# Optimization of Tribological Performance of hBN/ $Al_2O_3$ Nano-Particles

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## ABSTRACT

The purpose of this study is to determine the optimal design parameters and to indicate which of the design parameters that are statistically significant for obtaining a low coefficient of friction (COF) with hexagonal boron nitride (hBN) and alumina ($Al_2O_3$) nanoparticles, dispersed in Castor oil. Design of experiment (DOE) was constructed using the Taguchi method, which consists of L9 orthogonal arrays. Tribological testing was conducted using a four-ball tester according to ASTM standard D4172 procedures. According to the analysis of signal-to-noise (S/N) ratio and analysis of variance (ANOVA), COF and wear scar diameter were reduced significantly by dispersing several concentrations of hBN nanoparticles in conventional diesel engine oil, compared to without nanoparticles and with $Al_2O_3$ nanoparticle additive.

# 1. INTRODUCTION

### 1.1 Problem Statement

The purpose of this study is to determine the optimal design parameters and to indicate which of the design parameters that are statistically significant for obtaining a low coefficient of friction (COF) with hexagonal boron nitride (hBN) and alumina ($Al_2O_3$) nano particles, dispersed in Castor oil.

### 1.2 Background

Nano particles can be considered as modern lubricant additives. They present several major advantages over organic molecules that are currently used as lubricant additives. Their nanometer size allows them to enter into the contact area like molecules. They are immediately efficient; even at ambient temperatures. Therefore, no induction period is necessary to obtain interesting tribological properties. Various types of nanoparticles were used to prepare nano lubricants, including polymers, metals, and organic and inorganic materials.

### 1.3 Review of Literature

Studies reported that copper (Cu) nanoparticle used as oil additives can improve the anti-wear, load-carrying, and friction-reduction performance of SJ 15W/40 gasoline engine oil. This was in agreement with several other authors’ work, where they use nanoparticles of zirconia/silica (ZrO3/SiO2) composite, copper oxide (CuO), titanium oxide (TiO2), and nano-diamond as oil additives. Even the addition of a low concentration of nanoparticle (between 0.2% and 3% vol.) into lubricating oil is sufficient to improve tribological properties**.**

# 2. OBJECTIVES

- Study and analysis of physical properties of engine oil
- Variance of wear and tear

# 3. METHODOLOGY AND WORKING ALGORITHM

- Tribological testing will be conducted in three phases, namely:
- $1^{st}$ phase : pure castor oil testing for flash point, pour point, etc.
- $2^{nd}$ phase :testing on pin on disc after adding $Al_2O_3$/hBN nanoparticles .

- Primary and secondary data are collected through experimentation and research papers.

# 4. PHASE I: PURE CASTOR OIL TESTING

## 4.1 Why Castor Oil?

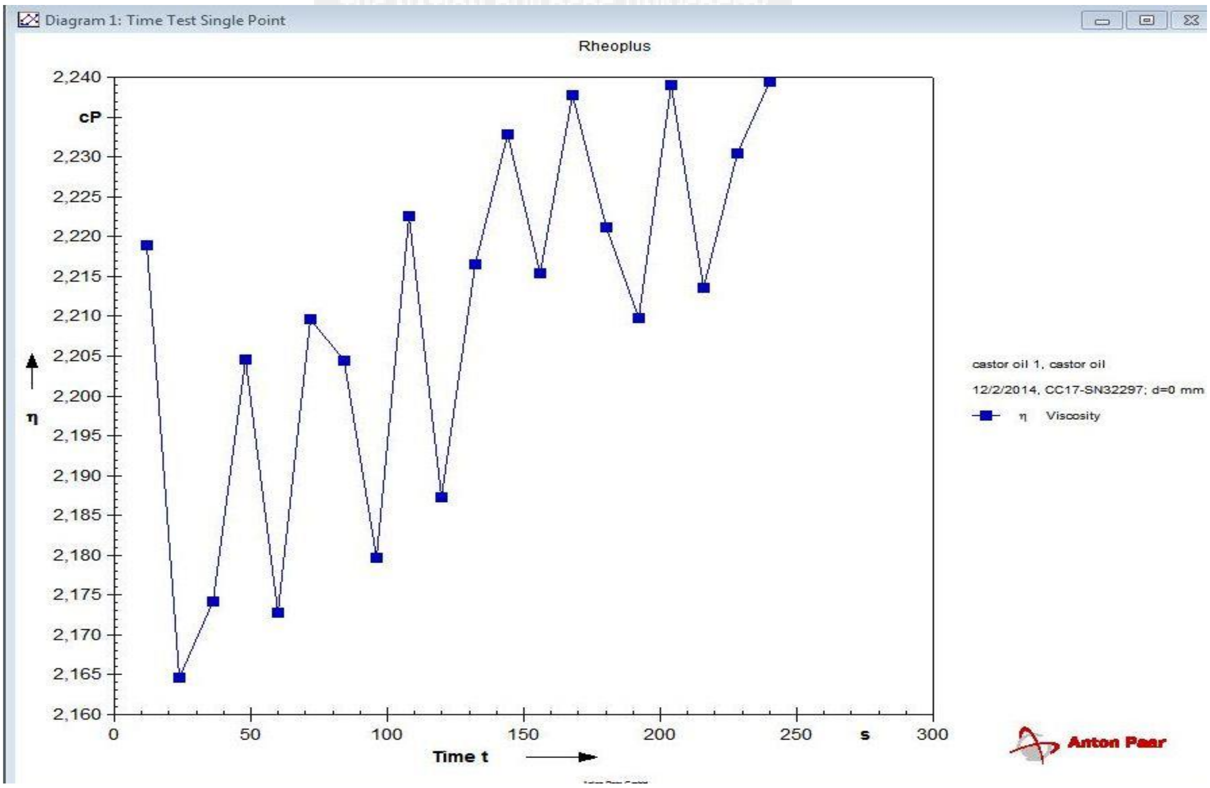
- Vegetable oils, due to their good lubricity and biodegradability are attractive alternatives to petroleum-derived lubricants
- Castor oil has better low temperature viscosity properties and high temperature lubrication than most vegetable oils
- It is a useful lubricant in jet, diesel, and race car engines.[

## 4.2 Chemical Properties

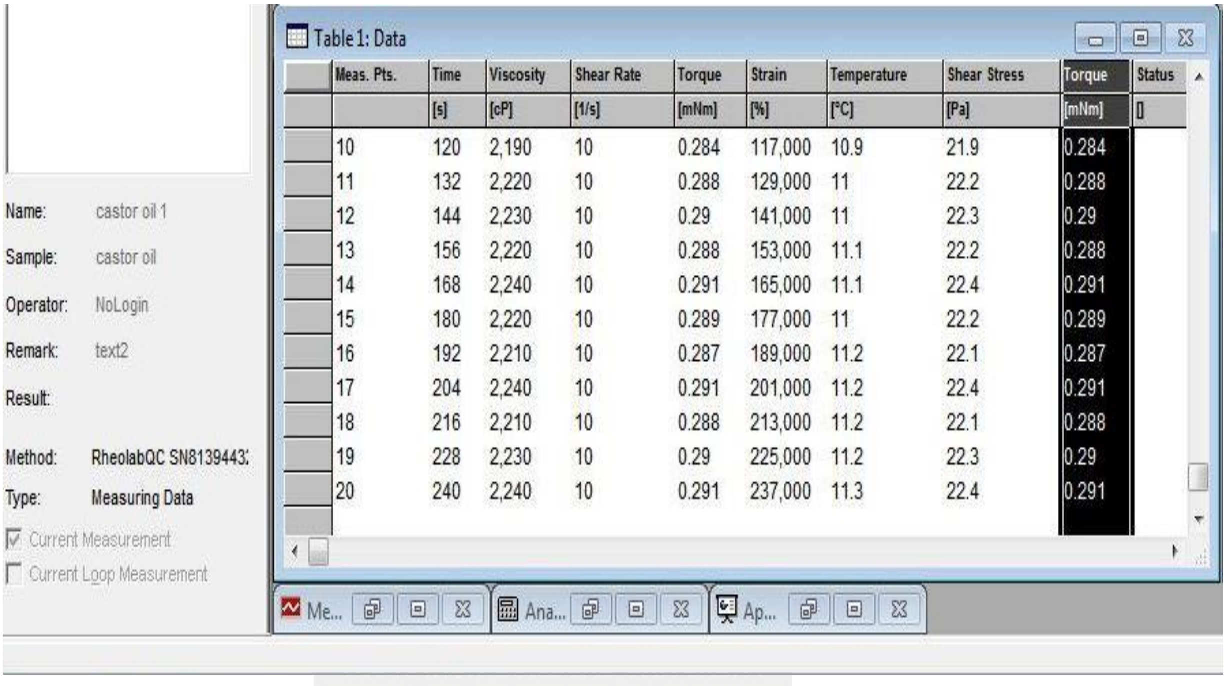
Flash point: 229$^{o}$C
Pour point: -24$^{o}$C
Fire Point: 449$^{o}$C
Density : 961 kg/m$^{3}$
Dynamic Viscosity (at 10$^{o}$ C) : 2420 cP

## 4.3 Experimental Results

*Graph for viscosity (cP) at 10 degree C, as measured by Rheometer*

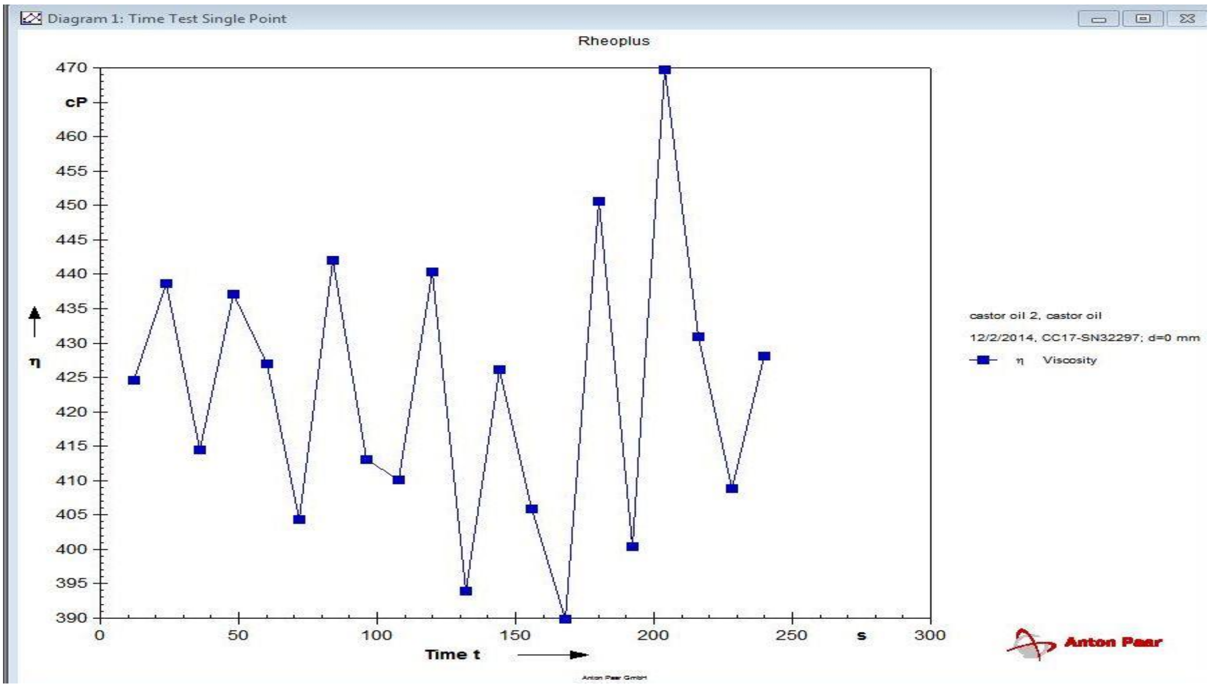


*The viscosity of castor oil by experimental methods is obtained to be approx 2220 cP, verifying the observational values.*




| Meas. Pts. | Time | Viscosity | Shear Rate | Torque | Strain | Temperature | Shear Stress | Torque | Status |
|---|---|---|---|---|---|---|---|---|---|
| | [s] | [cP] | [1/s] | [mNm] | [%] | [°C] | [Pa] | [mNm] | [] |
| 10 | 120 | 2,190 | 10 | 0.284 | 117,000 | 10.9 | 21.9 | 0.284 | |
| 11 | 132 | 2,220 | 10 | 0.288 | 129,000 | 11 | 22.2 | 0.288 | |
| 12 | 144 | 2,230 | 10 | 0.29 | 141,000 | 11 | 22.3 | 0.29 | |
| 13 | 156 | 2,220 | 10 | 0.288 | 153,000 | 11.1 | 22.2 | 0.288 | |
| 14 | 168 | 2,240 | 10 | 0.291 | 165,000 | 11.1 | 22.4 | 0.291 | |
| 15 | 180 | 2,220 | 10 | 0.289 | 177,000 | 11 | 22.2 | 0.289 | |
| 16 | 192 | 2,210 | 10 | 0.287 | 189,000 | 11.2 | 22.1 | 0.287 | |
| 17 | 204 | 2,240 | 10 | 0.291 | 201,000 | 11.2 | 22.4 | 0.291 | |
| 18 | 216 | 2,210 | 10 | 0.288 | 213,000 | 11.2 | 22.1 | 0.288 | |
| 19 | 228 | 2,230 | 10 | 0.29 | 225,000 | 11.2 | 22.3 | 0.29 | |
| 20 | 240 | 2,240 | 10 | 0.291 | 237,000 | 11.3 | 22.4 | 0.291 | |

*Graph obtained for viscosity vs. time at 40 degree C.*




Name: castor oil 2
Sample: castor oil
Operator: NoLogin
Remark: text2
Result:
Method: RheolabQC SN8139443:
Type: Measuring Data

Current Measurement
Current Loop Measurement

Table 1: Data

| Meas. Pts. | Time | Viscosity | Shear Rate | Torque | Strain | Temperature | Shear Stress | Torque | Status |
|---|---|---|---|---|---|---|---|---|---|
| | [s] | [cP] | [1/s] | [mNm] | [%] | [°C] | [Pa] | [mNm] | [] |
| 10 | 120 | 440 | 10 | 0.0572 | 119,000 | 40.3 | 4.4 | 0.0572 | M- |
| 11 | 132 | 394 | 10 | 0.0512 | 131,000 | 40.3 | 3.94 | 0.0512 | M- |
| 12 | 144 | 426 | 10 | 0.0553 | 143,000 | 40.3 | 4.26 | 0.0553 | M- |
| 13 | 156 | 406 | 10 | 0.0527 | 155,000 | 40.3 | 4.06 | 0.0527 | M- |
| 14 | 168 | 390 | 10 | 0.0506 | 168,000 | 40.2 | 3.9 | 0.0506 | M- |
| 15 | 180 | 451 | 10 | 0.0585 | 180,000 | 40.3 | 4.51 | 0.0585 | M- |
| 16 | 192 | 400 | 10 | 0.052 | 192,000 | 40.3 | 4 | 0.052 | M- |
| 17 | 204 | 470 | 10 | 0.061 | 204,000 | 40.2 | 4.7 | 0.061 | M- |
| 18 | 216 | 431 | 10 | 0.056 | 216,000 | 40.3 | 4.31 | 0.056 | M- |
| 19 | 228 | 409 | 10 | 0.0531 | 228,000 | 40.3 | 4.09 | 0.0531 | M- |
| 20 | 240 | 428 | 10 | 0.0556 | 240,000 | 40.3 | 4.28 | 0.0556 | M- |

Me... Ana... Ap...

# 5. PHASE II: AFTER ADDING $Al_2O_3$/ hBN NANO-PARTICLES

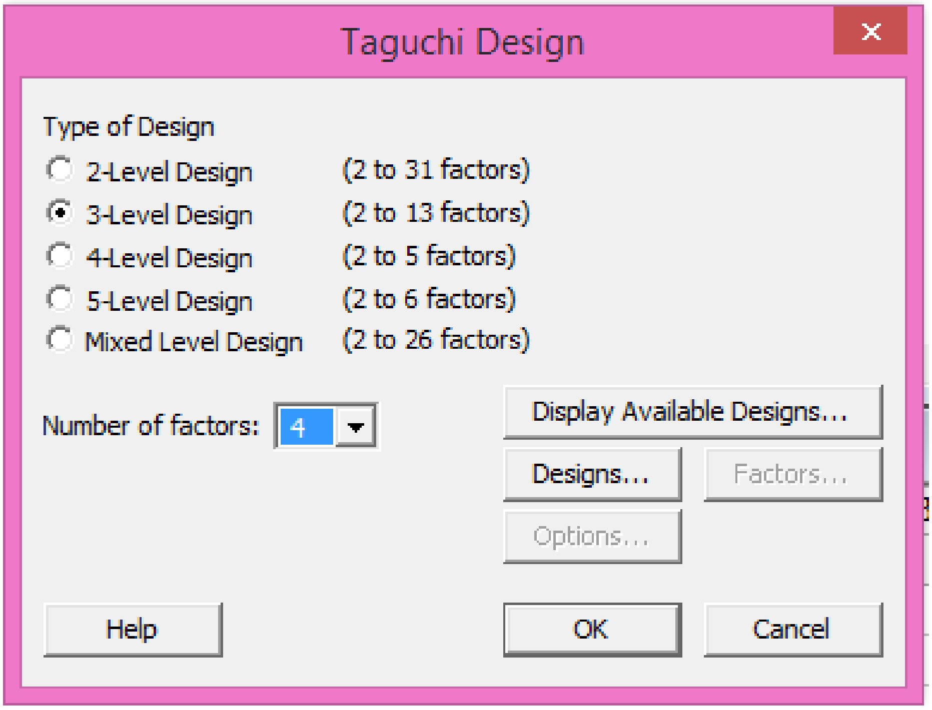
## 5.1 Design Parameters

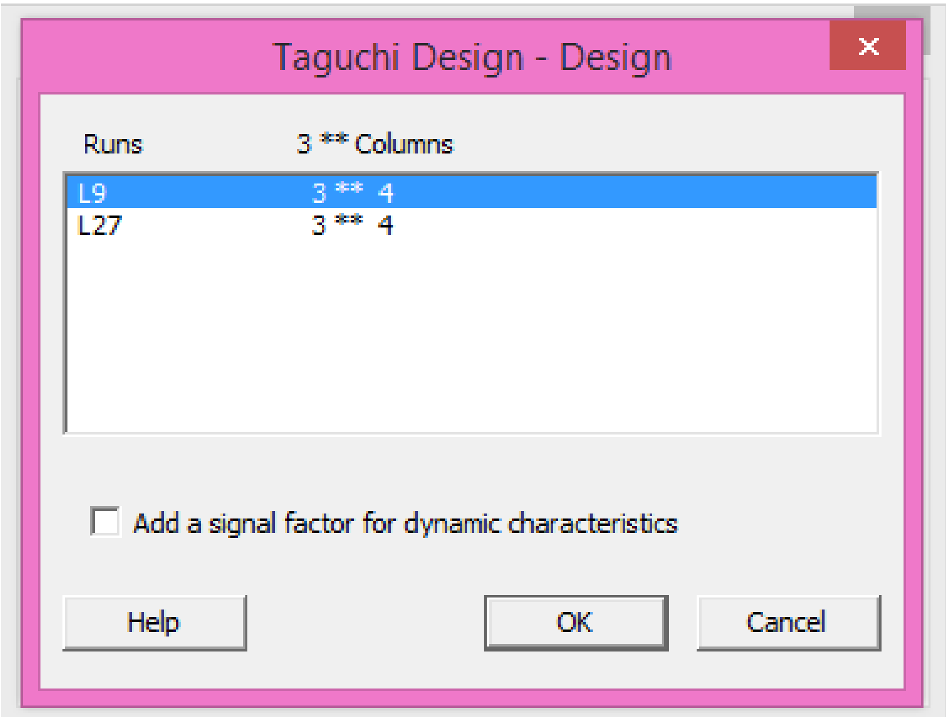
| | 1 | 2 | 3 |
|---|---|---|---|
| **hBN (vol %)** | **0** | **2%** | **4%** |
| **$Al2O_3$ (vol %)** | **0** | **3%** | **6%** |
| **Sliding Velocity (rpm)** | **300** | **600** | **900** |
| **Load (N)** | **50** | **100** | **150** |

## 5.1 Taguchi Methods

Taguchi designs are used for robust parameter design, in which the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions.

## 5.2 Experimental Results


Taguchi Design
Type of Design
2-Level Design (2 to 31 factors)
3-Level Design (2 to 13 factors)
4-Level Design (2 to 5 factors)
5-Level Design (2 to 6 factors)
Mixed Level Design (2 to 26 factors)
Number of factors: 4
Display Available Designs...
Designs...
Factors...
Options...
Help
OK
Cancel


Taguchi Design - Design
Runs
3 ** Columns
L9 3 ** 4
L27 3 ** 4
Add a signal factor for dynamic characteristics
Help
OK
Cancel

Worksheet 1 ***

| ↓ | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| | A | B | C | D |
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

A *pin on disc tribometer* consists of a stationary "pin" under an applied load in contact with a rotating disc. The pin can have any shape to simulate a specific contact, but spherical tips are often used to simplify the contact geometry. Coefficient of friction is determined by the ratio of the frictional force to the loading force on the pin.

The pin on disc test has proved useful in providing a simple wear and friction test for low friction coatings such as diamond-like carbon coatings on valve train components in internal combustion engines.

Worksheet 1 ***

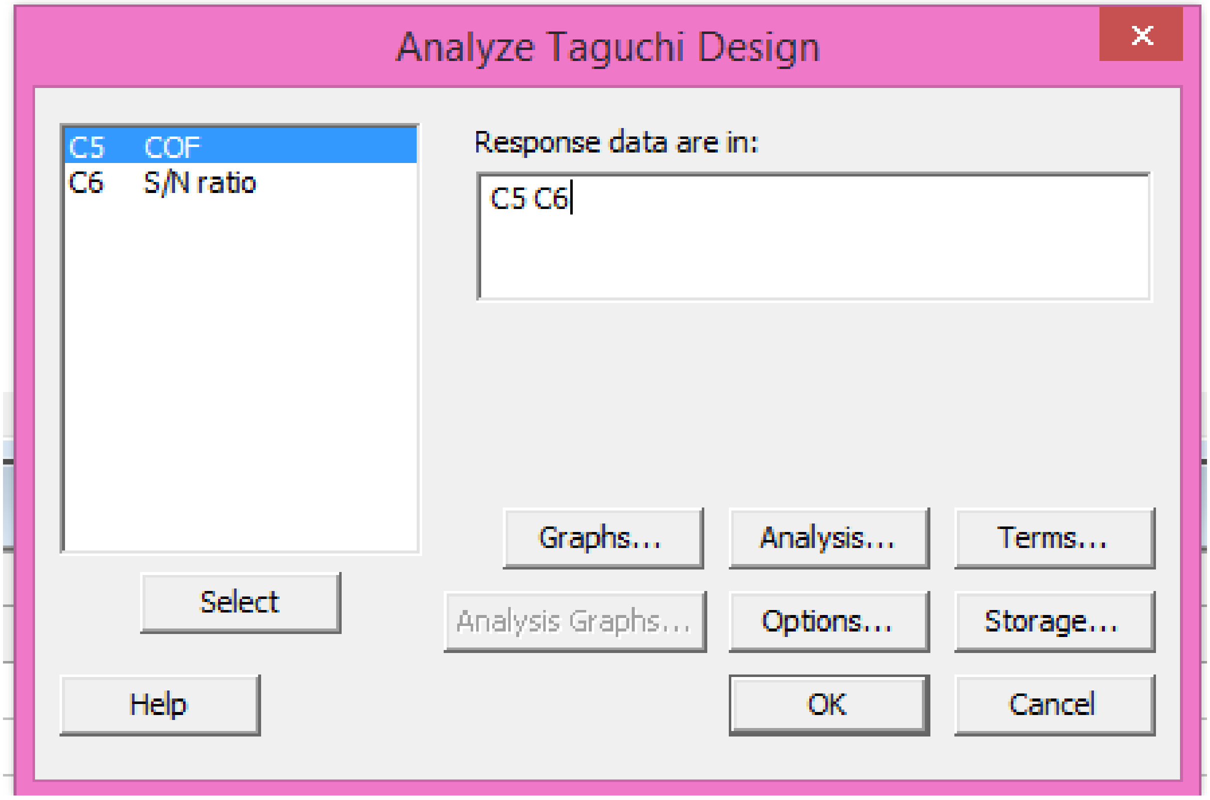
| ↓ | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| | A | B | C | D | COF |
| 1 | 1 | 1 | 1 | 1 | 0.0756 |
| 2 | 1 | 2 | 2 | 2 | 0.0997 |
| 3 | 1 | 3 | 3 | 3 | 0.1567 |
| 4 | 2 | 1 | 2 | 3 | 0.0884 |
| 5 | 2 | 2 | 3 | 1 | 0.1365 |
| 6 | 2 | 3 | 1 | 2 | 0.1501 |
| 7 | 3 | 1 | 3 | 2 | 0.0666 |
| 8 | 3 | 2 | 1 | 3 | 0.0970 |
| 9 | 3 | 3 | 2 | 1 | 0.1560 |

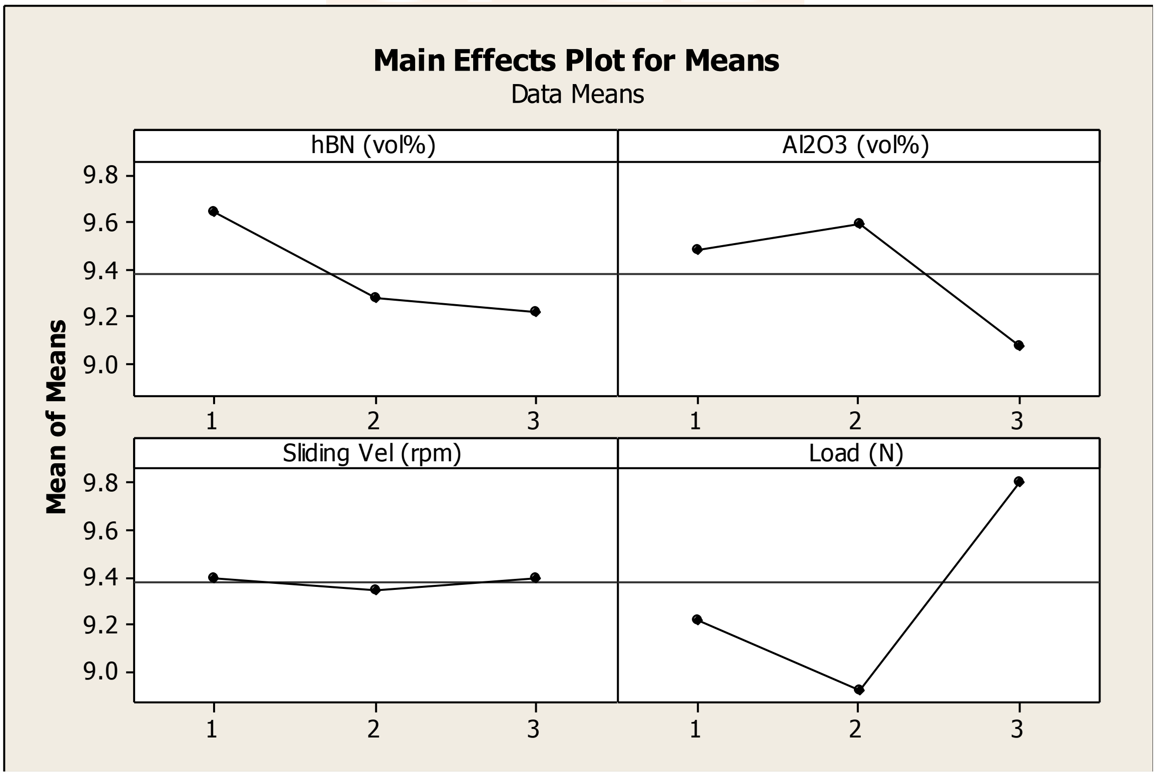
The S/N ratio used for this type response was given by:

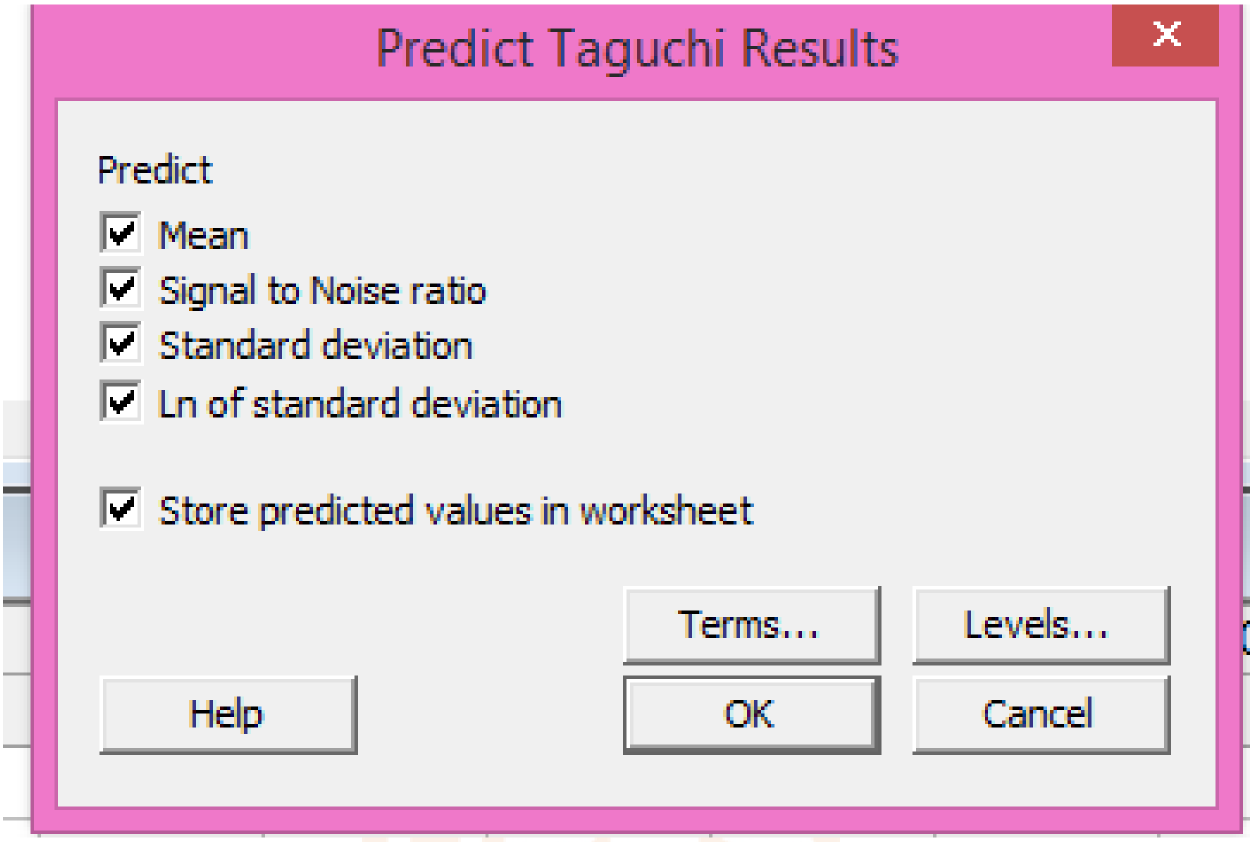
$$S/N = -10\log_{10}\left(\sum \frac{y^2}{n}\right)$$

Where, $n$ is the number of measurement values in a test and $y$ is the measured value in the test.

| ↓ | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| | hBN (vol%) | Al2O3 (vol%) | Sliding Vel (rpm) | Load (N) | COF | S/N ratio |
| 1 | 1 | 1 | 1 | 1 | 0.0756 | 18.6112 |
| 2 | 1 | 2 | 2 | 2 | 0.0997 | 18.6223 |
| 3 | 1 | 3 | 3 | 3 | 0.1567 | 20.3004 |
| 4 | 2 | 1 | 2 | 3 | 0.0884 | 20.3501 |
| 5 | 2 | 2 | 3 | 1 | 0.1365 | 18.0361 |
| 6 | 2 | 3 | 1 | 2 | 0.1501 | 16.9004 |
| 7 | 3 | 1 | 3 | 2 | 0.0666 | 17.6900 |
| 8 | 3 | 2 | 1 | 3 | 0.0970 | 20.5400 |
| 9 | 3 | 3 | 2 | 3 | 0.1560 | 16.7500 |


Analyze Taguchi Design
C5 COF
C6 S/N ratio
Response data are in:
C5 C6
Graphs...
Analysis...
Terms...
Select
Analysis Graphs...
Options...
Storage...
Help
OK
Cancel


Main Effects Plot for Means
Data Means
hBN (vol%)
Al2O3 (vol%)
Sliding Vel (rpm)
Load (N)
Mean of Means
9.8
9.6
9.4
9.2
9.0
1
2
3






Worksheet 1 ***

| ↓ | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | COF | S/N ratio | PSNRA1 | PMEAN1 | PSTDE1 | PLSTD1 | |
| 1 | 1 | 1 | 1 | 1 | 0.0756 | 18.6112 | -2.93973 | 9.3434 | 13.1066 | 2.57312 | |
| 2 | 1 | 2 | 2 | 2 | 0.0997 | 18.6223 | -2.91729 | 9.3610 | 13.0975 | 2.57242 | |
| 3 | 1 | 3 | 3 | 3 | 0.1567 | 20.3004 | -2.87620 | 10.2286 | 14.2437 | 2.65632 | |
| 4 | 2 | 1 | 2 | 3 | 0.0884 | 20.3501 | -2.93484 | 10.2192 | 14.3272 | 2.66216 | |
| 5 | 2 | 2 | 3 | 1 | 0.1365 | 18.0361 | -2.87883 | 9.0863 | 12.6569 | 2.53820 | |
| 6 | 2 | 3 | 1 | 2 | 0.1501 | 20.5400 | -2.88335 | 10.3450 | 14.4178 | 2.66847 | |
| 7 | 3 | 1 | 3 | 2 | 0.0666 | 17.6900 | -2.94490 | 8.8783 | 12.4616 | 2.52265 | |
| 8 | 3 | 2 | 1 | 3 | 0.0970 | 16.9004 | -2.91059 | 8.4987 | 11.8818 | 2.47501 | |
| 9 | 3 | 3 | 2 | 1 | 0.1560 | 16.7500 | -2.84850 | 8.4530 | 11.7337 | 2.46247 | |

ANOVA is statistically based, used for detecting differentials occurring in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels.

**Two-way ANOVA: S/N ratio versus hBN (vol%), Al2O3 (vol%)**

```
Source        DF       SS       MS     F      P
hBN (vol%)     2   1.2963  0.64815  0.19  0.836
Al2O3 (vol%)   2   2.0154  1.00772  0.29  0.762
Error          4  13.8461  3.46152
Total          8  17.1578

S = 1.861   R-Sq = 19.30%   R-Sq(adj) = 0.00%
```

Wo

| ↓ | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|
| | hBN (vol%) | Al2O3 (vol%) | Sliding Vel (rpm) | Load (N) | COF | S/N ratio | RESI1 |
| 1 | 1 | 1 | 1 | 1 | 0.0756 | 18.6112 | -0.80603 |
| 2 | 1 | 2 | 2 | 2 | 0.0997 | 18.6223 | -0.97730 |
| 3 | 1 | 3 | 3 | 3 | 0.1567 | 20.3004 | 1.78333 |
| 4 | 2 | 1 | 2 | 3 | 0.0884 | 20.3501 | 1.68197 |
| 5 | 2 | 2 | 3 | 1 | 0.1365 | 18.0361 | -0.81440 |
| 6 | 2 | 3 | 1 | 2 | 0.1501 | 16.9004 | -0.86757 |
| 7 | 3 | 1 | 3 | 2 | 0.0666 | 17.6900 | -0.87593 |
| 8 | 3 | 2 | 1 | 3 | 0.0970 | 20.5400 | 1.79170 |
| 9 | 3 | 3 | 2 | 3 | 0.1560 | 16.7500 | -0.91577 |

## 6. CALCULATIONS AND RESULTS

The chemical properties of castor tested so far have experimental values as:

**Flash point: 229$^{o}$C**
**Pour point: -24$^{o}$C**
**Fire Point: 449$^{o}$C**

**Density : 961 kg/m$^{3}$**
**Dynamic Viscosity (at 10$^{o}$ C) : 2420 Cp**

According to the category of the performance characteristic, a greater S/N value corresponds to a better performance. Therefore, the optimal level of COF parameters is the level with the greatest S/N value. Based on the analysis of the S/N ratio, the optimal COF for the vol.% contribution was obtained as 2 vol.% AlO3 and 3 vol.% hBN.

## Bibliography


- Wu, Y.Y., Tsui, W.C., Liu, T.C., 2007. Experimental analysis of tribological properties of lubricating oils with nanoparticle additives, Wear 262, p. 819.
- Xiaodong, Z., Xun, F., Huaqiang, S.,Zhengshui, H., 2007. Lubricating properties of Cyanex 302-modified $MoS_2$ microspheres in base oil 500SN, Lubr. Sci. 19, p. 71.
- Liu, G., Li, X., Qin, B., Xing, D., Guo, Y., Fan, R., 2004. Investigation of the mending effect and mechanism of copper nano-particles on a tribologically stressed surface, Tribol. Lett. 17, p. 961.
- Lee, K., Hwang, Y., Cheong, S., Choi, Y., Kwon, L., Lee, J., Kim, S.H., 2009. Understanding the role of nanoparticles in nano-oil lubrication, Tribol Lett. 35, p. 127

## REFERENCES


- http://www.sciencedirect.com.scihub.org/science/article/pii/S1877705813020390
- http://www.wikipedia.org
- http://ducom.com/2014/product-update-universal-high-temperature-tribometer/

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