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Research Article

Experimental assessment of tio$_2$-poe nanolubricant stability and optimization process using one factor at a time (OFAT) based on response surface methodology

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ABSTRACT

This paper aims to elaborate on the results of the experimental assessment of the stability of TiO_2-Polyester (POE) nanolubricant. There are six samples in this investigation, with each concentration of 0.02 vol%. The TiO2 nanoparticles were dispersed into synthetic lubricant POE for 30 min using a magnetic stirrer. Then, the samples were sonicated for 0, 40, 60, 80, 100, and 120 min, respectively—the visual observation for 720 hours, UV visible spectrophotometry, and absolute zeta potential employed to investigate the samples. After data acquisition, optimization with one factor at a time (OFAT) is applied to determine the most optimum sample. The results show that the sample with sonication treatment for 120 min is the most optimum. This finding was confirmed by the absorbance ratio value of 0.95 with an -80.48mV zeta potential. The output of ANOVA analysis shows the regression coefficient is 0.9999, and the adjusted R^2 value is 0.9998 with a p-value that is much smaller than 0.05, which is <0.0001. These results demonstrate that sonication duration has a significant effect on increasing the stability of TiO_2-POE nanolubricant.

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INTRODUCTION

Nanofluid for heat transfer application was initially introduced by Choi [1]. Several researchers then worked on a new sub-class of nanofluids based on lubricants known as nanolubricants. Several studies have found that nanolubricants can ramp up heat transmission in heat transfer equipment. Air conditioning system equipment, engine lubricants, vacuum pump cooling lubricants, and automotive air conditioning systems can benefit from nanolubricant. In most of these systems, improving the thermal conductivity of the low lubricant is the first step in escalating the heat transmission rate. The addition of nanoparticles to the lubricant increases thermal conductivity because the nanoparticles are well dispersed into a colloid.

Kedzierski and Gong reported an increase in heat transfer of 12% by adding CuO to POE synthetic lubricants with a mass concentration of 2%. CuO was mixed on magnetic stirring and ultrasonically treated for 24 hours to make nanolubricants. The light scattering technique was used to determine the nanolubricant's stability. This method permits ultraviolet light to pass through the nanolubricant sample and absorb the nanolubricant's particles [2]. Zawawi et al. reported that dispersing Al_2O_3-SiO_2 to Polyalkylene Glycol (PAG 46) can increase the thermal conductivity of nanolubricant by 2.41% at 0.1 vol%. A two-step approach was used to make the Al_2O_3-SiO_2/PAG 46 nanolubricant. An ultrasonic bath is utilized to prevent nanolubricant aggregation and sedimentation. This Al_2O_3-SiO_2/PAG 46 nanolubricant is designed to be used in air conditioning systems in automobiles. Evidence suggests that Al_2O_3-SiO_2/PAG 46 nanolubricant should be used in automotive air conditioners at a concentration of less than 0.1 percent. [3]. Sharif et al. reported that using SiO_2/PAG nanolubricant in a car's air refrigeration system improved the system's performance. The work done and the power used by the compressor both decreased by 16.5 and 4%, respectively. The increase in heat transfer convection that occurred in the flow of refrigerant and lubricant in the air conditioning system and compressor pipes leads the compressor work and power consumption to decrease. As a result, by enhancing heat transfer convection in the refrigeration system, the application of SiO_2/PAG nanolubricant can improve compressor and refrigeration system performance. These data suggest that a nanolubricant with a concentration of 0.05 vol % be used to attain this value [4].

Regarding nanolubricant stability, Dhanola et al. [5] reported that Al_2O_3-SiO_2/PAG 46 nanolubricant is engineered to be used in air conditioning systems in vehicles. Evidence suggests that Al_2O_3-SiO_2/PAG 46 nanolubricant should be used in automotive air conditioners at a concentration of less than 0.1 %. After 30 storages, the zeta potential of the elements 1:2, 1:3, and 1:4 dropped by 41%, 20%, and 55%, respectively. Mahbubul et al. [6] reported that longer sonication effectively reduces nanoparticle sedimentation, resulting in more excellent nanofluid stability. With increased sonication duration, thermal conductivity increases while viscosity decreases. Nanoifluids' thermophysical characteristics will deteriorate as storage time increases. Thermal conductivity escalates as the duration of sonication surges. For a 5-hour sonication session, the maximum increase is around 3%. The sample's thermal conductivity reduced over time when preserved for 10, 20, and 30 days after it was prepared. Chen et al. [7] looked at how mixing time and sonication period affected the thermal conductivity and stability of aqua Al_2O_3/paraffin mixture. The results reveal that 3 hours 15 min is the best sonication time. The nanofluid stability did not change much when mixing time was reduced using magnetic stirring and sonication.

Adelekan et al. [8] reported that adding TiO_2 in a domestic refrigerator can elevate the coefficient of performance (COP) by 12%, hitting a maximum of 2.8 at a 40 g of refrigerant charge. Compared to mineral oil/LPG refrigerants, this enhancement in COP is attributable to amplify in the heat transmission rate in the refrigeration system, which stimulates an increase in cooling capacity.

This study determined the effectiveness of sonication period on the stability of the six TiO_2-POE nanolubricants sampling using visual observation for 720 hours, UV visible spectrophotometry, and absolute zeta potential. Then, using the one factor at a time (OFAT) method based on the Response Surface Method, the outcomes of the experimental assessment were used to determine the most optimum sample. The findings reveal that the duration of sonication has a significant response on the stability of TiO_2-POE nanolubricant.

Nanolubricant Preparation

For this study, Sigma-Aldrich in Saint Louis, Missouri, USA, produced TiO_2 nanoparticles in powder form with a typical particle size of 21 nm and a pureness of 99.5%, according to the manufacturer's specifications. The essential characteristics of TiO_2 nanoparticles are listed in Table 1. The nanoparticles are dispersed in a Polyolester (POE) lubricant to form a nanolubricant. The nanolubricant was synthesized employing a two-step method as noted by Sharif et al. [9] and Redhwan et al. [10]. The initial stage uses magnetic stirring to disperse TiO_2 nanoparticles into POE lubricant without heating, as noted by Ravisankar et al. [11] and Madani et al. [12]. An ultrasonic homogenizer UP400S manufactured by Hielscher Germany was used to sonicate the nanolubricant. The purpose of an ultrasonic homogenizer is based on the fact that it can deliver more energy than a traditional ultrasonic bath [13, 14]. As a result of the findings, the nanolubricant's homogeneity will be improved while the sonication duration is reduced [15, 16]. The use of an ultrasonic homogenizer is particularly effective in preventing nanolubricant agglomeration and sedimentation with the base fluid oil. Furthermore, Nabil

Table 1. Physical and thermal characteristics of TiO_2 nanoparticle

Properties	Metric
Morphology	Spherical shape
Molar mass	79.87 g/mol
Average diameter	21nm
Typical Color	White
Melting point	1,843 °C
Dielectric constant (1 MHz)	85
Thermal conductivity at 25 °C	11.7 Wm/K
Density	4 g/cm^3
Dielectric strength	4 kV/mm

Table 2. Characteristics of POE oil [19]

Properties	Value
Dynamic viscosity at 40 °C	70.1 mPas
Dynamic viscosity at 100 °C	9.1 mPas
Density at 15 °C	0.960 g/cm^3
Viscosity Index	105
Flash Point	252° C

et al. [17] and Yashawantha et al. [18] suggested using a Field Emission Scanning Electron Microscopy (FESEM) machine to characterize the geometry and physiology of dry TiO_2 nano powder.

The data for the ultrasonic device is 400 W, 24 kHz, 50% amplitude, and 0.5 cycles. Six samples were used in this study, all of which had the same concentration volume of 0.02 vol%. For samples 1, 2, 3, 4, 5, and 6, a 30-minute stirring with various sonication treatments was performed, namely 0, 40, 60, 80, 100, and 120 min for samples 1, 2, 3, 4, 5, and 6. In the results and discussion, each sample will be discussed in further detail. Figure 1 depicts a schematic of this process.

Under the SUNISO brand, a Belgian group corporation supplies POE lubricants. SUNISO is a Belgian group corporation. Table 2 lists the primary nature of POE lubricant.

Nanoparticle suspensions are found to be effective electromagnetic wave absorbers within UV–Visible wavelength ranges where 85% of solar energy is dissolved. While conventional base fluids absorb 15% of solar energy within infrared wavelength range, nanoparticles have unique thermal and optical properties which are the basis of thermal applications [1–3]. In the field of particle suspension, long term stability of suspended nanoparticles is the key for any thermal application which includes such type of suspensions [4].

Owing to the advancement in nanotechnology during the past 20 years or so, applications of nanoparticles in solar thermal systems have been proposed. Compared to larger particles, the suspension with nanoparticles exhibits better stability with unique performance. In addition, the clogging and fouling would be less significant for suspension with nanoparticles [5,6]. Absorption of light within the nanoparticle suspensions, largely by the nanoparticles, leads to a temperature rise in the suspensions that can then be exploited as thermal energy.

For that, the radiative properties of the suspended particles and the media that contains those particles should be investigated deeply. As there are many particles in a particulate medium, the scattered photon from a particle may interact with those from other particles. This means, an incident beam can be scattered more than one time and they can be scattered again by the nearby particles [7,8].

The potential of using nanoparticles in the direct absorption solar collectors was first proposed by Tyagi et al. [9], they compared the collectors' performance using water/Al nanofluid as the working media. The radiative properties of water/TiO_2 nanofluid were investigated by Said et al. [10], the transmissivity of the nanofluid was achieved up to 60% in the particle volume fraction 0.08%, and it was proven that the water/TiO_2 nanofluid is a good option for the direct absorption solar collectors. More recently, the radiative properties are measured for the different metal oxide nanoparticles under the effects of temperature and particle concentration [11,12]. Several nanofluids were prepared for this purpose, water based with metal oxide (TiO_2, Al_2O_3, ZnO, CuO, and Fe_2O_3) were investigated, and results conducted that the water/TiO2 nanofluid with 0.05% volume fraction required minimum pumping power and show good radiative properties.

Through the analysis of the optical and thermal behavior of particulate media, it is clear that photo-thermal energy conversion is important to not only the solar thermal systems but also to the electric power generation and solar chemical technology. This research investigates the effects of nanoparticle suspensions (water/TiO_2 nanoparticle suspension) at different particle concentrations on the radiative properties and radiative transfer phenomena. The effect and contribution of the TiO_2 nanoparticles on the radiative properties in the UV-Vis-NIR wavelength ranges are observed, which have a significant impact for the solar thermal applications.

Nanolubricant preparation is divided into three steps. In the first phase, the needed lubricant and nanoparticle mass are calculated. The volume fraction ratio of nanoparticles to lubricants is determined using Equation 1. [12][20].

$$\phi = \frac{m_p / \rho_p}{m_p / \rho_p + m_l / \rho_l} \times 100\% \quad (1)$$

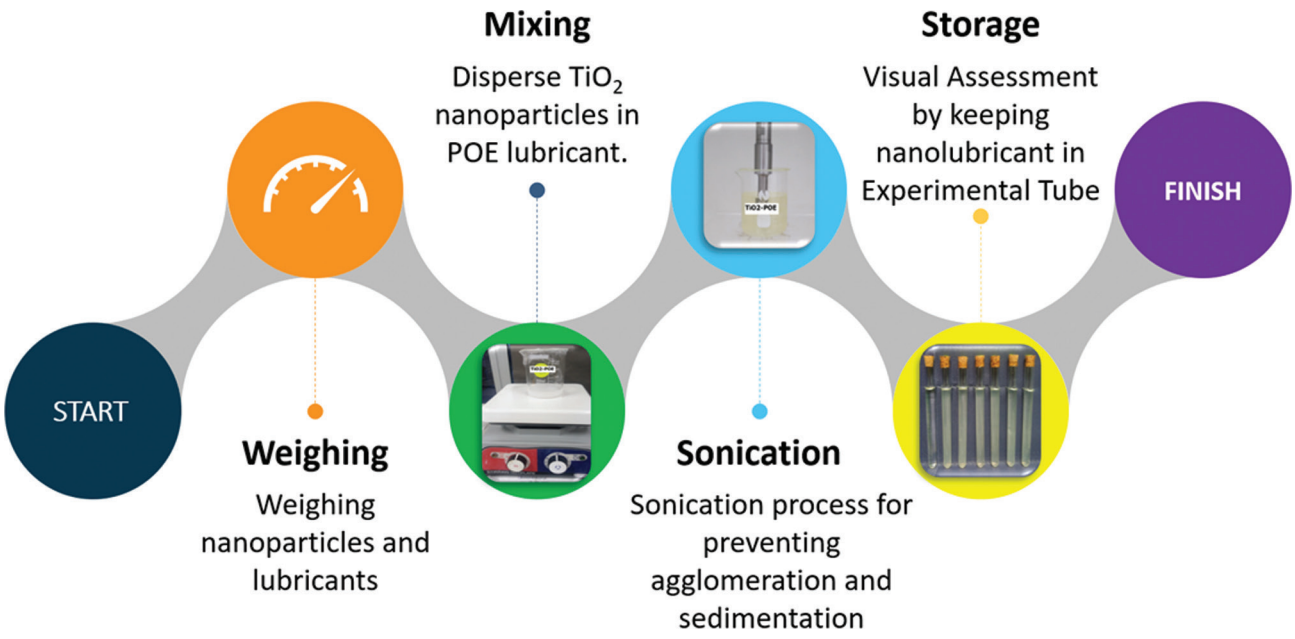

Figure 1. Schematic diagram of TiO_2-POE nanolubricants preparation using a two-step method.

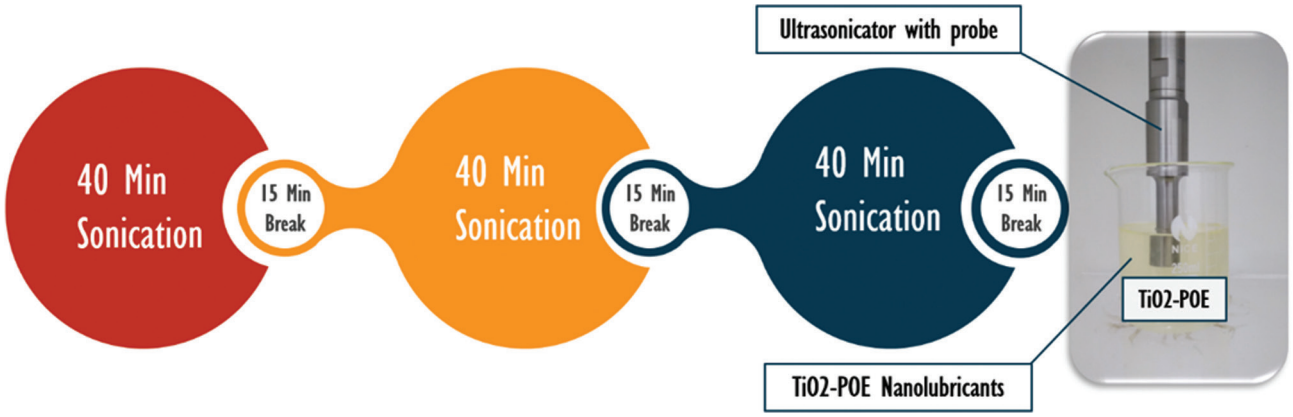

Figure 2. Interlude sonication method graphic.

Where Ø is the nanoparticle volume fraction %; m_p is the TiO_2 nano powder's mass; m_l is the lubricant mass; ρ_n is density of TiO_2 nano powder; and ρ_l is POE lubricant's density. Figure 1 depicts the flow of the two-step nanolubricant preparation process. After the weighing process, the nanoparticles are mixed in the lubricant with a magnetic stirrer. The formed nanolubricant is next subjected to a sonication process for a predetermined period.

In contrast to other types of nanofluid preparation, the TiO_2-POE nanolubricant is synthesized using an interlude sonication process. This interlude sonication technique is a staged sonication technique in which the sonication process is repeated every 40 min with a 15-min break before repeating the process for the next 40 min. The 15-min time is intended to achieve a soaking action between the POE lubricant and the nanoparticles. This immersion will increase the nanoparticles' wettability, as noted by Anssari et al. [21] and [22], resulting in a more vital interaction between the TiO_2 nanoparticle molecules and the lubricant. Furthermore, the 15 min pause allows the nanolubricant to naturally decline the temperature, preventing the connection between the TiO_2 nanoparticles and the lubricant from being destroyed, as shown in Figure 2.

Nanolubricant Stability Analysis

The straight visual approach, measuring the absorbance value with a spectrophotometer, and measuring the absolute value of the zeta potential was applied to persuade the

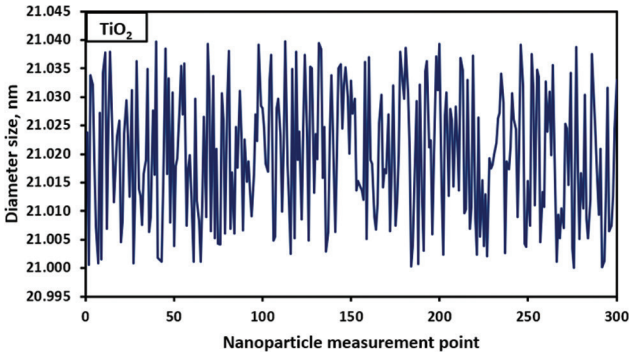

Figure 3. TiO_2 Nanoparticles diameter size distribution.

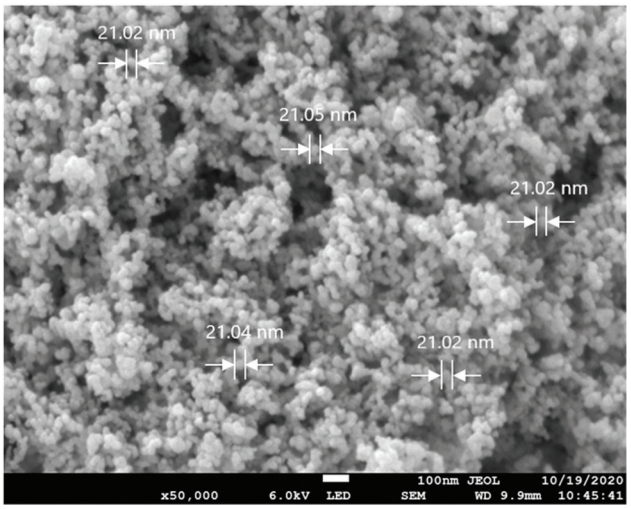

Figure 4. TiO_2 Nanoparticles morphology in 50,000 magnifications.

stability of the TiO_2-POE nanolubricant. These three assessments are linked together as done by previous researchers [23-25]. The goal of visual assessment is to detect the sedimentation and agglomeration of the formed nanolubricant visually. Ultraviolet-visible spectroscopy will be used to confirm the results of the visual examination. The absorbance ratio of the nanolubricant that was measured on the first day when the nanolubricant was synthesized is used to persuade the value of Ultraviolet-visible spectroscopy. The absorbance ratio was measured over 360 hours. The absolute zeta potential assessment results will confirm the highest absorbance ratio value results, as noted by Graves et al. [26].

Statistical Analysis of Data and Optimization Process

All of the tests were done three times, and the outcomes were recorded as mean amount. The experimental design's independent variables were optimized and evaluated using Design-Expert software. The model was statistically analyzed using the analysis of variance method (ANOVA). The R^2 coefficient and the adjusted R^2 coefficient were used to assess the superiority of the fit of the polynomial model equivalence, and the numerical and regression coefficient significance was validated using the F-test and p-value, respectively [27, 28].

The optimization procedure determines which sample has the best or most optimal value. In this study, the optimal parameter in the optimization process is to maximize the response in the form of the absorbance ratio of the components influencing the response. The goal of figuring out this optimization is to help reduce the number of experiments while increasing the response output [29].

RESULT AND DISCUSSION

TiO_2 Nanoparticle Characterization

Field Emission Scanning Electron Microscopy (FESEM) was employed to characterize TiO_2 nanoparticles. FESEM JSM-7800F from JEOL Ltd was used to confirm the physiology, dimension, and form of TiO_2 nanoparticles. The graph was acquired with a magnification setting of 50,000x and an LED mode of 7.0 kV. Particle size analysis was performed using Image J software, which was utilized to evaluate and validate the nanoparticle distribution over all ranges and average diameters as suggested by previous researchers [30-33].

Figure 4 depicts the diameter distribution of TiO_2 nanoparticles. TiO_2 nanoparticles have an average grain size of 21.12 nm, according to the data. This finding matches the manufacturer's specification. Figure 1 displays a FESEM image of dry TiO_2 nanoparticles supplied by the manufacturer, illustrating the distribution and morphology of the nanoparticles. The particles are spherical. As can be observed, the particles are in the shape of aggregates or agglomerates. These agglomerates or agglomerates must be broken down during the nanolubricant processing to achieve a stable nanolubricant. The stability of TiO_2-POE nanolubricant will be discussed in depth in the following section.

TiO_2-POE Nanolubricant Visual Analysis

The first step in verifying the stability of TiO_2-POE nanolubricant is a visual examination. The findings of 720 hours of observations are depicted in Figure 5. The first visible observations were made on the first day of making the nanolubricant, and the last visual observations were made on day 30. Figure 5(a) depicts the nanolubricant after it had been prepared on the observation tube. The six nanolubricant tubes, from left to right, exhibit nanolubricant samples that were sonicated for 0, 40, 60, 80, 100, and 120 min. All of the samples had equally distributed nanoparticles in the POE lubricant. There was no evidence of agglomeration or sedimentation in any of the samples at this stage. This phenomenon suggests that each sample has generated nanolubricant homogeneity.

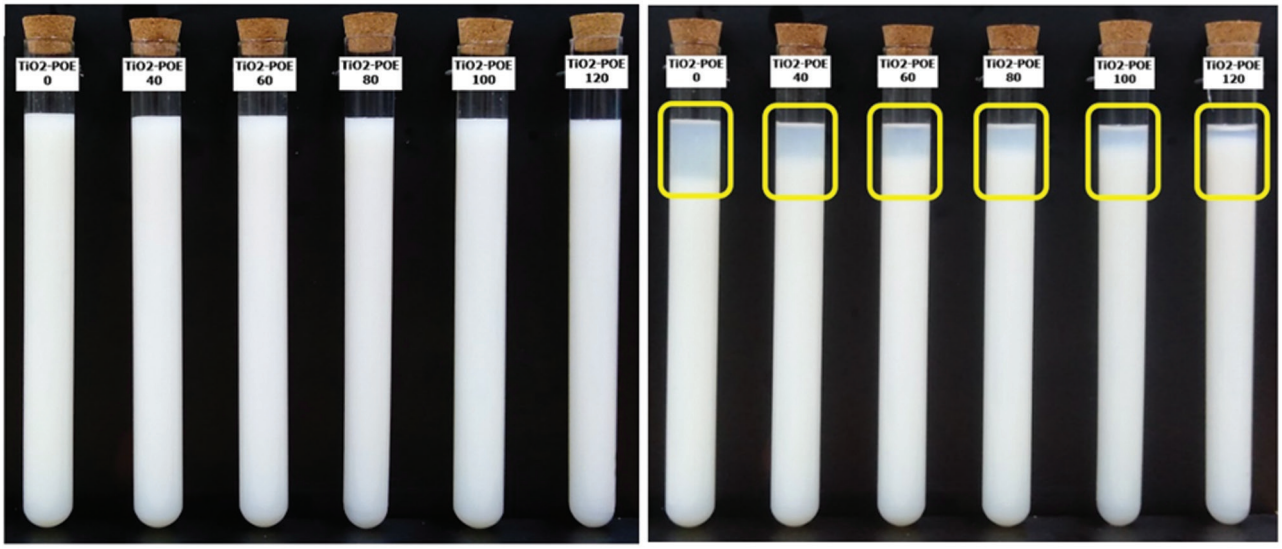

Figure 5. TiO_2-POE nanolubricant visual observation comparison (a) day 1 and (b) day 30.

Figure 5(b) shows the results of observations on day 30 after the nanolubricant had been in the observation tube for 720 hours. The nanolubricant sample that was not subjected to sonication suffered more damage, as demonstrated by sedimentation at the observation tube, as shown in yellow square in the figure. This phenomenon suggests that the nanolubricant is agglomerated to a great degree. The aggregation of the nanolubricant will facilitate sedimentation, as reported by Sharif et al. [34]. Two primary causative variables cause this phenomenon. The van der Waals force, which promotes amplification between nanoparticle molecules, is the first factor. The second factor is the concentration of the nano powder, which is superior than that of the lubricant, leading the nanoparticles to always fall to the tube's bottom due to gravitational forces. The sedimentation process in the nanolubricant sample will be accelerated due to the augmentation of these nanoparticles, as noted by Ali et al. [35].

The second sample was the one that was subjected to a 40-min sonication treatment. Although there is a significant drop in this sample, it is still apparent that part of the nanolubricant near the tube's bottom is in a more stable state. The sonication effect is responsible for this phenomenon. Nanoparticle particles break apart and run apart as they are augmented and clustered together, breaking their ties. The higher the level of augmentation in the nanolubricant, the greater the agglomeration that happens, putting the nanolubricant's sedimentation obvious visually.

The TiO_2-POE 0 graph, as shown in Figure 6(a), is a nanolubricant sample that has not been subjected to a sonication process. The wave spectral has fluctuated along the wavelength since the scanning measurement commencement. This finding demonstrates that agglomeration is widespread across the nanolubricant region. Figure 6(b) shows the same result, with no decrease in agglomeration but an increase in the number of graph spectrums. At the 410 nm wavelength, the comparison between absorbance measurements on the 1st and 30th days was determined.

TiO_2-POE Nanolubricant Absorbance Analysis

The amount of light that the sample can absorb in the cell cuvette is quantified by absorbance. The density of the nanolubricant sample is closely connected to absorbance. Technically, the light source emits a specified amount of UV light throughout the sample. The sample absorbs the light in the cell cuvette, and the results of the light absorption measurement with absorbance units will be presented on display.

A 3 ml sample of TiO_2-POE nanolubricant was inserted in each quartz cuvette cell for this experiment. In addition, the cuvette cell sample is inserted into the UV visible spectrophotometry slot, which has a measuring range of 1000-200 nm. When comparing the absorbance measurement findings from day 1 to day 30, it can be seen that all samples have a declining trend, as formerly done by Nugroho et al. [19] and Hou et al. [36]. The sample's comparison point is taken at 410nm, where a significant absorbance level has been attained by marking the curve's height on the graph of the absorbance measurement findings in all samples.

Figure 6 depicts the absorbance measurement results for all samples evaluated on day 1 and day 30. Both images indicate that UV light has efficiently absorbed the nanoparticles in the nanolubricant sample using UV visible spectrophotometry. This phenomenon is demonstrated by the findings of the scanning spectrum from 300-1000 nm. The two plots show several oscillating spectrum peaks. The peak

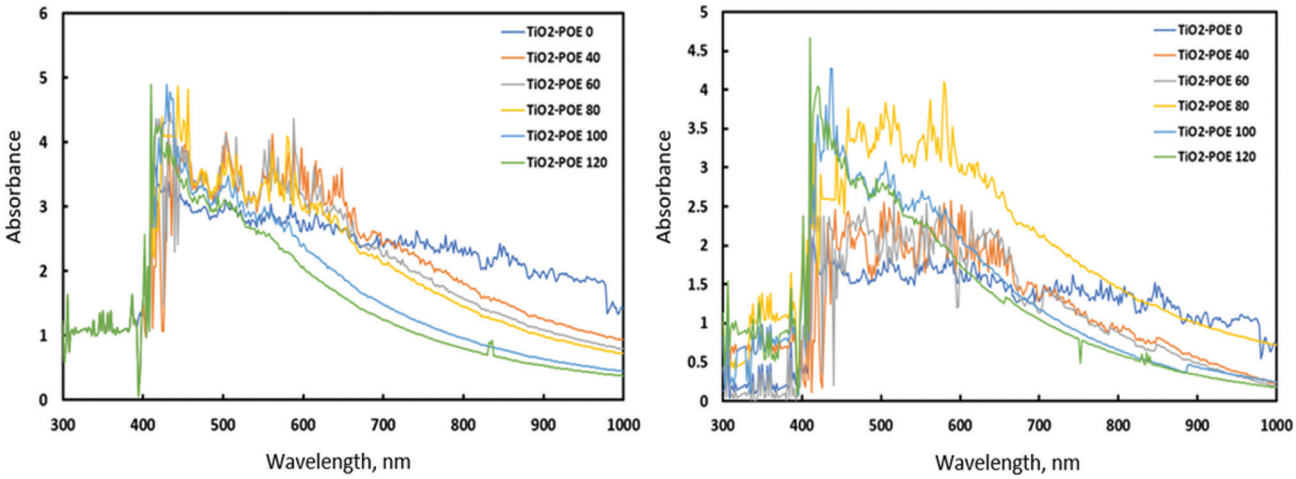

Figure 6. TiO_2-POE nanolubricant absorbance value comparison (a) day 1 and (b) day 30 from all samples.

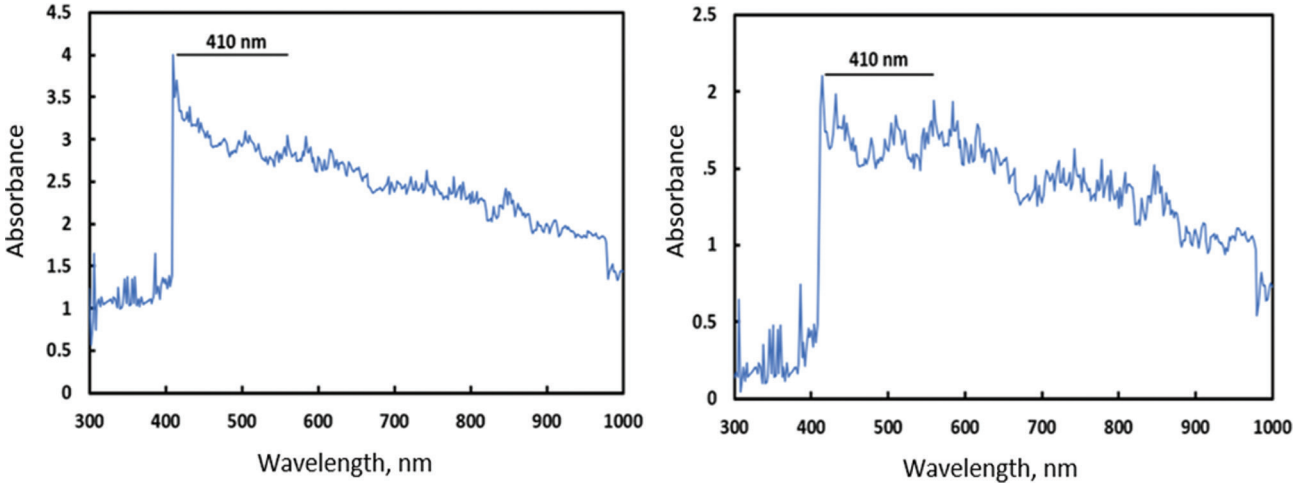

Figure 7. TiO_2-POE nanolubricant absorbance value comparison (a) day 1 and (b) day 30 from sample 1 with 0 min ultrasonication treatment.

of the spectrum depicts the addition of nanoparticles to the nanolubricant. The addition of nanoparticles to the nanolubricant sample promotes the production of agglomerates. Figures 6(a) and 6(b) show that nanoparticle augmentation is expanding in all samples. The increasing number of spectral peaks evidences this.

$$\bar{A}_r = \frac{A}{A_0} \tag{2}$$

The comparison of absorbance values in sample 1 is shown in Figure 7. The nanolubricant in sample 1 was made using simply a magnetic stirrer for 30 min, with no ultrasonication treatment. Figure 7(a) shows that, despite the nanolubricant being just prepared, several nanoparticle augmentations can be observed clearly from 1000 to 300 nm. The augmentation of nanoparticles is still visible and increases up to the point of 410 nm. There is a significant drop following that, followed by the same nanoparticle enhancement as before. Because the nanoparticles are not entirely dispersed in the lubricant, nanoparticle augmentation occurs in all regions of the lubricant [37].

The nanoparticles' Van der Walls force leads the TiO_2 nanoparticles to link together. The dipoles of the TiO_2 nanoparticle molecules provide the Van der Waals force for this nanolubricant. The electron distribution in the molecule creates the dipole. Molecules with high concentration levels become negative dipoles, allowing them to attract molecules with low concentration levels, such as molecules with positive dipoles and non-charged dipoles. This process

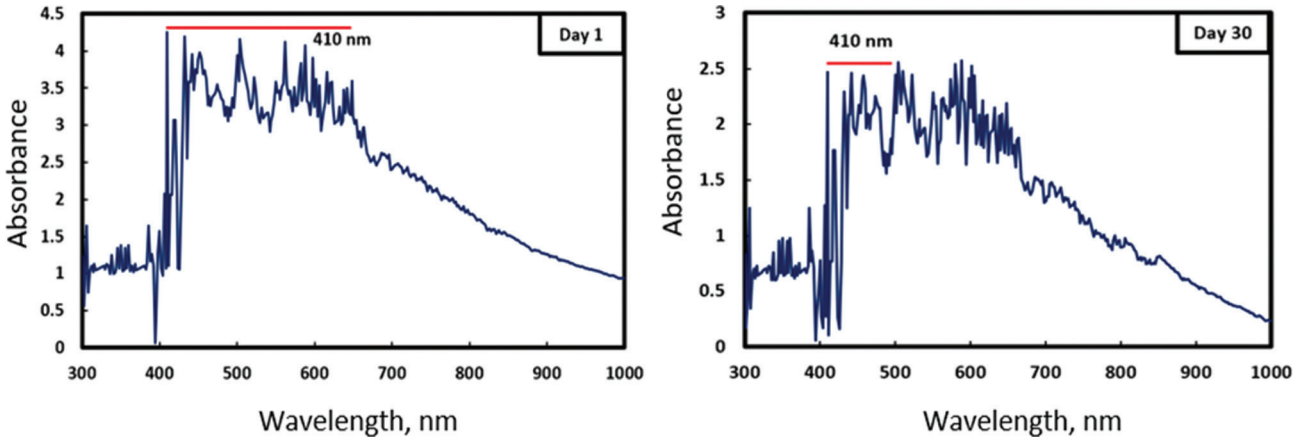

Figure 8. TiO_2-POE nanolubricant absorbance value comparison (a) day 1 and (b) day 30 from sample 2 with 40 min ultrasonication treatment.

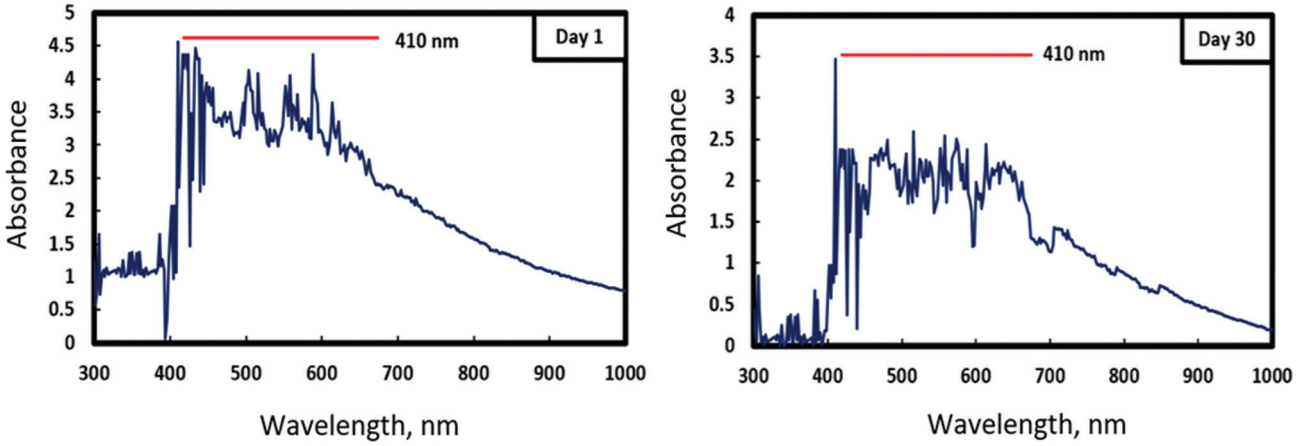

Figure 9. TiO_2-POE nanolubricant absorbance value comparison (a) day 1 and (b) day 30 from sample 3 with 60 min ultrasonication treatment.

is ongoing in the nanolubricant area, which contains the nanoparticles. As a result, the Van der Waals effect can be defined as the fusion of multiple nanoparticle molecules, resulting in an agglomeration as investigated by Tiwari et al. [38] and Sarsam et al. [39].

The 410 nm point was used as a reference to measure the rate of reduction in the absorbance value over time, as shown in Figure 7. The absorbance ratio value may be calculated based on this observation to estimate the stability level of TiO_2-POE nanolubricant as suggested by Zawawi et al. [40]. The initial absorbance (A) is compared to the final absorbance (A_o) produced by equation 2 to determine the absorbance ratio ($\bar{A}_r$). Figures 8, 9, 10, and 11 show the effect of ultrasonication duration on the absorbance value of samples 2, 3, 4, and 5 after ultrasonication treatment for 40, 60, 80, and 100 min, respectively. In general, absorbance values on the 30th day are decreasing when compared to the first day. This decrease is due to the formation of agglomerates from aggregated nanoparticles. The agglomeration's gravitational force promotes the sedimentation of the nanolubricant.

Figure 11 compares the absorbance values of sample 6 on day 1 and day 30. On the first day, the nanoparticles were well dispersed in the lubricant. The spectrum begins to fluctuate around 550 nm and reaches its highest peak point at 410 nm with a value of 4,905 in Figure 11(a). The spectral peak at 411 nm drops to 300 nm, a significant decrease. The presence of agglomerates at each spectral peak in the 1000-300 nm region is demonstrated by this phenomenon.

A spectral pattern in Figure 11(b) is comparable to the spectrum pattern on the absorbance data in Figure 11(b). However, the findings of UV visible spectrophotometry tests in Figure 8(b) show agglomeration at multiple spots along the 850-650 nm area, a drop in the spectral peak at

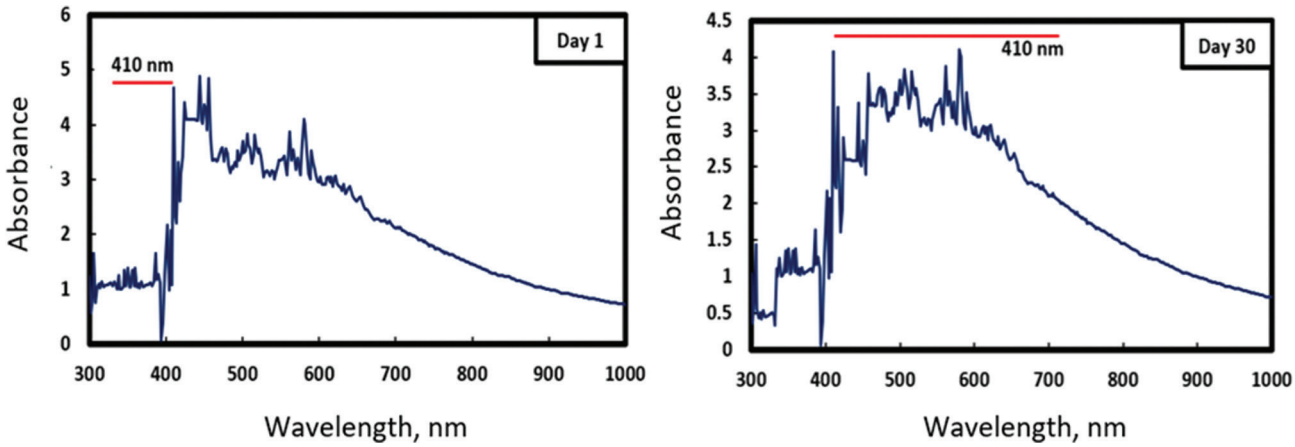

Figure 10. TiO_2-POE nanolubricant absorbance value comparison (a) day 1 and (b) day 30 from sample 4 with 80 min ultrasonication treatment.

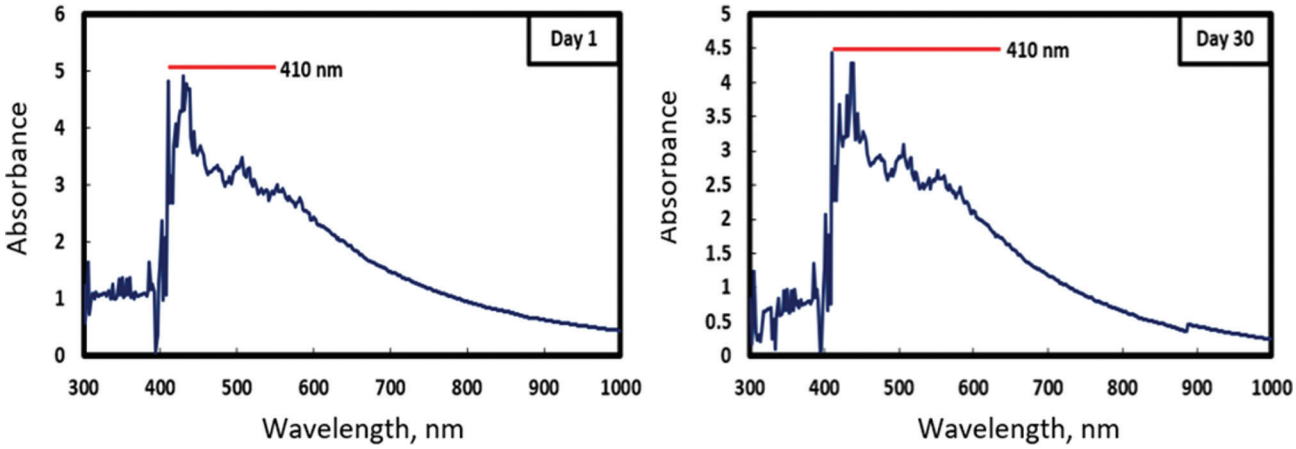

Figure 10. TiO_2-POE nanolubricant absorbance value comparison (a) day 1 and (b) day 30 from sample 5 with 100 min ultrasonication treatment.

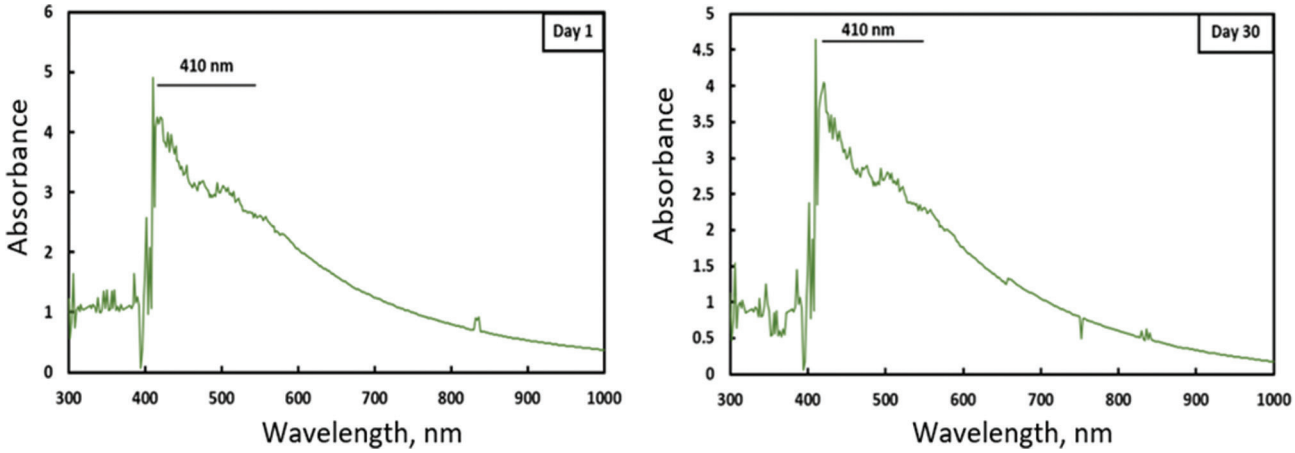

Figure 11. TiO_2-POE nanolubricant absorbance value comparison (a) day 1 and (b) day 30 from sample 6 with 120 min ultrasonication treatment.

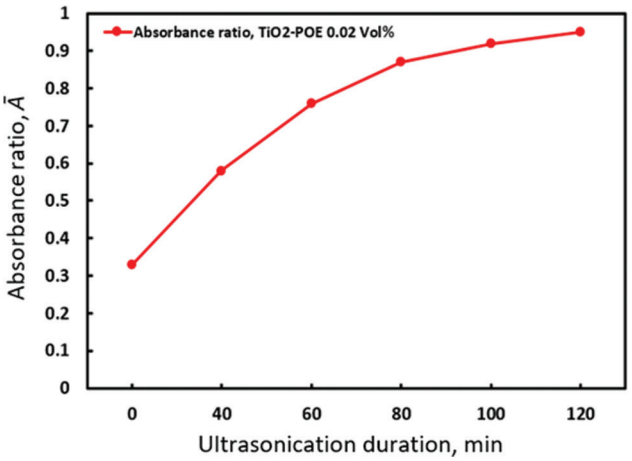

Figure 12. TiO_2-POE nanolubricant absorbance ratio as a dependent of ultrasonication duration.

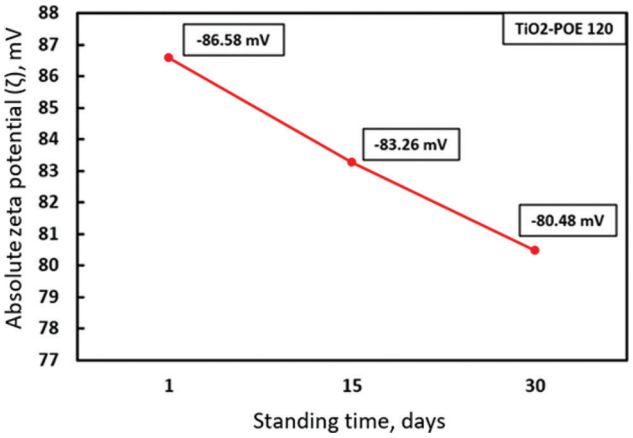

Figure 13. TiO_2-POE nanolubricant absolute zeta potential from sample 6.

410 nm to 4,648 nm, and spectral peaks, which are more volatile in the range of 411 – 300 nm.

This occurrence makes sense because the experiment was conducted on the 30th day when many nanoparticles were augmented and generated agglomeration at multiple nanolubricant regions [41]. Although there were new agglomerations at a few spots and a drop in the spectral peak in the 410 nm area, the absorbance value at that point did not change much. As a result, sample 6 is the one with the most negligible absorbance reduction value.

The duration of the nanolubricant's sonication treatment leads to an increase in the absorbance ratio, as shown in Figure 12. The sampling with the longest sonication period, 120 min, had the most excellent absorbance ratio value, 0.95, whereas the sampling with the shortest sonication period, 100 min, had a slightly lower absorbance ratio value, 0.92. This graph shows how sonication can prevent agglomeration and sedimentation in nanolubricant. As a result, the nanolubricant's stability can be obtained by applying the sonication treatment to the nanolubricant for the appropriate amount of time. The optimum sonication duration for achieving the best level of stability for TiO_2-POE nanolubricant was 120 min in this investigation.

TiO_2-POE Nanolubricant Zeta Potential Analysis

The goal of the zeta potential measurement on TiO_2-POE nanolubricant is to determine the sample's stability. The zeta potential is a significant degree of the stability of the nanolubricant dispersion because it determines the potential variance amid the dispersing medium and the steady fluid layer linked to the dispersed particles.

Figure 13 shows the absolute value of the TiO_2-POE sample's zeta potential after a 120-min ultrasonication treatment. On days 1, 15, and 30, the absolute zeta potential value was -80.48 mV, -83.26 mV, and -80.48 mV, respectively. According to the graph, the absolute zeta potential value decreases as sample storage duration increases. However, the resulting decrease in the absolute value of the zeta potential is modest. Mahbubul et al. [42] noted that nanofluids with an absolute zeta potential of -80.48mV are classed as excellent nanofluids, which have excellent of stability because they are in the -60 to -100 mV range. The surface charge of TiO_2 nano powder s is indicated by the negative absolute zeta potential of TiO_2-POE nanolubricant [43-45].

One Factor at A Time (OFAT)

This OFAT optimization technique aims to discover the optimum factor for the intended response as [46-49]. The parameters and constraints used in the response surface optimization process employing OFAT are indexed in Table 3.

In this investigation, the sonication duration compared to the absorbance ratio value is one measure of the nanolubricant's stability level. The original design type is designed with 11 runs, and this table consists of three primary components that explain the types of tests performed. The next step is to determine the detail factor, the sonication duration, which can range from 40 to 120 min. The absorbance ratio, which ranges from 0.58 to 0.95, is the dependent variable in this study. The absorbance ratio obtained a mean of 1.63793 with a standard deviation of 0.132157 based on the experimental data. The cubic model is the one that OFAT recommends.

Analysis of variance (ANOVA)

The statistical results based on ANOVA are presented in Table 4 and Table 5. The model is significant since it has a p-value of 0.0001, less than 0.05, and an F-value of 1179.53 and 18200.55. The F-value and p-values were also used to determine the significance of each component. The more significant the relevant coefficient term is, the bigger the degree of the F-value and the lower the p-value is. The

Table 3. OFAT outline

Subject	Response surface
Initial design	Quadratic
Runs	11
Factor	Sonication duration
Unit	Min
Low Actual	40.00
High Actual	120.00
Mean	80.00
Std. Dev	25.584
Response	Absorbance ratio
Unit	Abs. unit
Analysis	Polynomial
Min	0.58
Max	0.95
Mean	0.826364
Standard Deviation	0.132157
Model	Cubic

A-sonication time, A^2, and A^3 model terms were significant in this scenario, with F values of 2007.13, 7795.45, and 86.85 for each model as stated in Table 5, respectively.

According to Table 6, the duration of sonication has a substantial impact on the absorbance ratio. This number is confirmed by the correlation coefficient of regression (R^2) of 0.9989 in day 15th and 0.9999 in day 30th, which perfectly agrees with the adjusted R^2 of 0.9983 and 0.9998 respectively. These models have a high level of replication, which ensures that the results are accurate and dependable. A shallow pure error value of 0.000 indicates this.

Figures 14a and 14b show the adequacy of the regression model estimated by residuals and residuals versus predicted plots. The experimental and predictive points are collected near the normality line, as shown in Fig. 14a, confirming the analytical system's consistency. In contrast, as shown in Fig. 14b, is a randomly distributed residue across the baseline with no perceptible trend. Figure 14c. confirms the predicted value's closeness to the true value as reported by [28]. As a result of the three plots, it is possible to conclude that the cubic-square equation model is reliable enough to

Table 4. Analysis of variance (ANOVA) for absorbance ratio in Day 15th

Source	Sum of Squares	df	Mean Square	F value	p-value prob > F	Remark
Model	0.042	2	0.021	1779.53	<0.0001	Significant
A-Sonication Duration	0.041	1	0.041	3471.59	<0.0001	
A^2	1.035E-003	1	1.035E-003	87.46	0.0007	
Residual	4.734E-005	4	1.184E-005			
Lack of Fit	2.239E-005	2	2.367E-005			
Pure Error	0.000	2	0.000			
Car Total	0.042	6				

Table 5. Analysis of variance (ANOVA) for absorbance ratio in Day 30th

Source	Sum of Squares	df	Mean Square	F value	p-value prob > F	Remark
Model	0.17	3	0.058	18200.55	<0.0001	Significant
A-Sonication Duration	6.419E-003	1	6.419E-003	2007.13	<0.0001	
A^2	0.025	1	0.025	7795.45	<0.0001	
A^3	2.778E-004	1	2.778E-004	86.85	0.0005	
Residual	2.239E-005	7	3.198E-006			
Lack of Fit	2.239E-005	1	2.239E-005			
Pure Error	0.000	6	0.000			
Car Total	0.17	10				

Table 6. Coefficient of regression

Parameters	Ultrasonication duration standing time		Wavelength	
	Day 15th	Day 30th	Day 15th	Day 30th
Standard deviation	3.440E-003	1.788E-003	0.036	0.043
Mean	0.89	0.83	0.81	0.72
CV %	0.39	0.22	4.66	5.98
Press	1.340E-004	1.204E-004	0.014	0.021
R-Squared	0.9989	0.9999	0.9155	0.9614
Adjusted R^2	0.9983	0.9998	0.8733	0.9421
Prediction R^2	0.9968	0.9993	0.7696	0.8876
Adequate Precision	84.855	343.091	9.570	14.896

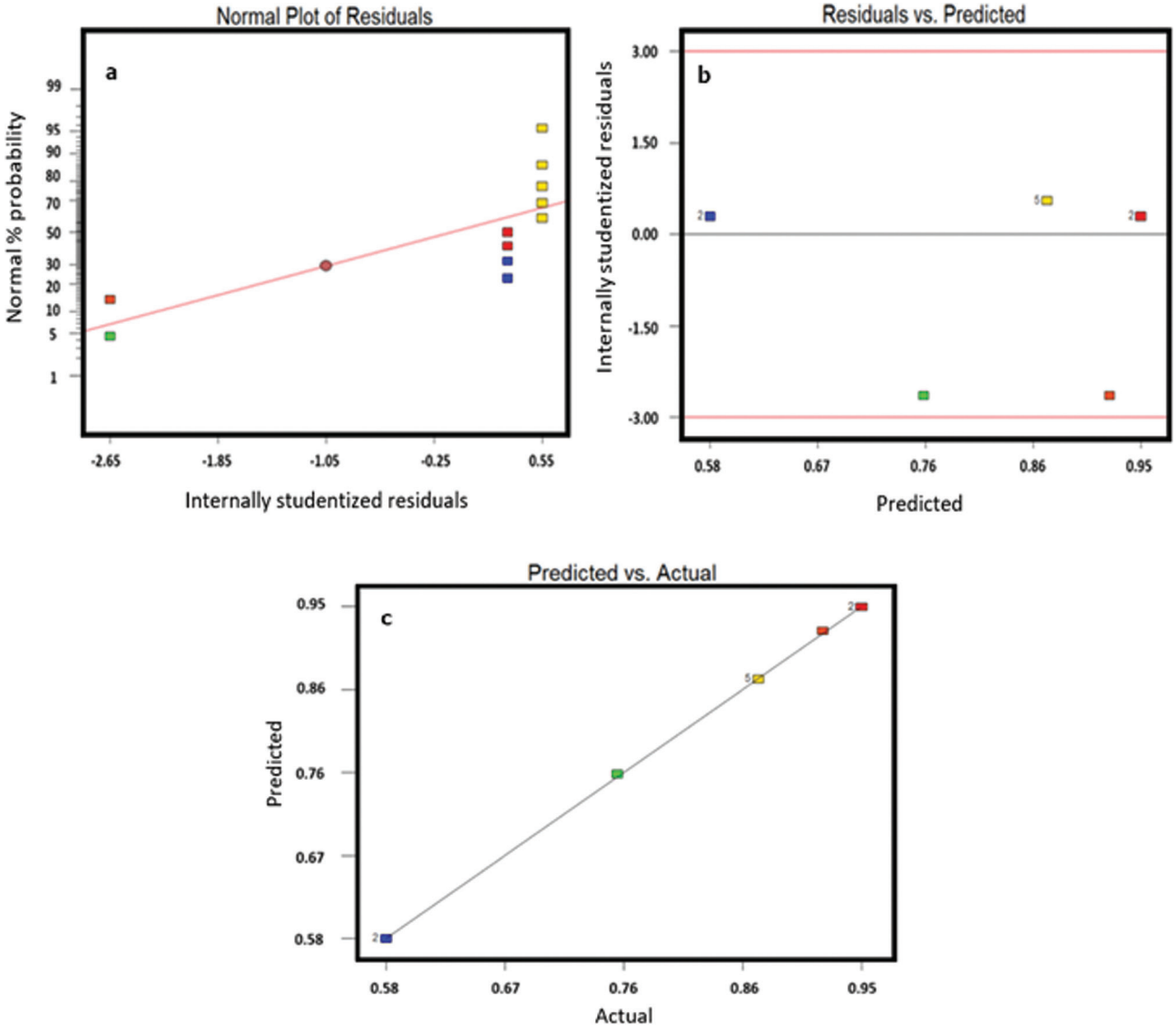

Figure 14. (a) Normal plot of residuals; correlation (b) amid residuals and predicted plot; (c) predicted and the present work findings plot.

establish a relationship between the effect of ultrasonication duration on the absorbance ratio.

R^2 has a high value due to the high accuracy of measurements made during the experimental process. Data measurements were performed three times to ensure the data's level of reliability and consistency, as suggested by Bahiraei et al. [50]. The use of a quartz cuvette allows for repeated data collection on the spectrophotometer without compromising the accuracy of the measurement results. These models are very close to the standing times of 15 and 30 days, demonstrating that the duration of ultrasonication has a significant effect on the absorbance ratio value in each sample. The coefficient of multiple determination (R^2 = 0.9989 and 0.9999 in the absorbance ratio model) and the second value of large R^2 indicate that the cubic model can reflect 99.89% and 99.99% of the total variation, respectively. As reported by Hemmat Esfe et al.[51] and Meybodi et al. [52], R^2 values close to 1 indicate a suitable model

Table 7. Uncertainty

Description	Absorbance ratio		Wavelength	
	Day 15th	Day 30th	Day 15th	Day 30th
Uncertainty	± 0.07	± 0.09	± 0.04	± 0.07

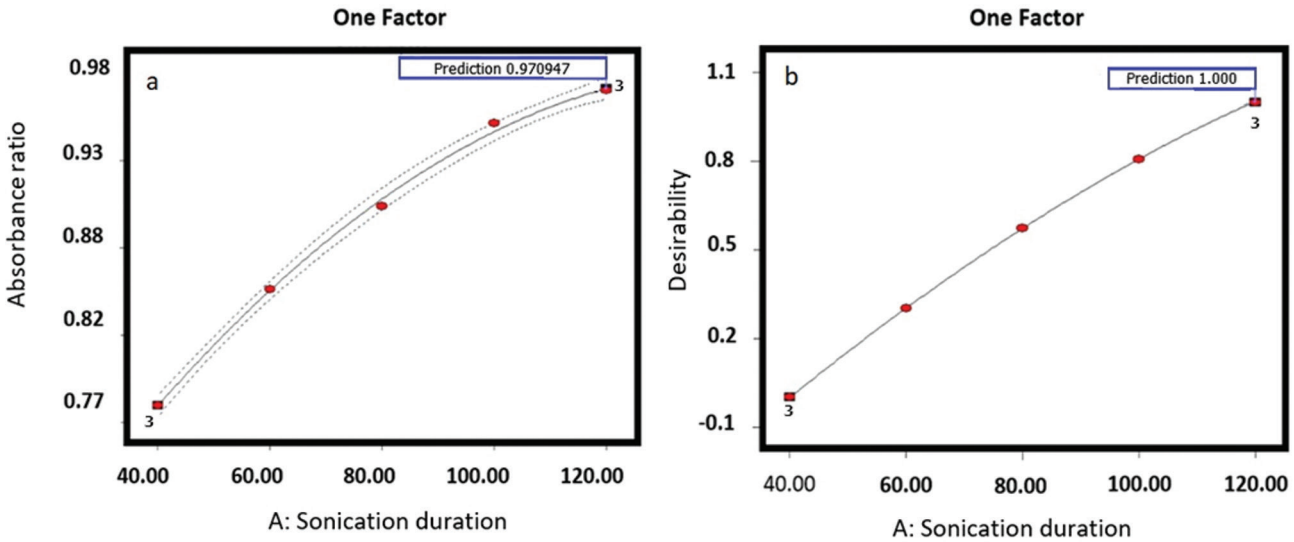

Figure 15. Plot of (a) absorbance ratio as the dependent of sonication and (b) desirability in a one factor at a time in day 15th.

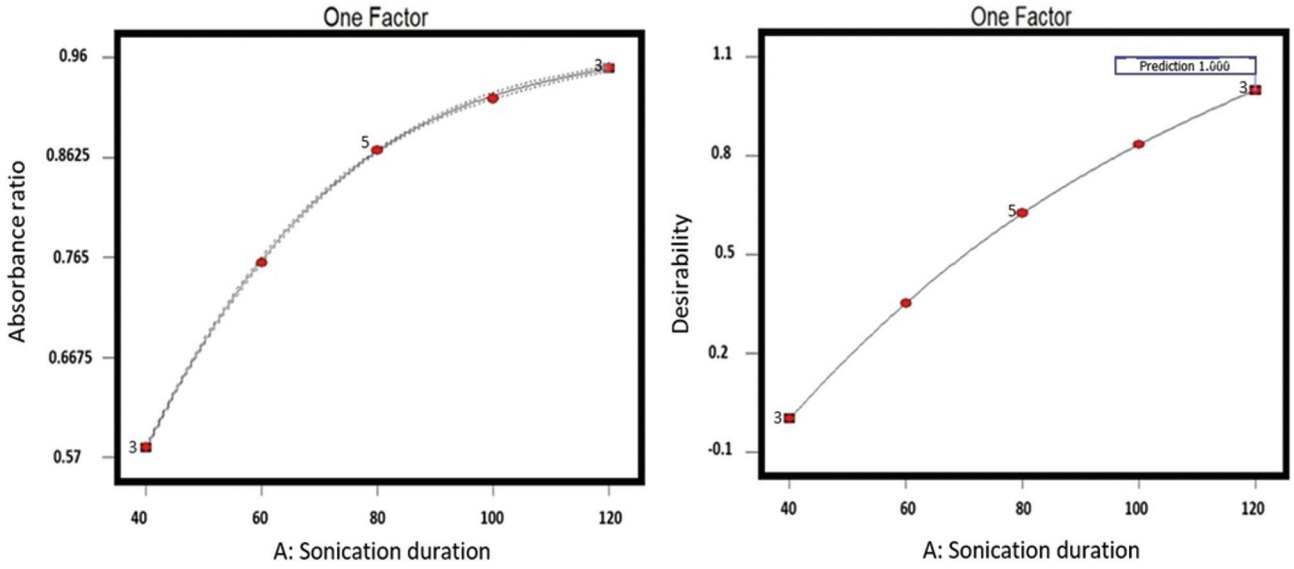

Figure 16. Plot of (a) absorbance ratio as the dependent of sonication and (b) desirability in a one factor at a time in day 30th.

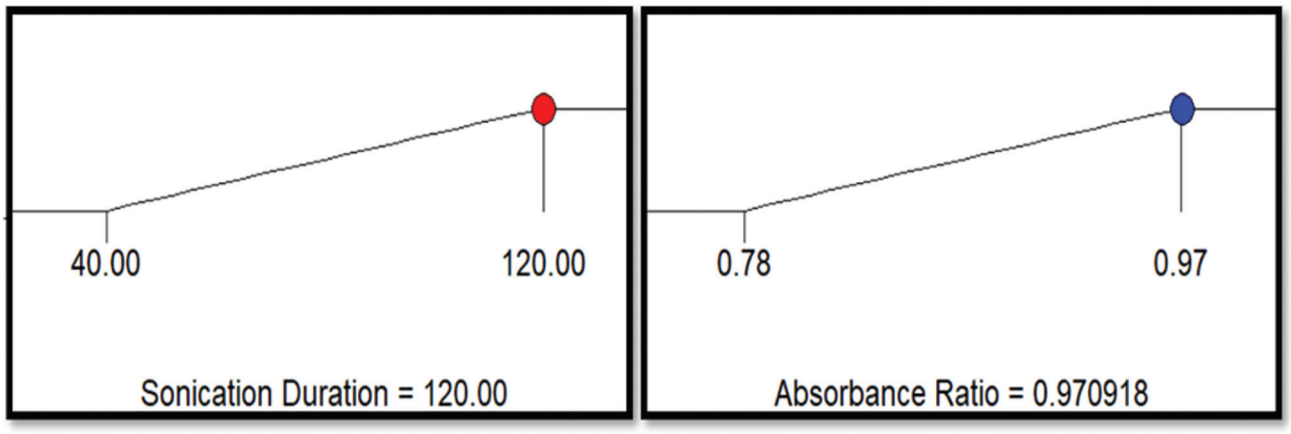

Figure 17. Plot of Ramps plot solution of OFAT in day 15th.

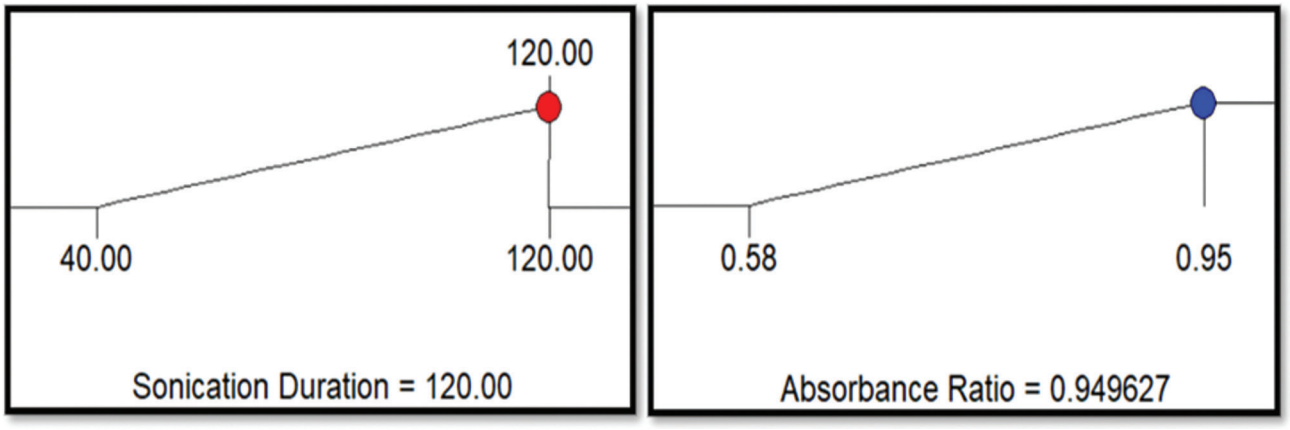

Figure 18. Plot of Ramps plot solution of OFAT in day 30th.

based on reliable and consistent data and very low error. However, the uncertainty has been calculated to quantity the error in this measurement as shows in Table 7.

Solution

Figure 16 (a) depicts the relationship between absorbance ratio and sonication duration. The sonication period of 120 min is the peak point for the maximum absorbance ratio value, as seen in the graph. The absorbance ratio at the sonication duration points of 100 min, on the other hand, is only slightly different from the absorbance ratio at the sonication duration point of 120 min. If the treatment is prolonged for longer than 120 min, the absorbance ratio may begin to decline. The findings are consistent with what has been published in the literature [53-56].

CONCLUSION

Several key points can be concluded based on experimental evaluation and process optimization employing one factor at a time:

Visual inspection, UV Visible spectrophotometry, and zeta potential were adopted to investigate the stability of TiO2-POE in an experimental setting. The outcomes of these three methods all verify each other. Sample 6 has the least amount of sedimentation during 720 hours when compared to the other samples. This result is confirmed by the fact that sample 6 has the highest absorbance ratio of 0.95 compared to the other samples. On day 1, day 15, and day 30, absolute zeta potential values of -86.58, -83.26, and -80.48 mV were used to validate the results of the absorbance ratio in this sample. Because it has an absolute value of zeta potential in the range of 60-100 mV, this finding classifies the TiO2-POE nanolubricant in sample 6 as a nanolubricant with an excellent level of stability.

The final model utilized in the OFAT analysis was a significant model using analysis of variance (ANOVA). The p-value, which is substantially smaller than 0.05 and is 0.0001, demonstrates this. R^2 are 0.9989 and 0.9999, and the adjusted R^2 value are 0.9983 and 0.9998 respectively,

according to the regression coefficient determined by the analysis of variance. The cubic vs. quadratic model is the best fit for this investigation since it can replicate data reliably and accurately. The absorbance ratios on days 15 and 30 were 0.970918 and 0.949627, respectively. As a result of the uncertainty calculation, these values fall between 0.970918 ± 0.07 and 0.949627 ± 0.09.

Based on OFAT analysis, sample 6 TiO_2-POE nanolubricant is recommended as the ideal sample since it has the most excellent absorbance ratio value of 0.95 with a desirability level of 0.999. Further visual, UV visible spectrophotometry, and absolute zeta potential assessment are recommended to be executed for a more extended period for instance, 1440 or 2160 h, to determine the most extended stability of TiO_2-POE nanolubricant

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NOMENCLATURE

min	Minute
abs	Absorbance
OFAT	One factor at a time
Std. Dev	Standard deviation
POE	Polyolester
Anova	Analysis of variance
UV	Ultraviolet
A	Initial Absorbance
A_o	Final Absorbance
$\bar{A}_r$	Absorbance Ratio

Greek symbols

ζ	Absolute zeta potential, mV
Ø	Concentration
P	Density

Subscripts

l	Refers to lubricant
p	Refers to nanoparticle

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the study's findings are included in the manuscript.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript

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