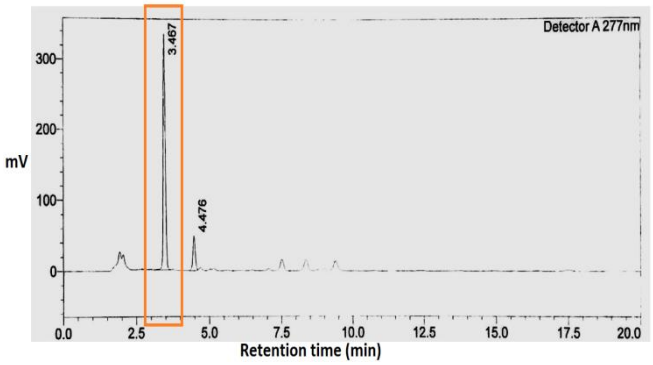

Fig. 17. Punga Oil having 1 g/L of 2FAL + 0.5 g CA + 0.5 g BHA with Retention Time 3.467 min

The recorded values show the potential strength of BHA with natural esters in sample 4, 9 and 14 with the reduction in the concentration of the furan (2FAL) and extensively improving the dielectric strength of base samples affected by the thermal fault. The internal standard calibration of furan across 2000-10000 µg/L responded linearly. Furan in 9 natural oil samples was identified in 30 min allowing simultaneous quality control analysis.

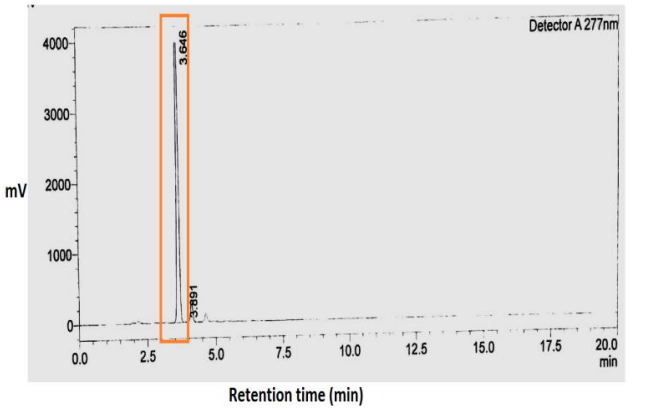

Fig. 18. Chromatography response of Punga Oil having 1 g/L of 2FAL + 1g BHT with Retention Time 3.646 min

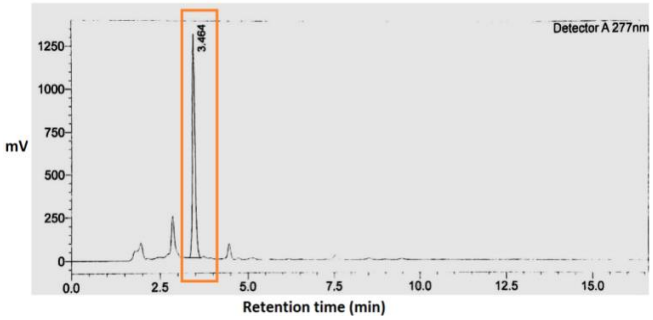

Fig. 19. Coconut Oil having 1 g/L of 2FAL + 1 g CA with Retention Time 3.464 min

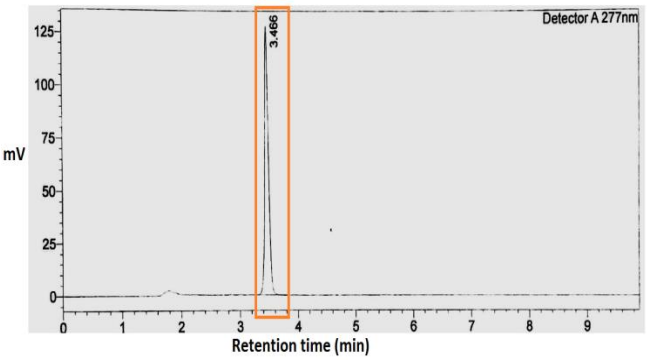

Fig. 20. Coconut Oil having 1 g/L of 2FAL + 0.5 g CA + 0.5 g with Retention Time 3.466 min

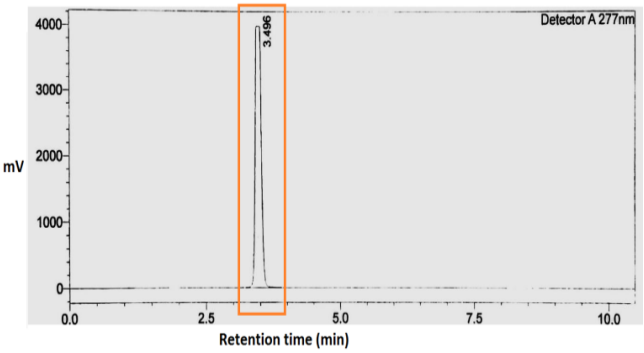

Fig. 21. Coconut Oil having 1 g/L of 2FAL + 1 g BHT with Retention Time 3.496 min

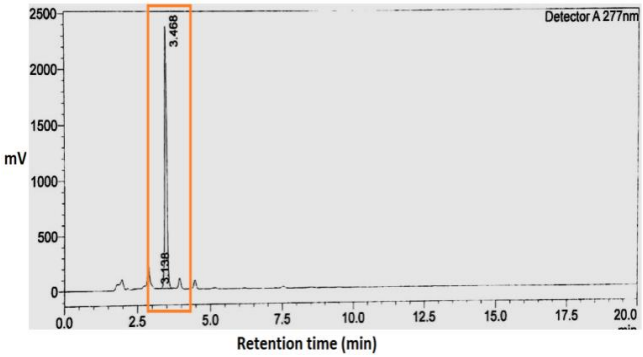

Fig. 22. Corn Oil having 1 g/L of 2FAL + 1 g CA with Retention Time 3.468 min

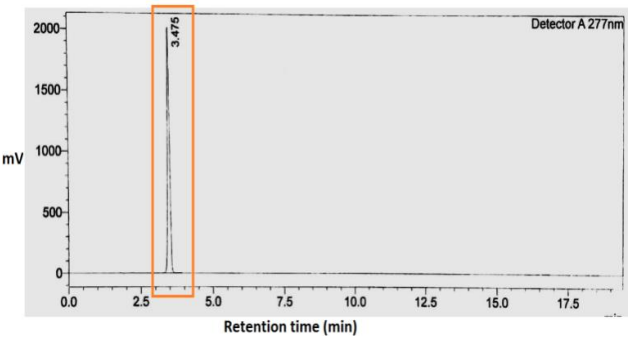

Fig. 23. Corn Oil having 1 g/L of 2FAL + 0.5 g CA + 0.5 g BHT with Retention Time 3.475 min

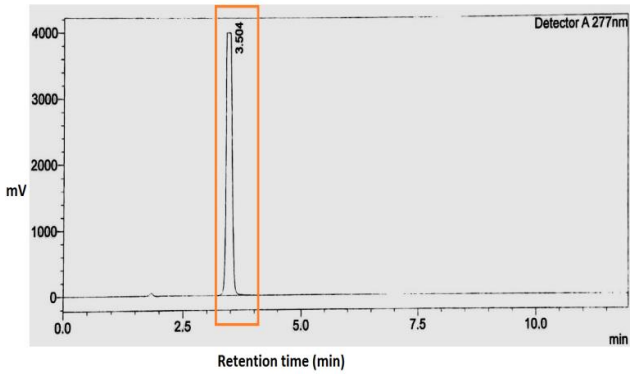

Fig. 24. Corn Oil having 1 g/L of 2FAL + 1 g BHT with Retention Time 3.504 min

7. Conclusion

The furan (2FAL) present in the natural ester sample was quantified using UV spectrometry and HPLC techniques before and after adding an antioxidant. The furan was identified by both the retention time and the chromatogram pattern using both the techniques. The effectiveness of natural and synthetic antioxidants (CA, CA+BHA and BHA) in single and combinatorial proportion is ensured by the retention time of the sample during a breakdown in UVSPEC. On the other hand, the concentration of furan before and after adding antioxidants is confirmed using chromatograph response of the HPLC technique, where the concentration of furan can be identified usingthe calibration curve. Upon comparing two techniques, HPLC method combines sensitivity with time effectiveness. The depreciation of furan concentration in the natural ester is vivid when amalgamated with natural and synthetic antioxidants, and furan depreciation percentage ranges from 60 % (1000 ppm to 632 ppm) to 1 % (1000 ppm to 9.8 ppm). However, BHA being highly oxidative stable proves to be active in retarding oxidation in the presence of furans. Thus maintaining a good holding time greater than 60 sec shows the active phase of BHT in delaying ionization due to free electrons and improves the insulating property of natural ester. Hence BHA is highly effective in enhancing and restoring the insulation strength of natural esters upto 100 or 180 % of its base values. The natural esters amalgamated with BHA can be used in power transformers since power transformers are highly susceptible to a thermal fault and produce 2FAL, a dangerous furan which deteriorates the critical characteristics of liquid dielectrics. The methodology can be extended to determine the behaviour of different furanic compounds in natural esters which result in the development of more calibrating standards.

References

1. Srinivasan, M., Ragupathy, U.S., and Raymon, A.: *Enhancement of Critical Parameters of Natural Ester Liquids Using SiO2 Insulating Nanoparticle*. In: Journal of Computational and Theoretical Nanoscience, Vol.14, No.10, 2017, pp. 4649-4654.
2. Roberto, A., Stephane Page, A.: *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, 2014, pp. 134-141.
3. Karthik, R., Sree Renga Raja, T., Sudhakar,T.: *Deterioration of Solid Insulation for Thermal Degradation of Transformer Oil.* In: Central European Journal of Engineering, Vol.3,No.2,2013, pp. 226-232.
4. IEEE, *Guide for loading Mineral-oil-immersed Transformers*. Annex I: Transformer Insulation Life, IEEE Standard C57.91, 1995
5. Emsley, A.M., Xiao, X., Heywood, R.J., Ali, M.: *Degradation of cellulosic insulation in power transformers, part 2: formation of furan products in insulating oil.* In: IEE Proc. Sci. Meas. Technol., Vol.147,2000, pp. 110–114.
6. Karthik, R., Sree Renga Raja, T., Willjuice Iruthayarajan, M.: *Investigations of furanic derivatives in transformer oil using ultra-violet light absorption property.* In: IET Electric Power Applications, Vol.7,No.2,2013, pp 123-130.
7. Karthik, R., Sree Renga Raja, T.: *Investigations of thermal degradation and spectral response of transformer oil.* In: ActaScientiarum Technology, Vol.35, No.2,2013, pp 255-262.