Multi-Response Optimization Of The Properties Of Mineral Oil Blended With Natural Ester Oil Using Desirability- Based Methodology

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Abstract: Energy demand of the whole world is fulfilled predominantly by products of fossil fuels in this century. In the field of power system transmission and distribution, transformers are major components which use petroleum-based mineral oil as potential insulating and cooling medium. Even though they are predominant in their field of applications, they have some disadvantages of non-biodegradability, scarcity of availability in future and environmental unsociable nature. The analysis is extended with the addition of synthetic antioxidants for studying changes in characteristics of different oil samples with individual and blended combinations. Critical characteristics such as breakdown voltage, flashpoint, fire point and viscosity are measured according to international standards before and after modification of oil samples. The analysis also extended to the desirability function approach which is very helpful for solving multi-objective optimization problems.

Keywords: Mineral oil, Ester oil, Synthetic Antioxidants, Breakdown, Viscosity, Optimization Method.

1. INTRODUCTION

Transformers form an imperative, expensive part of power system transmission and distribution network. In transformers, the supreme important parts are their insulating medium which comprises liquid and solid insulations. High insulating properties and cooling properties of liquid insulation in transformer ensure normal operation of transformer without failures [1-3]. Petroleum based mineral oil (transformer oil) is used as liquid insulation in oil-filled transformers over the past several decades. Mineral oil has better cooling properties, insulating properties, but lower values for flashpoint and firepoint temperature. Important constraints in usage of mineral oil for upcoming years are limited by the environmental aspect, lower possibility of resources in future and higher rating of equipment. In the environmental aspect, mineral oil poses severe limitations towards eco-system and affects the human beings and surrounding environment when it comes into contact with these by oil spills on soil and water resources [4 - 5]. Due to the increase in severe regulation on all products regarding environment and safety, alternative liquid insulating mediums are considered for applications in transformers [6]. Since the 1990's, vegetable oils have been experimented to replace traditional mineral oil due to their better characteristics than those of mineral oil, silicon oil and synthetic esters. In recent years, eco-friendly natural esters derived from plants and seeds of plants have been used [7]. Natural esters (vegetable oils) are triglyceride which has fatty acids composition. Fatty acids are classified as saturated fatty acids, mono-unsaturated fatty acid, polyunsaturated fatty acids based on the type of bond between molecules. [8 – 10]. Properties of natural esters such as viscosity, thermal characteristics, oxidation stability and ageing behaviour are determined by fatty acid composition [11]. Higher content of saturated fatty acid leads to high viscosity of natural esters. Meanwhile natural esters with higher content of poly-unsaturated fatty acids have low viscosity.

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viscosity of it [12]. Oxidation stability mainly depends on mono-unsaturated fatty acids. Another approach is the inclusion of enhancing agents with liquid insulation for obtaining optimized properties. Antioxidant materials have the ability to increase the oxidative stability and operational characteristic of oil insulations [7]. They resist the chain reactions in oils by reducing free radicals and peroxide formation. The quantity of antioxidants also influences the properties of oil. So, care should be taken while adding antioxidants beyond 1%. In mineral oil, oxidation stability is achieved by adding sulphur spices (uninhibited oil) or antioxidants (inhibited oil). Butylated Hydroxy Toluene (BHT) and Butylated Hydroxy Anisole (BHA) are the mostly used antioxidants in inhibited oil to achieve oxidation stability [13]. In this paper, investigations are carried out with some natural esters-based vegetable oils to satisfy the above constraints and requirements of liquid insulation with better properties. Natural esters are analyzed individually and of blended combinations with mineral oil at different concentrations. Critical properties such as breakdown voltage, flashpoint, firepoint and viscosity (at different temperatures) are measured according to the existing standards for all the samples. The investigations are extended towards analysis of critical properties of natural esters and blended combinations with inclusion of antioxidants. Various properties of oil determine the ability of oil as good Insulating liquids. The properties such as breakdown voltage, loss factor, dielectric dissipation factor, interfacial tension, acidity, volume resistivity, flash point, fire point, viscosity etc.are investigated for checking the suitability of oil samples as liquid insulation. Among this, the breakdown voltage, flashpoint, fire point and viscosity are considered as critical properties for selecting insulating liquid in primary investigation.

2 DESIRABILITY

2.1 Desirability Function Approach

The desirability function approach is very helpful for solving multi-objective optimization problems .Depending on the desirability of each response, the component or overall desirability value is then calculated. In this study, the individual desirability functions are calculated based on the type of the optimization functions, i.e. maximization or minimization using

Eqs. (1)–(3). If the target (Ti) for the response yi is a maximum value, the desirability is based on Eq. (1). If the target is a minimization one, the desirability is based on Eq. (2). Furthermore, if the target is located between the lower (Li) and upper (Ui) limits, the desirability is obtained based on Eq. (3).

$$d_i = \begin{cases} 0 & y_i < L_i \\ \left(\frac{y_i - L_i}{T_i - L_i}\right)^w & L_i \leqslant y_i \leqslant T_i \\ 1 & y_i > T_i \end{cases}$$

$$d_i = \begin{cases} 1 & y_i < L_i \\ \left(\frac{T_i - y_i}{T_i - L_i}\right)^w & L_i \leqslant y_i \leqslant T_i \\ 0 & y_i > T_i \end{cases}$$

$$d_i = \begin{cases} 0 & y_i < L_i \\ \left(\frac{y_i - L_i}{T_i - L_i}\right)^w & L_i \leqslant y_i \leqslant T_i \\ \left(\frac{U_i - y_i}{U_i - L_i}\right)^w & T_i \leqslant y_i \leqslant U_i \\ 0 & y_i > U_i \end{cases}$$

Next, the individual desirability functions are integrated as overall (composite or aggregated) desirability (D), which can be between 0 and 1. It is defined as the weighted geometric mean of all the previously defined desirability functions, calculated by Eq. (4),

$$D = \left(d_1^{w_1} \times d_2^{w_2} \times d_3^{w_3} \times \ldots \times d_n^{w_n}\right)^{\frac{1}{(w_1+w_2+w_3+\ldots+w_n)}} = \prod_{i-1}^{n} d_i^{w_i^{\frac{1}{\sum_{i=1}^{n} w_i}}}$$

where wi is a comparative scale for weighing each of the resulting di assigned to the ith response, and n is the number of responses. The optimal values of the parameters are determined to maximize overall desirability (D), by applying a reduced gradient algorithm with multiple starting points [14].

3 METHODOLOGY

The scope of this work is based on present scenario related with requirement to find alternative liquid insulating medium and enhancement in operational properties of insulating medium.

3.1 Base Oil Sample Details

SAMPLE	OIL	NATURE OF OIL
S1	Transformer Oil (TO)	Mineral
S2	Sunflower Oil (SFO)	Natural Ester
S3	Rice bran Oil (RBO)	Natural Ester
S4	Rape seed Oil (RSO)	Natural Ester
S5	Silicon Oil (SO)	Synthetic

***Table 1 Base** oil sample*

With this aim, some natural esters-based vegetable oil samples are chosen for the investigations. For reference purposes, silicon oil is chosen as one of the samples.

3.2 Blended Oil Sample Details

Sample	Oil 1		Oil 2	
	Base Oil	Percentage (%)	Base Oil	Percentage (%)
M1	S1	90	S2	10
M2	S1	75	S2	25
M3	S1	50	S2	50
M4	S1	90	S3	10
M5	S1	75	S3	25
M6	S1	50	S3	50
M7	S1	90	S4	10
M8	S1	75	S4	25
M9	S1	50	S4	50
M10	S1	90	S5	10
M11	S1	75	S5	25
M12	S1	50	S5	50

***Table 2** Blended oil sample*

Blending is the one of the ways to change the physiochemical characteristics of liquid insulations. By considering this concept, mineral oil is blended with all other samples with different ratios. The blended ratio of 90:10 are considered in this investigation for analyzing the influence of lower, medium and equal percentage of blended combination of natural esters/synthetic oil with the mineral oil [15].

3.3 Antioxidant Details

Chemical Name	Origin	Chemical Formula	Function
Butylated Hydroxy Anisole (BHA)	Synthetic Antioxidant	$C_{11}H_{16}O_2$	Free Radical Scavengers
Butylated Hydroxy Toluene (BHT)	Synthetic Antioxidant	$C_{15}H_{24}O$	Free Radical Scavengers and Metal Chelators

***Table 3 Antioxidant** sample*

These two antioxidants are chosen due to their frequent usage in mineral oils for improving oxidation stability. Both antioxidants are individually included with base oil samples and blended oil samples with the ranges of1.25g and 2.5g. Samples prepared with inclusion of antioxidants with oil constitute combinations. Investigations are carried out with measurement of critical properties of samples such as breakdown voltage, flashpoint, firepoint and viscosity (at different temperatures)of individual oil samples, blended oil samples, oil samples added with antioxidants as per international standards.

3.4 Sample A Details

Sample	Oil Constitutes
A1	S1+1.25g BHA
A2	S2+1.25g BHA
A3	S3+1.25g BHA
A4	S4+1.25g BHA
A5	S5+1.25g BHA
A6	M1+1.25g BHA
A7	M2+1.25g BHA
A8	M3+1.25g BHA
A9	M4+1.25g BHA
A10	M5+1.25g BHA
A11	M6+1.25g BHA
A12	M7+1.25g BHA
A13	M8+1.25g BHA
A14	M9+1.25g BHA
A15	M10+1.25g BHA
A16	M11+1.25g BHA
A17	M12+1.25g BHA

Table 4 *Blended antioxidant sample A*

3.5 Sample B Details

Sample	Oil Constitutes
B1	S1+2.5g BHA
B2	S2+2.5g BHA
B3	S3+2.5g BHA
B4	S4+2.5g BHA
B5	S5+2.5g BHA
B6	M1+2.5g BHA
B7	M2+2.5g BHA
B8	M3+2.5g BHA
B9	M4+2.5g BHA
B10	M5+2.5g BHA
B11	M6+2.5g BHA
B12	M7+2.5g BHA
B13	M8+2.5g BHA
B14	M9+2.5g BHA
B15	M10+2.5g BHA
B16	M11+2.5g BHA
B17	M12+2.5g BHA

Table 5 *Blended antioxidant sample B*

3.6 Sample C Details

Sample	Oil Constitutes
C1	S1+1.25g BHT
C2	S2+1.25g BHT
C3	S3+1.25g BHT
C4	S4+1.25g BHT
C5	S5+1.25g BHT
C6	M1+1.25g BHT
C7	M2+1.25g BHT
C8	M3+1.25g BHT
C9	M4+1.25g BHT
C10	M5+1.25g BHT
C11	M6+1.25g BHT
C12	M7+1.25g BHT
C13	M8+1.25g BHT
C14	M9+1.25g BHT
C15	M10+1.25g BHT
C16	M11+1.25g BHT
C17	M12+1.25g BHT

Table 6 *Blended antioxidant sample C*

3.7 Sample D Details

Sample	Oil Constitutes
D1	S1+2.5g BHT
D2	S2+2.5g BHT
D3	S3+2.5g BHT
D4	S4+2.5g BHT
D5	S5+2.5g BHT
D6	M1+2.5g BHT
D7	M2+2.5g BHT
D8	M3+2.5g BHT
D9	M4+2.5g BHT
D10	M5+2.5g BHT
D11	M6+2.5g BHT
D12	M7+2.5g BHT
D13	M8+2.5g BHT
D14	M9+2.5g BHT
D15	M10+2.5g BHT
D16	M11+2.5g BHT
D17	M12+2.5g BHT

Table 6 *Blended antioxidant sample D*

4 DESCRIPTION

For investigating individual base oil samples, 500ml of each sample is taken and their characteristics are measured according to standard procedures. Blended oil samples are prepared by taking 500ml of oil as 100%. Oil samples are blended as per required percentages of each oil sample with the help of sonicator. For complete blending of oils, the blending is kept for 30-45 minutes in sonicator. Characteristics of blended samples are also analyzed as per standards. For preparing antioxidants added oil samples, the required quantity of antioxidants is mixed with 500ml of oil samples (individual base samples and blended samples) in sonicator. Before that, the oil samples are heated up to the melting temperature of antioxidants for complete dispersion of antioxidants. All the oil samples are treated with heating upto 100˚C for half an hour and samples are kept in normal room temperature for minimizing the effect of moisture in measurement of oil properties. Breakdown voltage, flashpoint, firepoint and viscosity. Measurements of these properties are carried out in the room temperature and pressure [16].

Breakdown voltage measurements are conducted in breakdown voltage kit with test cell of 2.5mm gapped semispherical electrodes as per the standard of IEC60156 [17]. The test cell is filled with oil samples to marked level (above 40mm of electrodes). Flashpoint and firepoint are temperatures which indicate the flammable nature of liquid insulations. When temporary fire occurs on the surface due to vapour formation, that temperature is noted as flashpoint temperature. Further heating of oil will produce persevere fire on the surface after the introduction of test flame. That temperature is considered as firepoint temperature. Viscosity determines the flow nature of oil inside transformers which is indirectly related to the cooling capacity of oil. Oil with low viscosity will have good heat transfer capacity. For good transfer of heat in transformer tank, free circulation of oil is required which is possible with moderate viscous oil. Viscosity is also a function of temperature which is inversely proportional to temperature [17]. Time taken for flow of 50ml of oil through the orifice is noted, and viscosity is calculated from that time. This measurement is continued for different temperatures of oil for studying the viscosity-temperature profile. Oil is heated using an electric heater for the temperatures of 30°C, 40°C, 50°C, 60°C, 70°C, 80°C and 90°C. Breakdown voltage of oil samples prepared with antioxidants and different oil combinations is tabulated formineral oil and sunflower oil combinations, mineral oil andrice bran oil combinations, mineral oil and rape seed oil combinations and mineral oil and silicon oil combinations inprevious Section. From the obtained results of breakdown voltage forantioxidants added samples, it is evident that all oil samples (individually and blended combinations with antioxidants) have higher values of breakdown voltage than that of their original form except the samples. The samples are preparedby adding antioxidants with 90% of mineral oil and 10% ofsunflower oil are prepared by adding antioxidants with mineral oil and rape seed oil combinations. Base oil samples have higher increment percentage inbreakdown voltage after inclusion of antioxidants among allinvestigating oil samples. Blended oil combinations have slight increment in their breakdown voltages except samples prepared with 90% of mineral oil and 10% of rice bran oil combinations. Flashpoint and firepoint temperatures of antioxidants included mineral oil and sunflower oil combinations, mineral oil and rice bran oil combinations, mineral oil and rape seed oil combinations and mineral oil and silicon oil combinations. Among all investigating oil samples with antioxidants, samples prepared only with sunflower oil, rice bran oil and silicon oil have decreased values for flashpoint and firepoint temperatures. In blended combination, samples prepared with 75% of mineral oil and 25% of rice bran oil, 75% of mineral oil and 25% of oil, 50% of mineral oil and 50% of rape seed oil, 75% of mineral oil and 25% of silicon oil have lower flashpoint and firepoint than those of their individual samples. Base samples of pure vegetable oils and silicon oil show increased values for flashpoint and firepoint after inclusion of antioxidants.

Viscosities are measured at different temperatures and are shown for antioxidants added mineral oil and sunflower oil combinations, mineral oil and rice bran oil combinations, mineral oil and rape seed oil combinations and mineral oil and silicon oil combinations. All blended combinations prepared with silicon oil and antioxidants have reduced values of viscosity. Blended combinations of mineral oil and rice bran oil added with 1.25g of BHT have shown reduced values of viscosity than that of its individual form. This viscosity comparison based on temperature of oil is made to ensure viscosity values of insulating fluids at operating temperature inside transformers [19].

5 PROPERTIES

5.1 Properties of Antioxidant Added Oil Sample

Properties		Sample				
		S1	S2	S3	S4	S5
Breakdown voltage (kv)		23.4	31	35.6	32	30
Flashpoint (˚C)		164	280	230	320	284
Firepoint (˚C)		182	296	245	340	296
Viscosity (cSt)	30˚C	18.3	57	81.35	90.25	25.54
	40˚C	16.2	50.15	62.9	62.1	22.1
	50˚C	13.45	43.24	48.49	50.23	19.25
	60˚C	11.24	31.42	39.9	42.33	16.91
	70˚C	9.81	25.33	33.82	35.56	12.55
	80˚C	8.87	21.21	22.33	24.01	10.21
	90˚ C	7.53	19.5	13.64	13.67	8.89

Table 7 *Antioxidant added oil sample*

From the investigated properties of base oil samples, it is known that the breakdown voltage of natural ester-based vegetable oil samples and silicon oil is much higher than that of investigated mineral oil sample. Vegetable oils have higher breakdown voltage value than silicon oil. Similar trend is shown in the values of flashpoint and firepoint temperatures. Viscosity of mineral oil is much lower than that of vegetable oil samples. Viscosity of investigated samples is shown decreasing nature as temperature of oil samples increases. At 90ºC (operating temperature of transformer) [10].

5.2 Properties of Antioxidant Added Oil Sample

For evaluating the influence of antioxidants in properties of investigating oil samples, oil properties are measured according to specified standards after inclusion of antioxidants at required quantity with combinations of oils. Viscosity of various blended oil samples after inclusion of 1.25g of BHA with sunflower oil based blended oil samples, rice bran oil based blended oil samples, rapeseed oil based blended oil samples and silicon oil based blended oil samples are tabulated. Sunflower oil based blended oil samples, rice bran oil based blended oil samples, rapeseed oil based blended oil samples and silicon oil based blended oil samples are mixed with 2.5gBHA. 1.25g BHT is included in the Sunflower oil based blended oil samples, rice bran oil based blended oil samples, rapeseed oil based blended oil samples and silicon oil based blended oil samples and the breakdown voltage, flash point and fire point values. Measured viscosities of various blended oil samples after inclusion of 2.5g of BHT with sunflower oil based blended oil samples, rice bran oil based blended oil samples, rapeseed oil based blended oil samples and silicon oil based blended oil samples are tabulated.

6 OUTPUT RESULTS

6.1 Parameters of sample A and B

Sample	Breakdown Voltage	Flashpoint	Firepoint	Viscosity
A1	31	220	229	17.49
A2	48	276	228	36.24
A3	51	271	286	70.87
A4	53	280	290	72.85
A5	27	228	242	15.44
A6	23	193	206	20.64
A7	46	193	202	23.44
A8	37	188	229	27.85
A9	40	193	206	16.91
A10	30	201	206	25.93
A11	38	204	229	29.22
A12	27.3	180	186	27.43
A13	28.6	188	201	30.15
A14	30.7	205	218	32.51
A15	26	194	216	17.78
A16	31	186	203	15.44
A17	29	201	215	18.54

Table 8 *Parameters of sample A*

Sample	Breakdown Voltage	Flashpoint	Firepoint	Viscosity
B1	33	229	239	19.48
B2	48	279	288	36.54
B3	54	281	289	77.85
B4	55	288	305	82.86
B5	30	230	252	17.4
B6	25	194	207	23.65
B7	49	197	200	23.6
B8	40	190	227	32.87
B9	44	197	207	18.94
B10	34	205	208	27.93
B11	40	206	232	30.24
B12	28	188	189	27.43
B13	30	189	204	30.15
B14	32	207	219	32.51
B15	28	195	218	19.75
B16	33	187	205	16.46
B17	33	203	217	17.53

Table 9 *Parameters of sample B*

6.2 Parameters of sample C and D

Sample	Breakdown Voltage	Flashpoint	Firepoint	Viscosity
C1	32	270	233	18.02
C2	47	278	290	37.26
C3	53	273	288	72.87
C4	56	285	294	74.85
C5	27	230	245	16.44
C6	25	191	200	20.61
C7	45	196	202	22.4
C8	39	186	209	25.8
C9	42	195	211	17.95
C10	32	205	206	23.9
C11	39	206	221	27.21
C12	29.3	188	191	25.43
C13	27.6	188	201	32.16
C14	28.7	203	210	34.58
C15	28	195	212	19.78
C16	33	181	190	12.4
C17	31	198	207	13.54

Sample	Breakdown Voltage	Flashpoint	Firepoint	Viscosity
D1	30	220	230	18.4
D2	49	280	290	35.5
D3	56	280	291	79.85
D4	55	280	303	83.87
D5	32	233	255	17.46
D6	24	190	205	23
D7	44	195	205	23.12
D8	38	197	229	30.87
D9	42	199	209	18
D10	34	204	209	29.94
D11	39	203	234	33.24
D12	26	186	191	26.43
D13	33	181	205	32.14
D14	30	205	215	34.51
D15	26	193	215	18.71
D16	34	185	206	17.46
D17	30	198	209	15.53

Table 10 *Parameters of sample C and D*

6.3 Ranks for Sample A and B

Sample	Individual Desirability				Composite Desirability	Rank
	Breakdown Voltage	Flashpoint	Firepoint	Viscosity		
A1	0.25	0.37037	0.36134	0.969594	0.42439657	9
A2	0.78125	0.88889	0.85714	0.691486	0.80097426	2
A3	0.875	0.84259	0.84034	0.17784	0.57613902	4
A4	0.9375	0.92593	0.87395	0.148472	0.57932171	3
A5	0.125	0.44444	0.47059	1	0.40210747	11
A6	0	0.12037	0.16807	0.922872	0	32
A7	0.71875	0.13889	0.13445	0.881341	0.32979234	18
A8	0.4375	0.07407	0.36134	0.81593	0.31264729	21
A9	0.53125	0.12037	0.16807	0.978196	0.3202078	20
A10	0.21875	0.19444	0.16807	0.844408	0.27873709	23
A11	0.46875	0.22222	0.36134	0.79561	0.41599448	10

A12	0.134375	0	0	0.82216	0	32
A13	0.175	0.07407	0.12605	0.781815	0.18905502	29
A14	0.240625	0.23148	0.26891	0.746811	0.32521284	19
A15	0.09375	0.12963	0.2521	0.965292	0.23319926	26
A16	0.25	0.05556	0.14286	1	0.21105341	28
A17	0.1875	0.19444	0.2437	0.95402	0.30342495	22

Sample	Individual Desirability				Composite Desirability	Rank
	Breakdown Voltage	Flashpoint	Firepoint	Viscosity		
B1	0.3125	0.4537	0.44538	0.940077	0.49360402	5
B2	0.78125	0.91667	0.85714	0.687036	0.80585818	1
B3	0.96875	0.93519	0.86555	0.07431	0.4913174	6
B4	1	1	1	0	0	32
B5	0.21875	0.46296	0.55462	0.970929	0.48324752	7
B6	0.0625	0.12963	0.17647	0.878226	0.18824166	30
B7	0.8125	0.15741	0.11765	0.878968	0.33911783	15
B8	0.53125	0.09259	0.34454	0.741471	0.33481246	16
B9	0.65625	0.15741	0.17647	0.948087	0.36257989	12
B10	0.34375	0.23148	0.18487	0.814743	0.33087495	17
B11	0.53125	0.24074	0.38655	0.780481	0.44320574	8
B12	0.15625	0.07407	0.02521	0.82216	0.12445266	31
B13	0.21875	0.08333	0.15126	0.781815	0.21547613	27
B14	0.28125	0.25	0.27731	0.746811	0.3473782	14
B15	0.15625	0.13889	0.26891	0.936072	0.27186293	24
B16	0.3125	0.06481	0.15966	0.984871	0.23756233	25
B17	0.3125	0.21296	0.2605	0.969	0.36001715	13

Table 11 *Ranks of sample A and B*

6.4 Ranks for Sample C and D

Sample	Individual Desirability				Composite Desirability	Rank
	Breakdown Voltage	Flashpoint	Firepoint	Viscosity		
C1	0.25	0.85577	0.38053	0.92137	0.52333487	5
C2	0.71875	0.93269	0.88496	0.65216	0.78867538	2
C3	0.90625	0.88462	0.86726	0.15391	0.57194565	4
C4	1	1	0.92035	0.12621	0.58379371	3
C5	0.09375	0.47115	0.48673	0.94347	0.37738698	11
C6	0.03125	0.09615	0.0885	0.88513	0.12386138	28
C7	0.65625	0.14423	0.10619	0.86008	0.30492453	17
C8	0.46875	0.04808	0.16814	0.81251	0.23555661	23
C9	0.5625	0.13462	0.18584	0.92235	0.33753038	14
C10	0.25	0.23077	0.14159	0.83909	0.28773483	18
C11	0.46875	0.24038	0.27434	0.79278	0.39565895	9
C12	0.165625	0.06731	0.00885	0.81769	0.09477082	29
C13	0.1125	0.06731	0.09735	0.72352	0.15196569	27
C14	0.146875	0.21154	0.17699	0.68966	0.24815953	22
C15	0.125	0.13462	0.19469	0.89674	0.23281119	24
C16	0.28125	0	0	1	0	31
C17	0.21875	0.16346	0.15044	0.98405	0.26973527	20

Sample	Individual Desirability				Composite Desirability	Rank
	Breakdown Voltage	Flashpoint	Firepoint	Viscosity		
D1	0.1875	0.375	0.35398	0.91605	0.38858243	10
D2	0.78125	0.95192	0.88496	0.67679	0.8169424	1
D3	1	0.95192	0.89381	0.05625	0.46772089	7
D4	0.96875	0.95192	1	0	0	31
D5	0.25	0.5	0.57522	0.9292	0.5084095	6
D6	0	0.08654	0.13274	0.85169	0	31
D7	0.625	0.13462	0.13274	0.85001	0.31214221	15
D8	0.4375	0.15385	0.34513	0.74157	0.36228532	12
D9	0.5625	0.17308	0.16814	0.92165	0.35046946	13
D10	0.3125	0.22115	0.16814	0.75458	0.30600715	16
D11	0.46875	0.21154	0.38938	0.70841	0.40667479	8
D12	0.0625	0.04808	0.00885	0.80369	0.06799191	30
D13	0.28125	0	0.13274	0.7238	0	31
D14	0.1875	0.23077	0.22124	0.69064	0.28514977	19
D15	0.0625	0.11538	0.22124	0.91171	0.19529301	26
D16	0.3125	0.03846	0.14159	0.9292	0.19941461	25
D17	0.1875	0.16346	0.16814	0.95621	0.26494809	21

Table 12 *Ranks of sample C and D*

7 GRAPH

7.1 Main Effects Plot for Means

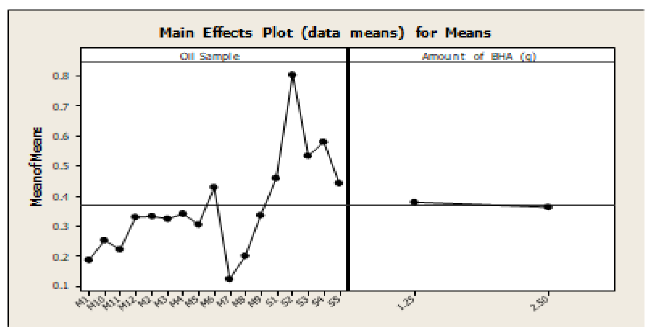

Figure 1 *Main effects plot for mean value*

7.2 Main Effects Plot for SN Ratios

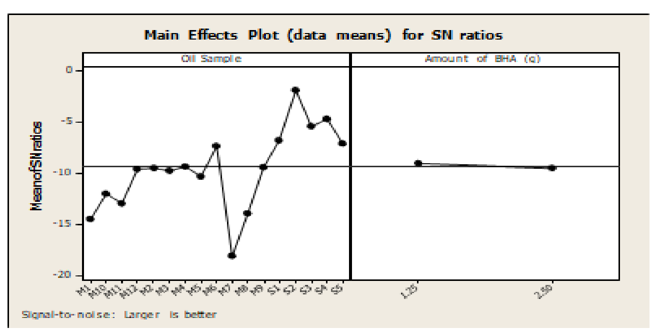

Figure 2 *Main effects plot for SN Ratio value*

8 CONCLUSION

In the present reporting validation of optimization problem performed by previous researchers has been checked by using desirability function approach followed by response surface methodology. The results that have arrived at optimal solution are very close to the results obtained by previous investigators. The desirability function approach is very helpful to tackle multi-objective optimization problems by reducing the objectives as well as constraints. The aim of the work is to show the application feasibility of desirability function approach optimization technique. Evaluation analysis of blended insulating oils with antioxidants reveals that inclusion of antioxidants has the ability to enhance the critical properties of insulating oil samples. Antioxidants have influence on properties of oils in such a way that they have combined positive and negative impacts on properties of oil samples. Initial cost of antioxidants added oil samples is high due to the price of antioxidants. But that drawback is overcome by constructional outcomes of antioxidants. Hence overall investigations have produced vivid solution to problems in traditional mineral oil in the aspects of environmental and technical characteristics. Those effects are diverse based on the selection of base oil samples, blending ratio, antioxidant section and quantity of antioxidants. Other than regular observations, this work exposes more positive influential aspects of antioxidants in insulating liquids such as less carbon formation during testing, less tendency of gas formation and increase in life time.

9 FUTURE WORK

As a recommendation for the future research, the proposed method can be applied for different engineering and business multi-objective and single- objective optimization problems. Furthermore, other evolutionary optimization algorithms can be investigated to show other applications of the proposed parameter tuning approach. Besides, the proposed parameter tuning approach can be utilized in the case problems in which more than three performance metrics need to be optimized in the performance evaluation of the evolutionary optimization algorithm, or/and there are more than four parameters of the evolutionary optimization algorithm to be tuned. In addition, a sensitivity analysis of considering different weights for each performance metric of the evolutionary optimization algorithms can be considered as an extension of the proposed approach.

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