Research Article

Analysis of the Performance Characteristics of ZnO Nanoparticles' Dispersed Polyester Oil

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Analysis of performance characteristics of nanoparticles' dispersed oil has wide and an important role in oil industries. Zinc oxide nanoparticles are dispersed with polyester oil by using an ultrasonic vibrator and magnetic stirrer. Nanoparticles' concentration are taken as 0.1, 0.3, and 0.5 wt. %. The ball-milling process is used to reduce the size of the nanoparticles before the preparation of nanoparticles' dispersed polyester oil (NPDP). Spherical shape particles with an average size of 40 nm are achieved for unmilled nanoparticles, whereas spherical shape particles with an average size of 30 nm are achieved for ball-milled nanoparticles. Pin on disc analysis shows the coefficient of friction of unmilled and ball-milled NPDP. Ball-milled NPDP results in a lesser coefficient of friction. Thermal conductivity of unmilled and ball-milled NPDP is finalized through the transient hot-wire method. Ball-milled NPDP enhances the thermal conductivity of base polyester oil than the usage of unmilled NPDP in polyester oil. In this study, the assessment and optimization of nanoparticle concentration, temperature, and ball-milling processes of nanoparticles are also carried out using the design of experiment (Doe) approach. The L_9 orthogonal array-based full factorial design is used for the best optimization result. The response tables with graphs and optimal results have been obtained through the Taguchi method.

1. Introduction

Nanolubricants are playing an essential role in friction and wear reduction through the accumulation of nanoparticles. In an automobile, friction is created in an engine through the moving components, and it is produced more heat. Lubricants are used to reduce the frictional heat and the wear between the contacting surfaces with each other. Many of the experimental investigations have been focused on enhancing the performance of lubrication. One of the methods is to mix the nanoparticle additives into the general lubricants, and it is used to minimize friction and wear. The friction and wear between the surfaces of contact mainly depend on the shape,

size, and concentration of the nanoparticles which are added into the lubricating oil. It is confirmed through the study, which is conducted in copper nanoparticles mixed with lubrication oil. Tribological properties and coefficient of friction have been studied in copper nanoparticles [1]. The effect of nanoparticles with TiO_2 -based lubricant additives has been investigated on a load-carrying capacity of a journal bearing. The results have been shown that the load-carrying capacity was increased in journal bearing using TiO_2 nanoparticle lubricants compared to the oils without nanoparticles [2]. The experimental tribological investigation was conducted on lubricant oil containing boron nitride nanoparticles through atomic force microscopic SEM and

EDAX. Excellent tribological behaviors have been attained on the worn surface using boron nitride nanoparticles-based lubricant oil [3].

The tribological properties of nanofluid is depends on various parameters such as concentration of particle, type of particle, and producing methods. The efficient analyses of the complex system were carried out using statistical experimental design [4] and the Taguchi method. In the Taguchi method, the variation of the activities has been reduced through robust design. The objective of this technique was applied to produce products with high quality at a low price to the user. The proposed experimental design is based on the Taguchi method with an orthogonal array approach used to define the factors and their various levels. It permits the collection of the data to determine the most influential factor which affects the responses. Evaluation of variance with respect to the experimental data from the Taguchi techniques can be utilized to prefer new factor levels to optimize the efficiency characteristic [5].

Robust design is an essential technique for enhancing product quality, manufacturability, and reliability at the possible least price. In 1980, the introduction of Taguchi's robust approach led the major American industries to improve quality manufacturing process style. The robust design approach is to make the product perform its maximum efficiency by reducing the unnecessary deviations in the functionality of the component [6]. The small-sized electronic industries faced technical hurdles and stagnation in efforts to reduce the temperature in integrated circuits. The traditional convective cooling technique was assumed as unsuitable because of its huge required space to regulate the temperature of the integrated circuit, which was considered as impractical. Hence, it became imperative to make temperature transmission arrangements with high-conductivity materials to transfer the heat quickly and substituted with exterior atmosphere [7, 8]. An integral approach was required to address the problem, which could assist in designing an efficient heat transfer structure. This might be achieved by using high-conductivity materials, which not only benefit the temperature control but also reduce the consumption of materials and production costs. This led to further miniaturization for efficient heat transfer. High thermal conductivity particles of nanoscales have become the candidate material for cooling the integrated circuits. However, researchers faced the hindrance in finding the thermal conductivity of the nanoparticle mixed in fluid [9, 10]. Nanoparticle concentration is also used in the automobile engine for the cooling process [11]. Due to the electrical conductivity of the nanofluids, the transient hot wire is the most suitable method for the measurement of thermal conductivity [12]. Heat transfer has been analyzed in pin-fin material with microcoated fin and observed that it increased the rate of heat transfer [13]. In the following process, the nanoparticles with a concentration of 0.10%, 0.30%, and 0.50% are mixed with the refrigeration oil named polyester oil with the help of a magnetic stirrer. The result shows the enrichment of thermal conductivity by adding nanoparticles with the

base fluid. In order to check the result, we have taken an optimization process. The optimization process leads to the same value as the experimental value. It has also been optimized for the thermal conductivity process of water with the nanoparticle concentration, and the result has also been reviewed [14]. Multiresponse optimization was studied in minimum quantity lubrication of turning on Haynes alloy using Taguchi-based GRA [15]. Rheological behavior and their correlations with thermal conductivity and viscosity of oil-based nanofluids have been investigated [16]. Taguchi optimization and analysis of variance have been studied in the machining of duplex brass [17, 18]. The Taguchi method and the effect of S/N ratio on quality characteristics have been investigated [19]. Nanoparticle concentration and its effect were analyzed in turning of EN8 steel [20]. Thermal conductivity has been enhanced through zirconium oxide-based nanoparticles [21].

In the present concept, tribological properties of the polyester oil are processed with the accumulation of unmilled and ball-milled ZnO nanoparticles of 0.1, 0.3, and 0.5 wt.% concentration with the aid of a pin-on-disc tribometer under different controlled conditions. Thermal conductivity of the synthesized unmilled and ball-milled NPDP with varying the temperature (40, 50, and 60°C) and concentration of the nanoparticles (0.1, 0.3, and 0.5 wt. %) are also investigated. The obtained experimental results are verified with the results of the optimization technique Taguchi method.

2. Processing of Material for Experimentation

2.1. Grinding of Particles. Initially, the nanoparticles are purchased from sigma Aldrich company, USA. Zinc oxide nanoparticles played an important role in polyester oil. The size of the particles is processed under a ball mill (RETSCH, PM 100) for 15 hours at 340 rpm. The particle size has been reduced through tungsten carbide balls. The ball mill is operated in a clockwise and anticlockwise rotation for the starting period to control or regulate the feed of particles. After that, it is operated at high speed.

2.2. Microscopic View. The microscopic views of unmilled and ball-milled nanoparticles using TEM results are shown in Figure 1(a) at specified scale size and Figure 1(b) shows the result of EDX test and XRD values of nanoparticles. It specified the development of globular nanoparticles with different ranges of size between 30 nm and 60 nm which is achieved for unmilled particles. The size between 20 nm and 40 nm is achieved from ball-milled particles.

2.3. Synthesis of Nanoparticles' Dispersed Polyester Oil. The required mass concentration percentage is 0.1, 0.3, and 0.5 wt. % of unmilled and ball-milled zinc oxide nanoparticles are diffused into pure polyester oil with the aid of an ultrasonic vibrator and magnetic stirrer to obtain NPDP. The prepared samples are appropriately labeled and shown in Figure 2 (i and ii).

FIGURE 1: (a) TEM images of nanoparticles: (i) unmilled and (ii) ball milled. (b) EDX test result and XRD images.

FIGURE 2: (a) Photographs of NPDP with (i) unmilled nanoparticles and (ii) ball-milled nanoparticles. (b) TEM images of NPDP mixed with oil: (i) ball-milled nanoparticles and (ii) unmilled nanoparticles

3. Results and Discussion

Pin on disc apparatus is used to analyze the coefficient of friction of the synthesized NPDP. The transient hot-wire method is employed to compute the thermal conductivity of the samples. The results are discussed in the following sections.

3.1. Thermal Conductivity Analysis of NPDP. A nichrome wire of diameter 0.38 mm is utilized for the hot wire. Initially, the nichrome wire is immersed in the nanofluid, which was kept in equilibrium with the surroundings. The temperature and the output voltage have been increased through the electric resistance of the nichrome wire, and it is measured by an analog to digital converter. The thermal conductivity parameters of NPDP with unmilled and ball-milled nanoparticles are measured by using the apparatus shown in Figure 3, and its values are calculated by using [11]

$$k = \frac{q}{4\pi(T_2 - T_1)} \ln(t), \quad (1)$$

where k is thermal conductivity of fluid, q is the amount of heat, T_1 is temperature (initial), T_2 is temperature (final), and t is time taken to increase the temperature.

The calculation procedures are as follows: $Q = V \cdot I$, $V = 4V$, $I = 0.57$ A, $q = 2.28$ W, $T_2 = 40$, $T_1 = 35$, and $t = 42.81$ s.

The transient hot-wire thermal conductivity measurement method was trusted to gauge the thermal conductivity of solids and liquids. It functions on the principle that a material's electric resistivity was directly linked to its temperature. An extended thin metallic wire was suspended either vertically or horizontally in the materials whose thermal conductivity was usually to be calculated. The wire was energized through continuous heat supplied through continuous electrical power. Hence, the resistance of the suspended wire or the voltage drop has been modified until it reaches cryogenic temperature. The lead-based fluid additives were added to the nanoparticle to improve their concentration [22]. The nanofluid particles were utilized to improve the heat transfer [23–26]. The thermal conductivity of the synthesized NPDP before and after the ball-milling process is tabulated in Table 1.

3.2. Coefficient of Friction Analysis of NPDP. A pin on the disc tribometer is shown in Figure 4. It has a stationary pin and a rotating disc. The pin is processed over the rotating disc and is shaped with spherical tips along with contact

FIGURE 3: Thermal conductivity-measuring apparatus.

geometry. The coefficient of friction is estimated through the ratio between frictional force and the applied load. A pin-on-disc tribometer is used to analyze the tribological properties of the synthesized samples at different volumetric percentages as compared to ASTM G99. The test is carried out at 25°C with a velocity of 0.314 m/s and an applied load of 4 kg, 5 kg, and 6 Kg. The friction was measured by mass loss using a precision balance of 1g. Meanwhile, the values of the cohesion measure have also been recorded. Three test runs are performed and recorded for each test condition [27], and also, the specification of apparatus is given in Table 2.

The obtained results for NPDP with 0.3 wt. % unmilled and ball-milled nanoparticles are shown graphically in Figure 5(a) and 5(b), and the average coefficient of friction values of NPDP with 0.1, 0.3, and 0.5 wt. % of ball-milled nanoparticles is tabulated in Table 3.

From Figure 5(a) and 5(b), it is clearly shown that the coefficient of friction (CoF) varied with the increase in load for polyester oil without nanoparticles. The variation in CoF for a given time of 0–3600s is noticed to be higher for the load of 4 kg and compared with 5 kg or 6 kg loads. Figure 5(a) and 5(b) shows the higher decrease in coefficient of friction of polyester oil with 0.3 wt. % of ball-milled nanoparticles than that of NPDP with unmilled nanoparticles for loads 4, 5, and 6 kg. From Table 3, a higher percentage decrease in coefficient of friction is achieved for NPDP with 0.3 wt. % ball-milled nanoparticles than that of NPDP with 0.1 and 0.5 wt. % of nanoparticles. This study shows that dispersing ball-milled ZnO nanoparticles in the base polyester oil has produced better lubrication properties, minimizing the friction and wear rate.

3.3. Taguchi Approach. Taguchi [28] developed a method to predict the results based on the design of experiments through different parameters. Taguchi method-based S/N

ratio was used to decide the quality characteristics of the processing parameter. An increased S/N specified better quality characteristics. The adjustment of the S/N ratio and its process functionality has been discussed [29]. Taguchi proposed a structure of two separate experimental plans for the sound and control factors. No interactions were made among control factors and proposed responses' factors [30]. The experimental data and the thermal conductivity equation for the nanoparticle concentration were the main factors used in MINITAB software. The effect of the S/N ratio on response was the main criteria for the optimization problems [31]. According to Tables 4–6, ANOVA is used to determine the most significant parameter affecting output quality and characteristics by using quantities such as degree of freedom (f), sum of squares (SS), variance (V), percent contribution of each parameter (F-ratio), and contribution ratio or contribution of variance.

3.4. Before Ball-Milled Process. The L_9 orthogonal array experimental design was used in Taguchi approach to estimate the optimal parameters. The better criterion was chosen to obtain the better thermal conductivity of oil. Based on it, the signal-to-noise ratio (S/N) and means were estimated. The effect of input factors has a linear relation with the response, such as thermal conductivity. Determination of S/N ratio and means are shown in Table 7.

Figure 6 shows the S/N ratio effect on thermal conductivity before the ball-milled process. As per “higher the better” condition of the S/N ratio, the high peak points were considered from the plot. The optimal thermal conductivity was achieved at a temperature of 60°C, oil concentration with nanofluid of 0.5%, and sonication time of 45 minutes. The process input factors and their contribution to thermal conductivity are shown in Table 5. The temperature has been produced 71.26% of the effect on thermal conductivity.

TABLE 1: Experimental data for thermal conductivity of NPDP.

S.No	Temperature (°C)	Concentration (%)	Sonication time (min)	Unmilled Thermal conductivity (W/mK)	Ball milled Thermal conductivity (W/mK)	Differences Thermal conductivity (W/mK)
1	40	0.1	30	0.143	0.163	0.020
2	40	0.3	45	0.158	0.174	0.016
3	40	0.5	60	0.160	0.177	0.017
4	50	0.1	45	0.151	0.170	0.019
5	50	0.3	60	0.166	0.182	0.016
6	50	0.5	30	0.170	0.187	0.017
7	60	0.1	60	0.172	0.190	0.018
8	60	0.3	30	0.190	0.210	0.020
9	60	0.5	45	0.194	0.213	0.019

From the results of thermal conductivity of unmilled and ball-milled NPDP, it increased with the concentration of the nanoparticles and temperature. The thermal conductivity of ball-milled NPDP is higher than that of unmilled NPDP.

FIGURE 4: Pin on disc apparatus.

TABLE 2: The specifications of pin on disc apparatus.

Sl. no	Description	Parameters with units
1.	Load	5N to 200N
2.	Disc dimensions	165 mm × 8 mm
3.	Speed of disc	200 rpm to 2000 rpm
4.	Pin diameter used	3mm, 6 mm, and 10 mm
5.	Lubrication	Recirculation system
6.	Frictional force	Up to 200N

3.5. After Ball-Milled Process. The experimental design was followed by L_9 orthogonal array, and it was used to evaluate the optimal parameter of thermal conductivity after the ball-milled process. The better thermal conductivity of oil was achieved on the basis of the larger better criterion. Based on it, the signal-to-noise ratio (S/N) and means were estimated. Determination of SN ratio and means after the cryogenic treatment are shown in Table 6.

Figure 7 shows the S/N ratio effect on thermal conductivity after the ball-milled process. As per “larger the better” condition of the S/N ratio, the high peak points were considered from the plot. The optimal thermal conductivity was achieved at a temperature of 60°C, oil concentration with nanofluid of 0.5%, and sonication time of 30 minutes. The process input factors and their contribution to thermal conductivity after the ball-milled process are shown in Table 7. The temperature has produced a 75.48% of the effect on thermal conductivity.

(a)

(b)

FIGURE 5: (a) Coefficient of friction values of NPDP with 0.3 wt. % unmilled nanoparticles. (b) Coefficient of friction values of NPDP with 0.3 wt. % ball-milled nanoparticles.

TABLE 3: Coefficient of friction values of NPDP with different wt. % of ZnO ball-milled nanoparticles at various loads for 1 hour duration.

Load (kg)/force (N)	CoF (grade 60 oil)	CoF (0.1 wt. %)	CoF (0.3 wt. %)	CoF (0.5 wt. %)
4.0/39 N	0.102	0.055	0.023	0.094
5.0/49N	0.133	0.074	0.035	0.083
6.0/58N	0.132	0.099	0.090	0.097

TABLE 4: Variance analysis for thermal conductivity (unmilled process).

Basis	DF	SS	MS	F	P	%
Temperature	2	0.001607	0.000803	1033.00	0.001	71.26
Concentration	2	0.000641	0.000320	412.00	0.002	28.43
Sonication time	2	0.000006	0.000003	3.57	0.219	00.27
Error	2	0.000002	0.000001	---	---	00.04
Total	8	0.002255	---	---	---	100
S = 0.0008819		R-Sq = 99.93%		R-Sq(Adj.) = 99.72%		R-Sq(Adj.) = 98.60%

TABLE 5: S/N ratio and means for thermal conductivity (ball-milled process).

S/N ratios				Means		
Level	Temperature	Concentration	Sonication time	Temperature	Concentration	Sonication time
1	-15.33	-15.19	-14.63	0.1713	0.1743	0.1867
2	-14.92	-14.51	-14.67	0.1797	0.1887	0.1857
3	-13.80	-14.35	-14.75	0.2043	0.1923	0.1830
Delta	1.52	0.85	0.13	0.0330	0.0180	0.0037
Rank	1	2	3	1	2	3

TABLE 6: Variance analysis for thermal conductivity (ball-milled process).

Basis	DF	SS	MS	F	P	%
Temperature	2	0.001767	0.000883	184.91	0.005	75.48
Concentration	2	0.000543	0.000271	56.81	0.017	23.19
Sonication time	2	0.000022	0.000011	2.26	0.307	00.94
Error	2	0.000010	0.000005	---	---	00.39
Total	8	0.002341	---	---	---	100
S = 0.0021858		R-Sq = 99.59%		R-Sq(Adj.) = 98.37%		R-Sq(Adj.) = 91.73%

TABLE 7: S/N ratio and means for thermal conductivity (unmilled process).

S/N ratios				Means		
Level	Temperature	Concentration	Sonication time	Temperature	Concentration	Sonication time
1	-16.28	16.20	15.57	0.1537	0.1553	0.1677
2	15.80	15.35	15.56	0.1623	0.1623	0.1677
3	14.65	15.18	15.60	0.1853	0.1747	0.1660
Delta	1.63	1.02	0.04	0.0317	0.0193	0.0017
Rank	1	2	3	1	2	3

FIGURE 6: S/N ratio effect on thermal conductivity (unmilled process).

FIGURE 7: SN ratio effect for thermal conductivity (ball-milled process).

4. Conclusions

The thermal conductivity of nanoparticle concentrated polyester oil was investigated before and after the ball-milling process. The Taguchi method was used to determine the optimized parameter during the process. A ball-milled process and nanoparticle-based polyester oil were used to improve thermal conductivity. At the same time, the coefficient of friction has been reduced. Thermal conductivity has been improved to 0.020 W/mK using a ball-milled process. Taguchi optimization had been used to optimize thermal conductivity parameters during the ball-milling method. The optimal thermal conductivity was achieved prior to the ball-milling process at a temperature of 60°C, an oil concentration of 0.5 percent with a nanofluid, and a sonication time of 45 minutes. The improved thermal conductivity has been obtained after the ball-milled method at a temperature of 60°C, a concentration of oil with nanofluid of 0.5 percent, and a sonication time of 30 minutes. In both processes, temperature was the most influential parameter on thermal conductivity (before process, 71.26%, and after process, 75.48%).

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

This study was performed as a part of the employment of the authors.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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