DETERMINATION OF AN EFFICIENT POWER EQUIPMENT OIL THROUGH A MULTI-CRITERIA DECISION MAKING ANALYSIS

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Abstract:

Introduction/purpose: Several studies in the area of the development of nanofluids for power equipment have left a gap unfilled as to how to determine the best oil among the produced oils for power equipment application. Therefore, this study presents a multi-criterial decision making analysis to determine the best oil for power equipment.

Methods: The Grey relational analysis (GRA) and the Probability based multi-objective optimization techniques were employed as the multi-criterial decision making analytical tools for the optimization. Dielectric strength, dielectric loss, viscosity, and flash point were analyzed as multiple performance characteristics of different oils, after which different oil candidates were ranked based on their performance.

Results: Interestingly, the GRA and the Probability based multi-objective optimization techniques revealed that Jatropha oil + Neem nanofluid is the best oil candidate for power equipment and it is better than conventional mineral oil. The Probability based multi-objective optimization technique places Jatropha nanofluid over mineral oil, but not for the GRA technique. Also, mineral oil and ordinary Jatropha nanofluids are at a competitive level. Meaning, if Jatropha nanofluid is further worked on, it can beat mineral oil.

Conclusion: The two techniques substantially established that when Jatropha oil is mixed with Neem oil together with nanoparticles, there will

be better power equipment performance compared to mineral oil. It can be recommended that a further analysis should be conducted in the area of direct application of Jatropha + Neem nanofluid for power equipment to understand the overall behavior of power equipment compared to the conventional mineral oil.

Keywords: nanofluids, power equipment, grey relational analysis, probability optimization, vegetable oil, dielectric property, insulating property.

Introduction

Oil is filled in power equipment to serve as electrical insulation and for cooling. It ensures that there is heat transfer from power equipment and equally block arcing and corona discharge within the equipment system. In addition, it suggests the quality of the service lifespan of the equipment (Shafi et al, 2018; Oparanti et al, 2022). Since the beginning of the 20th century, mineral oil has been conventional oil for power equipment application because of its lifelong tendency, low cost, low viscosity, etc. (Fofana, 2013). Even though mineral oil exhibits the above mentioned advantages, it is disadvantaged due to its high fire risk and its non-biodegradable nature. Apart from its non-biodegradable nature, its leakage is detrimental to the environmental and toxic to living organisms (Tambuwal et al, 2022). These tradeoffs have motivated several researchers to dwell on the production of an alternative oil to mineral oil for power equipment from biodegradable sources, such as vegetables. Vegetable oil has been proven to be environmentally friendly, but generally exhibits high dielectric loss and poor viscosity (Abdelmalik, 2015; Rajab et al, 2011; Oparanti et al, 2020). Reports have shown that nanoparticles can be used to improve some insulating and electrical properties of oils for better performance (Mansour et al, 2012; Oparanti et al, 2021a, 2021b). Despite the improvement of vegetable oil as an alternative for mineral oil, there is a challenge in the selection and recommendation of optimal synthesis conditions for better performance in power equipment. Hence there is a need to research on the determination of optimal conditions in the production of nanofluids for better performance. This study applied two different multi-objective optimization techniques (the Grey relational analysis and the Probability based multi-objective optimization technique) to determine the best performing nanofluids for power equipment.

The Grey relational analysis (GRA) is usually applied when there is a need to optimize multiple performance properties, in addition to some uncertainties associated with the problem (Abifarin, 2021; Abifarin et al, 2022a, 2022b, 2022c; Abifarin et al, 2021; Avodi et al, 2021; Javed et al,

2019, 2020; Mahmoudi et al, 2019). The GRA was applied to address the uncertainties and complexities encountered in the choice of nanofluids with the best performance characteristics. Researchers have applied this optimization technique in different applications. Abifarin (2021) employed the GRA to assist Taguchi optimization in the fabrication of biomedical hydroxyapatite. Javed & Liu (2019) employed the bidirectional absolute GRA model for uncertainty systems, specifically in project management. Tosun (2006) employed the GRA to optimize drilling conditions for multiple performance characteristics. Tzeng et al. (2009) optimized turning operations using Taguchi assisted by the GRA. Abifarin & Ofodu (2022) modeled and employed the GRA for multiple performance properties of chemical additives and engine parameters for high efficient diesel engines. Kung & Wen (2007) applied the GRA and the grey decision maker to determine the relationship between company attributes and its financial performance using some venture capital enterprises in Taiwan as a case study. Hence, the GRA has been extensively proven to be effective as a multi-objective optimization technique. Furthermore, the Probability based multi-objective optimization technique has been recently developed to optimize more than one performance characteristics of conditions, process, systems, or products. Zheng et al. (2021) newly introduced the probability optimization technique in the selection of engineering materials based on some more than one essential attributes. Zheng (2022) selected some data relevant to material engineering and employed the technique to select material with better performance characteristics. Zheng et al. (2021) and Zheng (2022) were able to establish that Probability based optimization technique does not have any additional contributing factors which normally alter the accuracy of an optimization analysis as compared to some other existing ones. Ofodu & Abifarin (2022) applied the technique to optimize for high voltage thermofluids. The two optimization techniques were chosen because of their simplicity and proven accuracy in optimization analyses. This assertion has been proven in some past research studies a few ones of which have been discussed above. The two optimization techniques were also chosen to run the same problem for validation and comparative study.

Having highlighted the state of the art, this study employed two different optimization techniques to determine the best efficient power equipment oil. The two techniques, namely, the GRA and the Probability based multi-objective optimization technique were the numerical analysis chosen because of their simplicity and also to validate optimal predictions. The data analyzed was employed from the study of Tambuwal et al. (2022).

Data curation

The data used was obtained from the study of Tambuwal et al. (2022). The authors only investigated and reported the results without analyzing multiple performance characteristics, hence it was difficult to determine the oil sample with the best performance for power equipment. Table 1 presents the employed dataset in this study. The oil properties essential for power equipment are presented in the Table, i.e. breakdown strength, dielectric loss, viscosity, and flash point. These multiple properties were analyzed using two different multi-objective optimization techniques to determine the best performance oil sample for power equipment.

Table 1 – Insulating and electrical properties of different oil samples
Таблица 1 – Изоляционные и электрические свойства различных образцов масел
Табела 1 – Изолациона и електрична својства различитих узорака уља

Samples	Breakdown strength (kV mm^{-1})	Dielectric loss	Viscosity (mPas)	Flash point (^{o}C)
Mineral oil	36.8	0.00225	9.82	140
Jatropha oil	28.7	0.0551	11.07	245
Neem oil	15.1	0.0244	11.1	242
Jatropha + neem oil	15.8	0.02365	11.41	238
Neem nanofluid	18.5	0.002151	10.01	256
Jatropha nanofluid	25.7	0.00208	9.93	248
Jatropha + neem nanofluid	35.6	0.001862	9.874	261

Multi-criteria decision making analysis

Grey relational analysis (GRA)

The GRA was employed on four performance characteristics. The step by step methods in the GRA analysis are as shown below:

The Grey relational analysis was conducted on the experimental data presented in Table 1. The data was first normalized using grey relational generation. The breakdown strength and the flash point were normalized using the higher-the-better normalization condition, as given in Equation 1. The higher-the-better normalization was applied because higher breakdown strength shows a higher dielectric property which is needed for power equipment, while a high flash point is needed for higher insulating properties and reduced fire outbreak. Next, dielectric loss and viscosity

were normalized using the smaller-the-better normalization condition, as shown in Equation 2. The smaller-the-better normalization condition was chosen because as small as possible is required from the properties for better dielectric and insulation behavior of the oil. The normalized data sequence is presented in Table 2:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{1}$$

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{2}$$

$x_i(k)$ is the data being preprocessed for the ith experiment, and $y_i(k)$ is the initial sequence of the mean of the responses.

Table 2 – Normalized Insulating and electrical properties
Таблица 2 – Нормализованные изоляционные и электрические свойства
Табела 2 – Нормализована изолациона и електрична својства

Samples	$x_i(k)$ of Breakdown strength	$x_i(k)$ of Dielectric loss	$x_i(k)$ of Viscosity	$x_i(k)$ of Flash point
Mineral oil	1	0.99271	1	0
Jatropha oil	0.62673	0	0.21384	0.86777
Neem oil	0	0.57666	0.19497	0.84298
Jatropha + neem oil	0.03226	0.59074	0	0.80992
Neem nanofluid	0.15668	0.99457	0.8805	0.95868
Jatropha nanofluid	0.48848	0.99591	0.93082	0.89256
Jatropha + neem nanofluid	0.9447	1	0.96604	1

A comparison was made with an ideal sequence, $x_0(k)$ (k= 1, 2,…,7) for the four performance characteristics. The deviation sequence (Equation 3) was subsequently calculated to enable the determination of the grey relational coefficient (GRC). The grey relational generation and the deviation sequence of the four experimental data are shown in Table 4. The deviation data sequence is shown in Table 3:

$$\Delta_{oi}(k) = \|x_o(k) - x_i(k)\| \tag{3}$$

where $\Delta_{oi}(k)$, x_o (k), and x_i (k) are the deviation, the reference sequence, and the normalized data, respectively.

Table 3 – Deviation sequence of the insulating and electrical properties
Таблица 3 – Ряд отклонений изоляционных и электрических свойств
Табела 3 – Девијациони низ изолационих и електричних својстава

Samples	$\Delta_{oi}(k)$ of Breakdown strength	$\Delta_{oi}(k)$ of Dielectric loss	$\Delta_{oi}(k)$ of Viscosity	$\Delta_{oi}(k)$ of Flash point
Mineral oil	0	0.00729	0	1
Jatropha oil	0.37327	1	0.78616	0.13223
Neem oil	1	0.42334	0.80503	0.15702
Jatropha + neem oil	0.96774	0.40926	1	0.19008
Neem nanofluid	0.84332	0.00543	0.1195	0.04132
Jatropha nanofluid	0.51152	0.00409	0.06918	0.10744
Jatropha + neem nanofluid	0.0553	0	0.03396	0

The GRC values were computed using Equation 4. The GRC values show the relationship between the expected and obtained experimental data.

$$\xi_i(k) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_{oi}(k) + \zeta \Delta_{max}} \tag{4}$$

where $\xi_i(k)$ is the GRC value of the individual experimental data, computed as a function of Δ_{min} and Δ_{max}, the minimum and the maximum deviations of each experimental data. ζ is the distinguishing coefficient of 0.5, and it is usually assigned to each response.

Lastly, the grey relational grade (GRG) was calculated using Equation 5. The GRG, i.e., the converted singular response gives the overall multiple performance characteristics for the four experimental data. The GRC, the GRG, and the ranking are presented in Table 4:

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n} \xi_i(k) \tag{5}$$

γ_i is the GRG value obtained for the ith experiment and *n* is the number of performance characteristics.

Table 4 – GRC, the GRG and the ranking of oil types
Таблица 4 – Серый реляционный коэффициент (GRC), серый реляционный градиент (GRG) и ранжирование видов масел
Табела 4 – Сиви релациони коефицијент (СРК), сиви релациони градијент (СРГ) и рангирање типова уља

Samples	$\xi_i(k)$ of Breakdown strength	$\xi_i(k)$ of Dielectric loss	$\xi_i(k)$ of Viscosity	$\xi_i(k)$ of Flash point	GRG	Rank
Mineral oil	1	0.98563	1	0.33333	0.82974	2
Jatropha oil	0.57256	0.33333	0.38875	0.79085	0.52137	5
Neem oil	0.33333	0.54151	0.38313	0.76101	0.50475	6
Jatropha + neem oil	0.34066	0.5499	0.33333	0.72455	0.48711	7
Neem nanofluid	0.37221	0.98926	0.80711	0.92366	0.77306	4
Jatropha nanofluid	0.49431	0.99188	0.87845	0.82313	0.79694	3
Jatropha + neem nanofluid	0.90041	1	0.9364	1	0.9592	1

Probability based analysis

The Probability based multi-objective optimization analysis is based on the beneficial and unbeneficial utility index method.

The beneficial utility index method is applied to a characteristic desired to be as high as possible. The index characteristic indicator contributes positively to a partial preferable probability linearly. The breakdown strength and the flash point were run with the beneficial utility index method since the as high as possible condition is required for the properties. Equation 6 was used to compute the partial positive probability index (Pij), while Equation 7 was used to compute the normalized factor (α_j) of the jth utility index of the performance characteristic indicator.

$$Pij = \alpha_{ij}X_{ij}, \; i = 1, 2,...,n; \; j = 1, 2,..m \qquad (6)$$
$$\alpha_j = 1/(\mathrm{n}\overline{X}_J) \qquad (7)$$

where X_{ij} *is the j*[th] beneficial utility index of the characteristic performance indicator of the ith number of sample, n is the total number of samples considered in the study, while m is the total number of the utility indices of each sample involved, and X_j is the value of the arithmetic mean of the utility index of the sample characteristic performance indicator. The partial positive utility indexes for the breakdown strength and the flash point are shown in Table 5.

The unbeneficial utility index method is applied to a characteristic desired to be as small as possible. The index characteristic indicator contributes negatively to a partial preferable probability. Equation 8 was used to compute the partial negative probability index (Pij), while Equation 9 was used to compute its normalized factor (β_j) of the jth utility index of the performance characteristic indicator. and X_i is an arbitrary utility index of the characteristic performance indicator of the ith sampling number. The utility indexes for dielectric loss and viscosity are also shown in Table 5.

$$Pij = \beta_{ij}(X_{jmax} + X_{jmin} - X_i),\ i = 1, 2,...,n;\ j = 1, 2,..m \qquad (8)$$
$$\beta_{ij} = 1/[n(X_{j\min} + X_{j\max}) - nX_j] \qquad (9)$$

Furthermore, the total preferable probability of the analysis was computed using the product of the individual partial preferable probability of a corresponding candidate oil type. Afterwards, the ranking was done to show the candidate sample with the best performance characteristics. Please check Table 5 for proper highlights.

Table 5 – Partial and total probability utility index of oil types
Таблица 5 – Частичный и общий вероятностный индекс полезности типов нефти
Табела 5 – Индекс корисности делимичне и укупне вероватноће типова уља

Samples	Pij of Breakdown strength	Pij of Dielectric loss	Pij of Viscosity	Pij of Flash point	Pt*10E4	Pt*10E4	P Rank
Mineral oil	0.20887	0.19048	0.15134	0.08589	5.17133	5.17133	3
Jatropha oil	0.16289	0.00648	0.13476	0.1503	0.21388	0.21388	5
Neem oil	0.0857	0.11336	0.13436	0.14846	1.93808	1.93808	7
Jatropha + Neem oil	0.08968	0.11597	0.13025	0.14601	1.9779	1.9779	6
Neem nanofluid	0.105	0.19082	0.14882	0.15705	4.68307	4.68307	4
Jatropha nanofluid	0.14587	0.19107	0.14988	0.15215	6.35553	6.35553	2
Jatropha + Neem nanofluid	0.20205	0.19183	0.15063	0.16012	9.34816	9.34816	1

Discussion of results

The GRA was successfully applied to determine the best performance oil type in this study. Table 4 shows the ranking of the oil types. The results obtained show that a mixture of Jatropha oil and neem oil when nanoparticle is added is the best oil for power equipment, as it is ranked number one, followed by mineral oil. It is interesting to emphasize that the

GRA revealed that vegetable nanofluid is better than mineral oil, which is the second best oil type for power equipment application. This shows that vegetable oil, specifically a mixture of Jatropha and Neem sourced oil when nanoparticle is added, stands a good chance to replace mineral oil in power equipment application.

The Probability based multi-objective optimization technique was also successfully employed as shown in Table 5. The results obtained also revealed that a mixture of Jatropha oil and neem oil when nanoparticle is added is ranked as the best oil for power equipment, followed by Jatropha oil, then mineral oil. This technique further validates the choice of the best candidate oil for power equipment. To a higher level of confidence, the Jatropha oil + Neem nanofluid can better serve in power equipment.

Conclusion

Essentially, the Probability based multi-objective optimization technique places Jatropha nanolfuid over mineral oil, while it is the other way round for the GRA technique. It can be deduced from these findings that mineral oil and ordinary Jatropha nanofluids are at a competitive level. When Jatropha nanofluid is further worked on, it can be better than mineral oil. This claim is backed up by the results presented in the two techniques, i.e. when Jatropha oil is mixed with Neem oil together with nanoparticles, there will be better power equipment performance compared to the performance of the power equipment using mineral oil. In this study, recommendation is made that a further analysis should be conducted in the area of direct application of Jatropha + Neem nanofluid in power equipment to see the overall behavior of power equipment as compared to that of the conventional mineral oil.

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ОПРЕДЕЛЕНИЕ ЭФФЕКТИВНОСТИ МАСЛА ДЛЯ ЭНЕРГЕТИЧЕСКОГО ОБОРУДОВАНИЯ С ИСПОЛЬЗОВАНИЕМ МНОГОКРИТЕРИАЛЬНОГО АНАЛИЗА ПРИНЯТИЯ РЕШЕНИЙ

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Резюме:

Введение/цель: Поскольку несколько исследований в области разработки наножидкостей для энергетического оборудования не смогли определить лучшего кандидата среди масел для силовых установок, данное исследование посвящается анализу многокритериального принятия решений по определению масла − лучшего кандидата для энергетического оборудования.

Методы: Серый реляционный анализ и основанные на вероятности методы многокритериальной оптимизации были использованы для оптимизации. Диэлектрическая прочность, диэлектрические потери, вязкость и температура вспышки были проанализированы в качестве эксплуатационных характеристик различных масел, после чего различные масла-кандидаты были ранжированы в соответствии со своими характеристиками.

Результаты: Интересно, что серый реляционный анализ и многокритериальная оптимизация, основанная на вероятности

определили, что комбинация масел ятрофы + наножидкости нима является лучшим кандидатом для энергетического оборудования и, что она лучше, чем обычное минеральное масло. Метод многокритериальной оптимизации, основанный на вероятности отдает предпочтение наножидкости ятрофы по отношению к минеральному маслу, однако метод серого реляционного анализа не дал подобных результатов. Кроме того, минеральное масло и обычные наножидкости ятрофы находятся на одинаковом уровне конкурентноспособности, следовательно, наножидкость ятрофы может превзойти минеральное масло, если ее доработать.

Выводы: Два метода показали, что при смешивании растительного масла ятрофы с маслом нима и наночастицами достигается лучшая производительность энергетического оборудования, чем при использовании минерального масла. Считаем целесообразным провести дальнейшие анализы в области непосредственного применения ятрофы и наножидкостей нима в энергетическм оборудованим, с целью лучшего понимания общего поведения силовых установок и сравнения с ситуациями, когда используется обычное минеральное масло.

Ключевые слова: наножидкости, энергетическое оборудование, серый реляционный анализ, вероятностная оптимизация, растительное масло, диэлектрические свойства, изоляционные свойства.

ОДРЕЂИВАЊЕ ЕФИКАСНОГ УЉА ЗА ЕНЕРГЕТСКУ ОПРЕМУ КОРИШЋЕЊЕМ АНАЛИЗЕ ВИШЕКРИТЕРИЈУМСКОГ ОДЛУЧИВАЊА

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Сажетак:

Увод/циљ: Неколико студија из области развоја нанофлуида за енергетску опрему пропустило је да утврди које уље је најбоље међу уљима произведеним за примену у погонској опреми. Зато ова студија представља анализу вишекритеријумског одлучивања за одређивање најбољег уља погодног за енергетску опрему.