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Enhancement of Critical Characteristics of Transformer Oil Using Nanomaterials

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Abstract Maintaining continuous power supply is the major anxiety of power engineers throughout the world. Power transformer is one of the critical equipment which requires high level condition monitoring to sustain uninterrupted power supply. Insulation provided within the transformer is solid and liquid dielectrics, which plays a major role in determining the life time. Transformer oil (TOL) is a liquid dielectric which acts as an insulating medium as well as coolant. In this paper, an effort has been made to enhance the critical characteristics of transformer oil using nanoparticles. Nanofluids are prepared by mixing the nanoparticles (aluminium oxide, aluminium, copper oxide, and copper) for various volume concentrations with TOL as base fluid by sonication process. Various critical parameters like viscosity, breakdown voltage (BDV), Flash point, Fire point, pH value and Spectral response characteristics of nanofluids are analyzed.

Keywords Transformer · Dielectric liquid · Nanomaterials · Nanofluids · Break down voltage

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الخلاصة

إن الحفاظ على استمرار مصادر الطاقة يشكل قلقاً كبيراً لمهندسي الطاقة في جميع أنحاء العالم. ويُعدّ محول الطاقة واحداً من المعدات الهامة التي تتطلب مستوى عالياً من المراقبة للحفاظ على عدم انقطاع مصدر الطاقة. إن العوازل المتوفرة ضمن المحوّل هي عباره عن عوازل كهربائية صلبة وسائلة تلعب دوراً رئيسياً في تحديد زمن الحياة، ويعد المحول السائل (TOL) عازلاً كهربائياً سائلاً يعمل بمثابه وسط عازل وكذلك كمبرد.

في هذه الورقه تم بذل جهد كبير لتعزيز الخصائص الحرجة لزيت المحول باستخدام جزيئات النانو. ويتم إعداد موائع النانو عن طريق خلط جزيئات النانو (أكسيد الألمنيوم، والألمنيوم، وأكسيد النحاس والنحاس) لتراكيز مختلفة الأحجام مع TOL كقاعدة للمائع بوساطة عملية sonication. وقد تم تحليل باراميترات حرجة مختلفة مثل اللزوجة وتوزيع الجهد (BDV) ونقطة الوميض ونقطة الحريق وقيمة الرقم الهيدروجيني وخصائص الاستجابة الطيفية لموائع النانو.

1 Introduction

Transformer oil is typically a highly refined mineral oil that is stable at high temperature which has excellent properties to suppress arcing, serve as coolant and provide electrical insulation. Das et al. [1] presented the comprehensive experimental data set for thermal conductivity of nanofluids with variation in nanoparticle materials, sizes and particle volume fraction. Kiyuel kwak et al. [2] has conducted analysis on viscosity of copper oxide nanomaterials with water as base fluids. Murshed et al. [3] examined the enhancement of critical parameters like viscosity and thermal property for water using cylindrical and spherical shaped nanomaterials. Karthik et al. [4] presented an overall literature review for analysis of transformer oil characteristics with the aid of nanoparticles. Karthik et al. [5] presented a general characteristics analysis of viscosity, acidity, breakdown voltage, dissolved gas and furan analysis of various ranges of aged transformer oil.

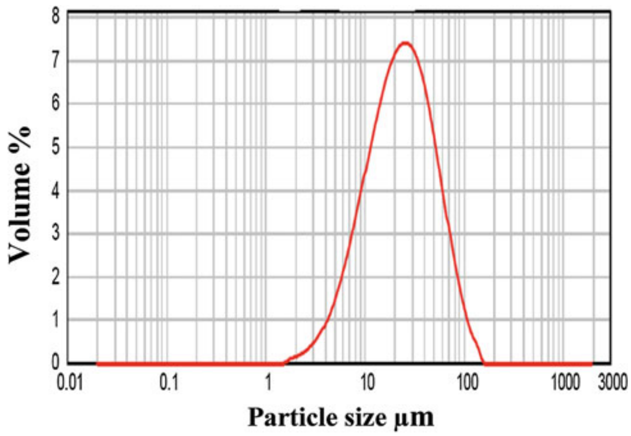

Fig. 1 Particle size distribution for aluminium

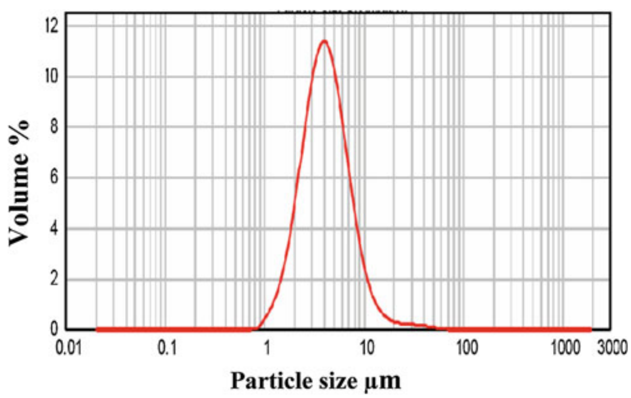

Fig. 2 Particle size distribution for aluminium oxide

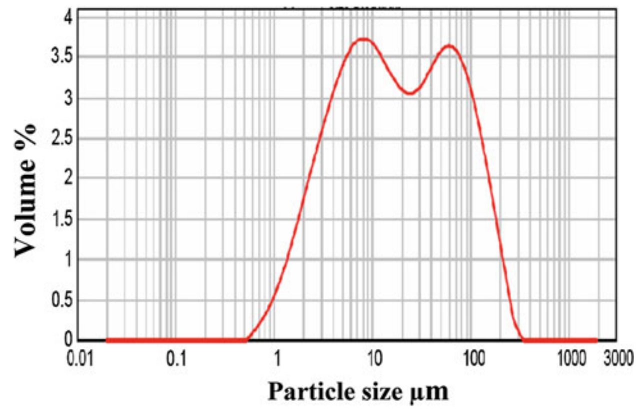

Fig. 3 Particle size distribution for copper

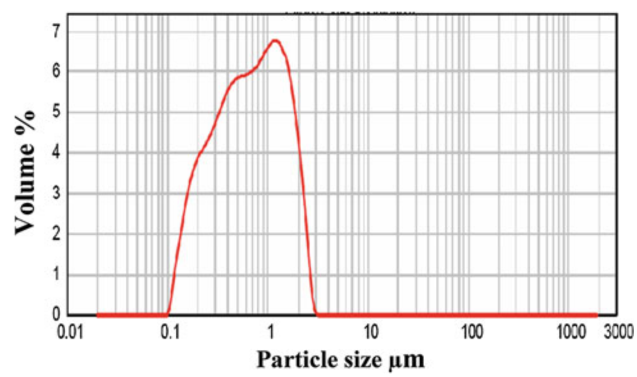

Fig. 4 Particle size distribution for copper oxide

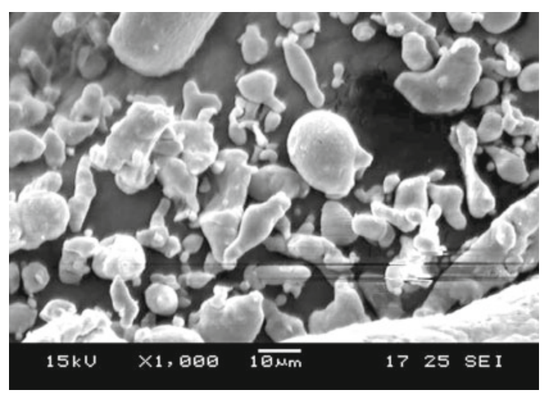

Fig. 5 SEM image for aluminium

At present scenario in the field of nanomaterials based TOL, Das et al. has conducted experimental analysis of nanofluids with water, TOL, ethylene glycol as base fluids for cooling requirements. He observed only the enhancement of thermal conductivity characteristics of TOL. In this work as initiative, enhancement in various critical characteristics like flash point, fire point, viscosity, break down voltage (BDV) and pH values of TOL based nanofluids were examined.

2 Nanofluids

Nanofluids are prepared by dispersing the nanoparticles with base fluid (TOL) by sonication process. The particle distributor size analyzer and SEM images help us to determine the distribution and size of nanoparticles respectively. Nanofluids are prepared for different partial volume fraction concentrations. The distribution of particles using particle distributor size analyzer is shown in the Figs. 1, 2, 3 and 4. Size of the nanoparticles is estimated using SEM images shown in Figs. 5, 6, 7 and 8. The sizes are confirmed as aluminium oxide (5,000 nm), aluminium (10 µm), copper oxide (500 nm) and copper (100 µm).

The particle size distribution Fig. 1 illustrate that size of aluminium varies between 1 and 100 µm and it's having maximum distribution at the range of 10 µm. Figure 2 shows that size of aluminium oxide ranges between 1 and 10 µm and maximum at 5 µm (5,000 nm). Figure 3 illustrate that size of copper ranges between 1 and 150 µm and the distribution is also not a uniform one, maximum distribution is found at 100 µm. Figure 4 shows that size of copper oxide ranges between 0.1 and 1.25 µm and it is maximum at 0.5µm (500 nm). In ultrasound sonication process, the nanoparticles and TOL is placed in a chamber. The setup consists

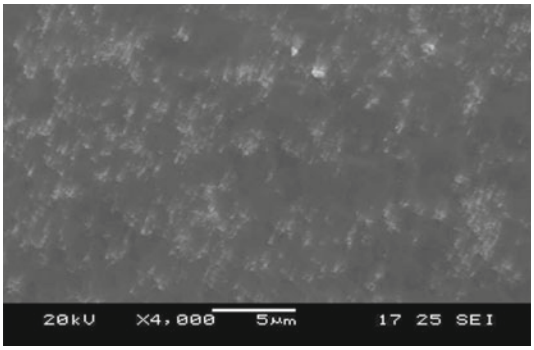

Fig. 6 SEM image for aluminium oxide

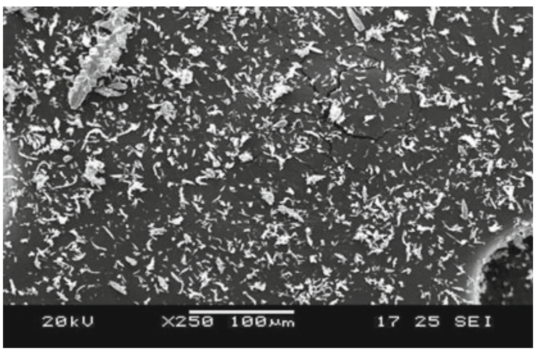

Fig. 7 SEM image for copper

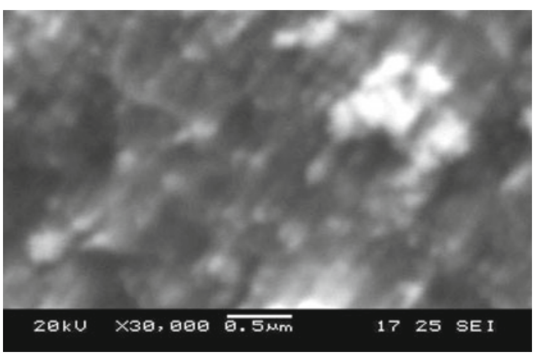

Fig. 8 SEM image for copper oxide

of ultrasonic sound generating transducers which is usually piezo electric materials, these materials produces ultra sonic waves in the fluid.

3 Experimental Setup and Results

Viscosity of oil is the measure of oil resistance to shear [6]. Viscosity is more commonly known as resistance to flow. If lubricating oil is considered as a series of fluid layers superimposed on each other, the viscosity of the oil is a measure of the resistance to flow between the individual layers. A high viscosity implies high resistances to flow, while a low viscosity indicates a low resistance to flow. Viscosity varies inversely with temperature, nanofluids viscosity is measured using Red wood viscometer. Flash and fire point is one of the critical thermal property of TOL. Nanofluids thermal property is measured using Martin Pensky open cup apparatus [7]. Breakdown voltage of transformer oil is analyzed [8] by BDV test kit range up to 80 kV. In order to obtain uniform field distribution during measurement of BDV, sphere-sphere type of eletrodes are used as shown in Fig. 9. UV Spectral response comprises of two factors such as absorbance and transmittance. It is mainly measured to confirm the proper mixing of nanoparticles with TOL. If the particles are mixed in perfect manner, the absorbance peak get reduces and there will be no transmission [9]. Pure transformer oil should be of low absorbance and high transmittance. UV-visible spectrophotometer is used to analyse absorption capability of nanofluids. As per ASTM (American Society for Testing and Materials), IEC, IS standards [10] UV—Visible test is not an mandatory test, as initiative nanofluids were subjected to UV light sources and their Spectral response characteristics was examined, which gives some idea towards quantity of particles mixed with TOL. pH value of nanofluids is the measure of base or acid level. The level of pH is determined using digital pH meter. Critical parameters of TOL are measured for various particle volume fractions 0.01, 0.05, 0.1, 1 and 2 % of copper (Cu), copper oxide (CuO), aluminium (Al) and aluminium oxide (Al_2O_3). The test results of pure transformer oil and TOL based nanofluids are given in the Tables 1, 2 and 3 respectively. Percentage enhancements of

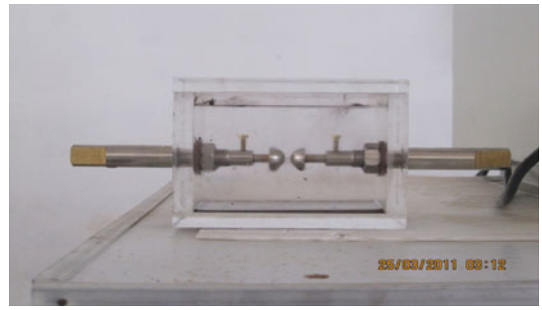

Fig. 9 Electrodes configuration: BDV measurement

Table 1 Test results of ideal TOL

Parameters	Values	
Flash point (°C)	140	
Fire point (°C)	160	
BDV (Kv/mm)	32	
pH	7.05	
Viscosity (centistokes)	30 °C	21.50
	40 °C	17.77
	50 °C	11.80
	60 °C	9.88
	70 °C	7.87
	80 °C	6.10

Table 2 Test results for using aluminium oxide, copper oxide, copper nanomaterials

Material	Particle volume fraction (%)	Flash point (°C)	Fire point (°C)	Breakdown voltage (kV)		pH value	Absorption (band width)	Viscosity	
				Before heated to 100 °C	After heated to 100 °C			Temperature (°C)	Viscosity
Al_2O_3	0.01	165	180	10	22	8.06	928	30	29.49
								40	22.61
								50	17.78
								60	16.04
								70	13.35
								80	10.85
Al_2O_3	0.05	160	170	13	28	7.8	915	30	24.83
								40	21.77
								50	17.5
								60	15.45
								70	12.73
								80	10.21
Al_2O_3	0.1	160	180	12	33	7.77	914	30	25.11
								40	20.36
								50	16.62
								60	13.35
								70	10.85
								80	9.23
CuO	0.01	165	175	13	41.5	8.3	1,032	30	27.58
								40	21.21
								50	17.78
								60	13.65
								70	12.11
								80	10.53
CuO	0.05	165	175	15.5	44	7.21	924	30	26.76
								40	22.05
								50	16.62
								60	13.04
								70	10.85
								80	9.23
CuO	0.1	165	175	15	47	7.39	962	30	25.66
								40	19.22
								50	13.35
								60	11.48
								70	9.56
								80	8.22
Copper	1	170	180	10	29	7.23	979	30	24.28
								40	21.21
								50	14.25
								60	12.42
								70	10.85
								80	9.88

Table 2 continued

Material	Particle volume fraction (%)	Flash point (°C)	Fire point (°C)	Breakdown voltage (kV)		pH value	Absorption (band width)	Viscosity	
				Before heated to 100 °C	After heated to 100 °C			Temperature (°C)	Viscosity
Copper	2	170	180	13	33	7.11	980	30	23.44
								40	21.48
								50	16.33
								60	11.8
								70	9.88
								80	7.87

Table 3 Test results for TOL using aluminium nanomaterials

Material	Particle volume fraction (%)	Flash point (°C)	Fire point (°C)	Breakdown voltage (kV)		pH value	Absorption (Bandwidth)	Viscosity	
				Before heated to 100 °C	After heated to 100 °C			Temperature (°C)	Viscosity
Al	1	160	170	10	12	7.58	931	30	24.28
								40	19.79
								50	14.85
								60	12.73
								70	10.85
								80	9.887
Al	2	160	170	23.5	27	13.18	928	30	22.6
								40	18.65
								50	13.65
								60	11.8
								70	9.56
								80	8.22

Table 4 Percentage enhancement of critical parameters

Materials	Particle volume fraction (%)	Enhancement of flash point (%)	Enhancement of fire point (%)	Enhancement of BDV after heated (%)	Enhancement of viscosity (at 80 °C) (%)	Enhancement of pH (%)
Al_2O_3	0.01	17.85	12.5	31.25 (Reduced)	77.86	14.32
Al_2O_3	0.05	14.28	6.25	12.50 (Reduced)	67.37	10.63
Al_2O_3	0.1	14.28	12.5	3.12	51.31	10.21
Al	1	14.28	6.25	62.50 (Reduced)	62.08	7.51
Al	2	14.28	6.25	15.62 (Reduced)	34.75	86.18
CuO	0.01	17.85	9.37	29.68	72.62	17.73
CuO	0.05	17.85	9.37	37.50	51.31	2.26
CuO	0.1	17.85	9.37	46.87	34.75	4.82
Cu	1	21.42	12.5	9.37 (Reduced)	61.96	2.55
Cu	2	21.42	12.5	3.12	29.01	0.85

critical parameters are listed in Table 4. From the results it is confirmed that flash point, fire point and viscosity of nanofluids based TOL shows better improvement than ideal TOL. BDV characteristic shows a slight reduction in value, but after heating to 100 °C the BDV gets increased. pH value was with in the base limit, hence problems due to acid level content is eliminated. The sonication process is performed using ultrasonic bath as shown in Fig. 10.

Fig. 10 Sonication process-ultrasonic

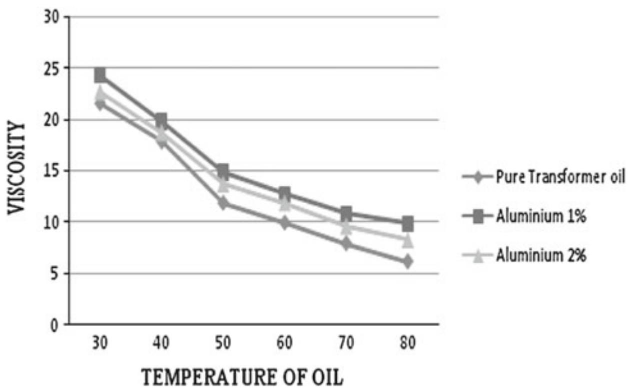

Fig. 11 Viscosity of aluminium nanofluids

Main drawback of suspending micron sized particles (aluminium and copper) with TOL is sedimentation of particles and related barrier problems.

3.1 Viscosity

Measurement of Viscosity is carried out by varying the temperature from 30 to 80 °C for various particle volume fractions. Viscosity indicates fluidity; oil with low viscosity has more fluidity and gives better cooling. At lower ambient temperature the viscosity sharply rises and the speed of oil circulation reduces. Hence measurement of viscosity is carried out for various temperatures.

Viscosity of aluminium oxide, aluminium, copper oxide and copper nanofluids is higher than viscosity of pure TOL, therefore flow rate of nanofluids reduces. On increasing the particle volume concentration and temperature of nanofluids, it reduces viscosity of nanofluid and the flow rate gets increased. Variations of nanofluids viscosity to temperature is shown in Figs. 11, 12, 13 and 14.

From the Figs. 11, 12, 13 and 14 it is identified as, whenever temperature of TOL based nanofluids gets increases it reduces the viscosity and the flow rate gets increased.

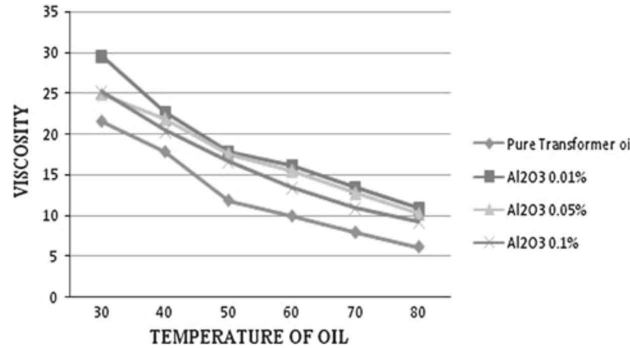

Fig. 12 Viscosity of Al_2O_3 nanofluids

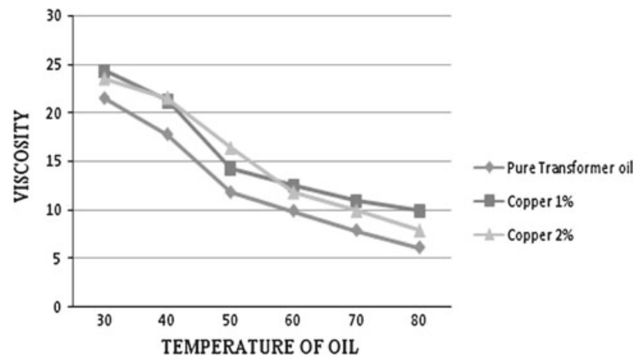

Fig. 13 Viscosity of copper nanofluids

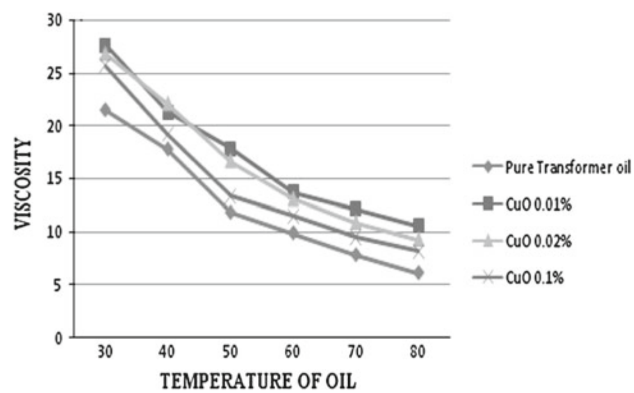

Fig. 14 Viscosity of copper oxide nanofluids

3.2 Breakdown voltage

Breakdown strength analysis of transformer oil is carried as per Indian standard IS6792 specifications. BDV of Aluminum Oxide, aluminium, Copper oxide and copper nanofluids is found to be lesser than the pure TOL, reasons for this decrease in the BDV of nanofluids are of;

- Impurities may be present in the nanoparticles.
- Nanoparticles used are of metallic type which reduces the BDV value.
- Size of the nanoparticle and Particle volume fraction.

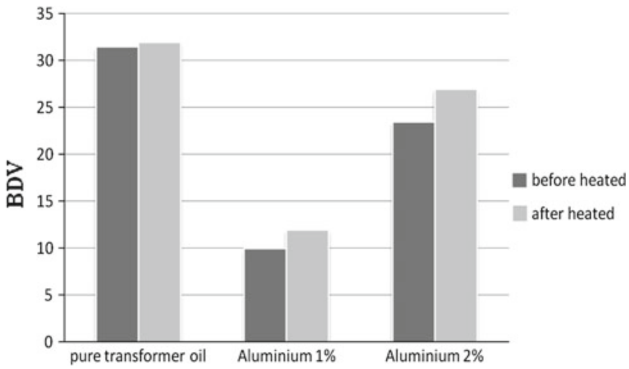

Fig. 15 BDV of Al nanofluids

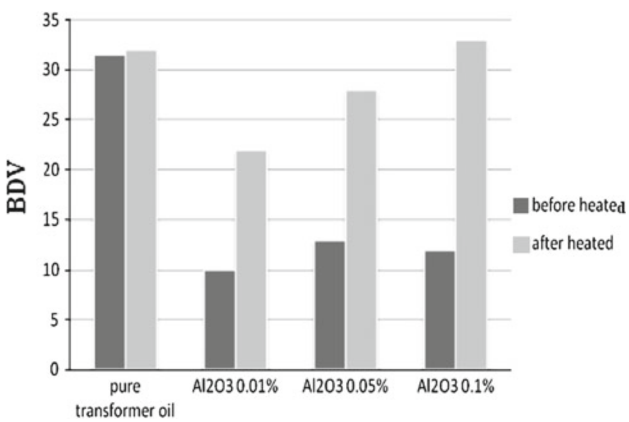

Fig. 16 BDV of Al_2O_3 nanofluids

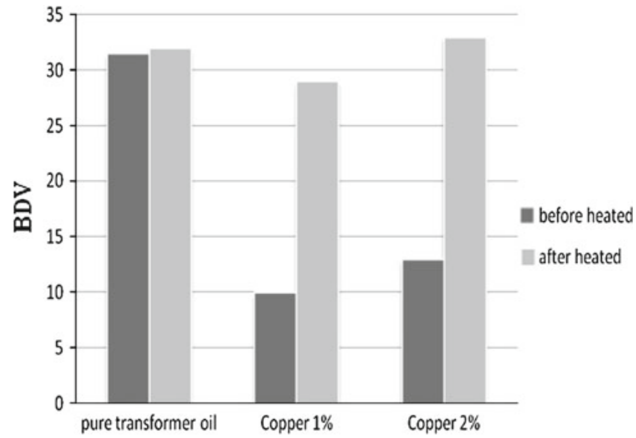

Fig. 17 BDV of copper nanofluids

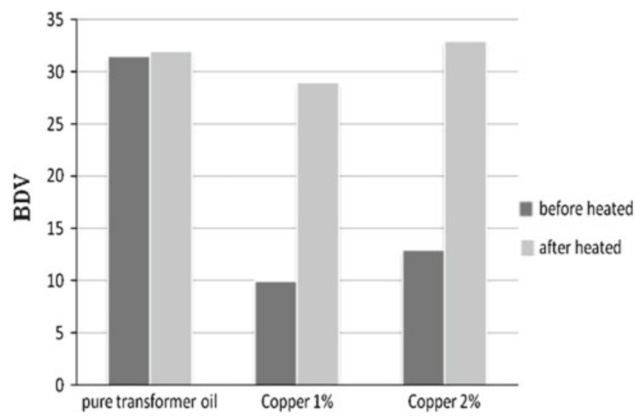

Fig. 18 BDV of copper oxide nanofluids

BDV of nanofluids is improved by exact determination of particle volume fraction and also by heating the nanofluids up to 100 °C, then cooled to room temperature. Any moisture contents present in nanofluids reduces the BDV, on heating the nanofluids the moisture content gets evaporated, which in turn increase the breakdown voltage. Although metallic nanoparticles are used, from the results it is observed on increasing particle volume fraction trends to increase the BDV value. Variations of nanofluids BDV to particle volume fraction is shown in Figs. 15, 16, 17 and 18. Copper oxide and copper nanomaterials shows tremendous increase of BDV than other materials. As a future work an effort shall be made to utilize non- metallic nanoparticles to enhance the BDV value.

At initial stage as shown in Figs. 15, 16, 17 and 18, TOL based nanofluids shows low value of BDV compared to pure TOL, but after heated to 100 °C BDV value shows fine improvement.

3.3 Flash Point and Fire Point

Flash point refers to both flammable as well as combustible liquids. Flash point of a volatile liquid is the lowest temperature at which it can vaporize to form an ignitable mixture in air. Fire point is the temperature at which the vapour continues to burn after being ignited. It is the lowest temperature at which, on further heating beyond the flash point, the sample will support combustion for 5 s. Flash and fire point test is carried out in Pensky–Martens open cup apparatus as per American Society of testing and materials ASTM D3828.

Flash point and fire point values of aluminium oxide, aluminium, copper oxide and copper based nanofluids shows tremendous increase for various particle volume fractions. It is confirmed from the results, thermal property of TOL shows excellent improvement than other critical parameters. Variations in flash point and fire point for different volume fraction of particles are shown in Figs. 19 and 20. From the figure it is observed that copper nanoparticles based TOL shows highest enhancement of flash point and fire point.

3.4 Measurement of pH Value

pH value is used to be a familiar terms indicating acidity and base level of liquid. Nanofluids pH value is at base level

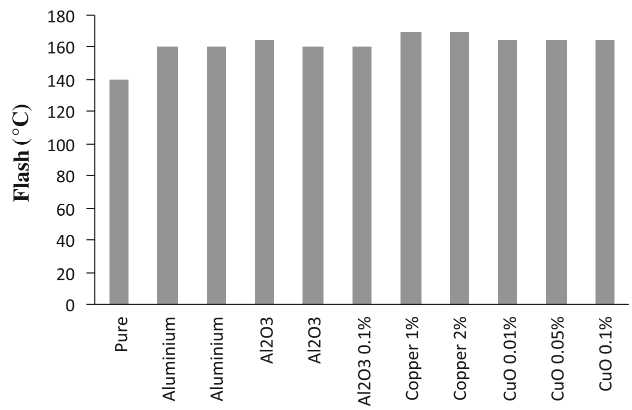

Fig. 19 Flash points of nanofluids

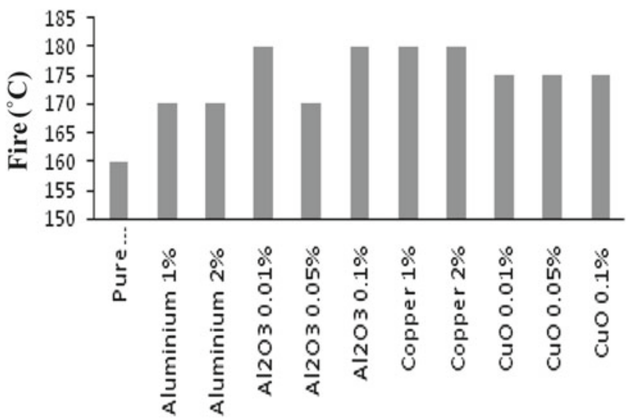

Fig. 20 Fire points of nanofluids

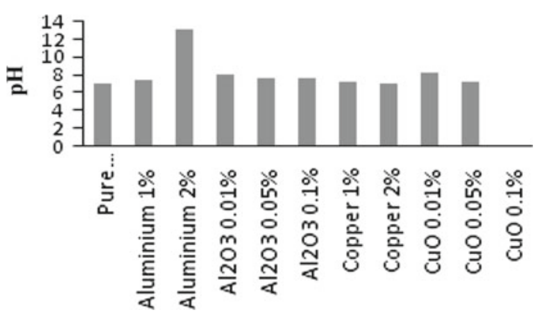

Fig. 21 pH values of nanofluids

(above 7). It indicates non availability of acid contents in nanofluids based TOL. pH value is measured using digital pH meter. Variations of nanofluids pH value for different volume fraction of particles is shown in Fig. 21. From the figure it is observed almost all of the TOL based nanofluids are at base level only.

3.5 Spectral Response of Nanofluids

Absorption is defined as the ratio of the radiant flux absorbed by a body to that incident upon it. Spectral absorptions refer to absorptions measured at a specified wavelength. Ultraviolet visible spectrophotometers quantify the optical properties of

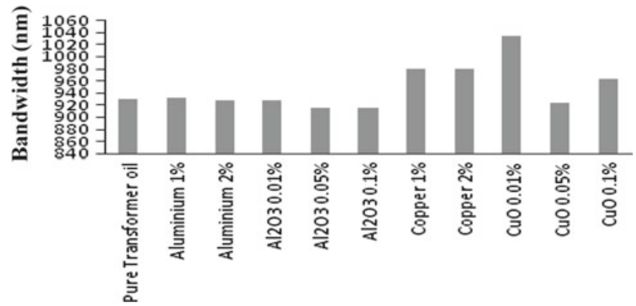

Fig. 22 Spectral response of nanofluids

samples in Ultraviolet and visible wavelength region. Spectrophotometer determines amount of light with particular wavelength transmitted and absorbed through TOL.

Spectral response analysis for TOL based nanofluids is performed using single beam UV-Visible spectrophotometer. Bandwidth value obtained during the measurement of absorption peak is shown in Fig. 22. During measurement of transmission capability of nanofluids based TOL; it is observed zero percentage transmission peaks for all samples, which implies that all the nanoparticles are mixed with TOL. From the results it is confirmed on increasing the particle volume fraction of fluids the bandwidth width also seems to be increasing and lies in the visible region. UV-Visible test is not a mandatory test as per standards, but as initiative the Spectral response characteristics has been analyzed, which gives some idea towards the spectral response of nanofluids and quantity of particles mixed with TOL.

4 Conclusion

Variations in particle volume fraction of nanoparticles based TOL shows tremendous improvement in viscosity, flash and fire point. Breakdown voltage of nanofluids is slightly lower than pure TOL, but based on exact particle volume fraction and maintenance of temperature BDV can be improved. pH value of the nanofluids are at base level, hence it is conferred that nanofluids doesn't create complexity due to acid contents. Enhancement in critical parameters of transformer oil can be achieved by determining exact size and fraction volume of nanoparticles, which will be surely an alternate medium for traditional mineral oils.

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