UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

# OPTIMIZATION OF BORON-BASED NANOLUBRICANT FOR DIESEL ENGINE

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Doctor of Philosophy

2016

**OPTIMIZATION OF BORON-BASED NANOLUBRICANT FOR DIESEL ENGINE**

**Muhammad Ilman Hakimi Chua Bin Abdullah**

**A thesis submitted**
**In fulfillment of the requirements for the degree of Doctor of Philosophy in Mechanical Engineering**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2016**

**DECLARATION**

I declare that this thesis entitled "Optimization of Boron-based Nanolubricant for Diesel Engine" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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## APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature :…………………………………………… 

Supervisor Name :…………………………………………….

Date :…………………………………………….

**DEDICATION**

To my beloved wife

# ABSTRACT

Wear and friction are unavoidable in engineering application nowadays. One of common solution to overcome these problems is by using lubricant which can reduce this friction and wear to a minimum level for promising to a better efficiency. The purposes of this study were to investigate the effect of boron based nanolubricant on the tribological mechanism and engine performance. Design of Experiment (DOE) was constructed using the Taguchi method, which consists of $L_9$ orthogonal arrays. The optimal design parameters were determined and indicated which of these design parameters are statistically significant for obtaining a low Coefficient of Friction (COF) with hexagonal boron nitride (hBN) and/or alumina ($Al_2O_3$) nanoparticles, dispersed in conventional diesel engine oil (SAE 15W40) as optimized nano-oil. Tribological testing was conducted using a four-ball tester according to ASTM standard D4172 procedures. The optimized nano-oil was physco-chemical characterised and the effect of dilution by biodiesel (B100) were tested before undergo for engine performance test. The optimized nano-oil was tested using AIRMAN YANMAH YX2500CXA single cylinder diesel engine which coupled with 20 horse power eddy current dynamometer. The engine performance, emission and fuel consumption testing were conducted and recorded by using DynoMite 2010 software parallel with emission analyser and fuel measurement. From analysis of Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA), COF and wear scar diameter 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. Contribution of 0.5 vol.% of hBN and 0.3 vol.% of oleic acid, as a surfactant, can be an optimal composition additive in conventional diesel engine oil, to obtain a lower COF. In addition, the predicted value of COF by utilizing the levels of the optimal design parameters (0.5 vol.% hBN, 0.3 vol.% surfactant), as made by the Taguchi optimization method, was consistent with the confirmation test (average value of COF = 0.07215), which fell within a 95% Confidence Interval (CI). The optimized nano-oil shown an improvement in viscosity index where it showed a 3% better VI (Viscosity Index) reading compared to the conventional engine oil in advanced the COF obtained by 20% diluted nano-oil is still maintained in lower condition compared to diluted conventional engine oil which indicated that, dilution of optimized nano-oil did not affect the detergency of the lubricant. Result of engine performance shows that, the torque and power of conventional engine oil containing hBN nanoparticle are improved approximately 12.86% and 9.1% compared with conventional engine oil. The Brake Specific Fuel Consumption (B.S.F.C) shows significant efficiency approximately 13~32% and the gas emission of $CO_2$ and HC reduce approximately 27.5% and 5.27%. As conclusion the damage of the material due to adhesive wear type with intensive plastic deformation was less pronounced tested by optimized nano-oil.

## *ABSTRAK*

*Kehausan dan geseran sukar untuk dielakkan dalam aplikasi kejuruteraan pada masa kini. Salah satu penyelesaian bagi masalah ini adalah dengan menggunakan pelincir di mana ia mampu mengurangkan geseran dan menurunkan kehausan pada tahap yang rendah bagi menjanjikan keberkesanan yang lebih efisen. Tujuan kajian ini adalah bagi menghuraikan kesan boron pada nano-pelicir berdasarkan mekanisma tribologi dan prestasi engin. Perangkaan ujikaji (DOE) telah direka dengan menggunakan kaedah Taguchi yang terdiri daripada susunan ortoganal* $L_9$*. Rekaan parameter yang optimum ditentukan dan dikenalpasti bagi memastikan rekaan parameter ini secara statistiknya sesuai untuk mendapatkan pekali geseran yang rendah dengan penggunaan heksagonal boron nitride (hBN) dan/atau alumina (*$Al_2O_3$*) nano-partikel yang telah diselerakan dalam minyak pelincir* (SAE 15W40) *sebagai* Optimized Nano-oil*. Ujian tribologi telah dijalankan menggunakan mesin* four-ball tester *dengan merujuk kepada procedur* ASTM standard D4172. Optimized Nano-oil *yang telah diketeristikkan secara fizikal-kimia dan kesan kecairannya dengan biodiesel (B100) telah diuji sebelum ke ujikaji prestasi engine.* Optimized Nano-oil *juga telah diuji menggunakan* AIRMAN YANMAH YX2500CXA *satu selinder diesel engin yang telah disambungkan pada dynamometer berarus eddy 20 hp. Ujian prestasi engin, gas buangan dan penggunaan bahan api telah dijalankan dan dicatat menggunakan perisian* DynoMite 2010 *sejajar dengan tetapan* emission analyser *dan penyukatan minyak pembakaran. Daripada analisa* Signal-to-Noise (S/N) ratio *dan* Analysis of Variance (ANOVA)*, pekali geseran dan diameter calar kehausan secara signifikannya berkurang semasa diuji dengan sebahagian komposisi nano-partikel hBN di dalam minyak pelincir diesel dibandingkan dengan minyak pelincir asal dan minyak pelincir beserta sebahagian komposis nano-partikel* $Al_2O_3$*. Sumbangan 0.5 vol.% nano-partikel hBN dan 0.3 vol.% asid oleic sebagai pemankin, boleh meyumbangkan kepada komposisi optimum bagi mendapatkan pekali geseran yang rendah. Selain itu, nilai pekali geseran jangkaan berdasarkan laras pengoptimuman rekaan parameter (0.5 vol.% hBN, 0.3 vol.% pemankin), melalui pengoptimuman kaedah Taguchi, adalah setara dengan ujian pengesahan (nilai purata COF = 0.07215), di mana berada dalam 95% selang keyakinan (CI). Optimized Nano-oil juga menunjukkan peningkatan indek kelikatan sebanyak 3% lebih tinggi dibandingkan dengan minyak pelincir asal, selain itu nilai pekali geseran juga berkurang bagi 20% pencairan* Optimized Nano-oil*, menunjukkan bahawa pencairan tidak mengubah sifat pelinciran* Optimized Nano-oil *walaupun dicairkan dibangdingkan dengan minyak pelincir asal yang dicairkan. Keputusan daripada ujikaji prestasi engin pula menunjukkan, kilasan dan kuasa yang terjana daripada optimized nano-oil meningkat sebanyak 12.86% dan 9.1% dibandingkan dengan minyak pelincir asal. B.S.F.C menunjukkan kerberkesanan sebanyak 13~32% dan pebuangan gas* $CO_2$ *dan HC berkurang sebanyak 27.5% dan 5.27%. Kerosakan permukaan berpunca daripada kehausan lekatan secara perubahan plastik kurang kelihatan semasa diuji dengan optimized nano-oil.*

**ACKNOWLEDGEMENTS**

Foremost, I would like to express my sincere gratitude to my supervisor Dr. Mohd Fadzli Bin Abdollah for the continuous support of my Doctoral study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this dissertation. I would like to thank also to my co-supervisor Dr. Yusmady Bin Mohamed Arifin for his help along the journey of my study. I could not have imagined having an excellent supervisors and mentors for my study.

Beside my supervisor, I would like to thank the rest of my dissertation committee: Assoc. Prof. Dr. Noreffendy Tamaldin, Mr. Hilmi Amiruddin, and Nur Rashid Mat Nuri for their support, encouragement and insightful comments.

My sincere thanks to those who made this dissertation possible: Mr. Ismail Bin Ibrahim, Mr. Nor Izwan Bin Junoh, Mr. Ridzuan Bin Ahmad, Mr. Azrul Syafiq Bin Mazlan and Mr. Mahader Bin Muhamad from mechanical engineering lab's Universiti Teknikal Malaysia Melaka (UTeM). I also wish to thank Mr. Redzuan, Mr. Farid and Mr. Kamal from Hakita Engineering Sdn Bhd. Extended thank also to my best friend Mr. Rizuan Bin Razak, my lecturer Prof Jaharah A. Ghani, other lab equipment supportive Prof Masjuki B. Haji Hassan.

It is honour for me to thank the scholarship from MyBrain15 (MyPhD) under MOE, (Ministry of Education) Malaysia for the financial support, including the cost of living and tuition fees during my Doctoral study in Universiti Teknikal Malaysia Melaka, (UTeM). I also with to thank Faculty of Mechanical Engineering (FKM) and Faculty of Engineering

Technology (FTK) for the research grant PJP/2012/FKM(11A)S1086 and FRGS/2013/FTK/TK06/02/3/F0016 which mostly supporting for my research cost.

I would like to express my deeply thanks to my wife and my daughter, Siti Rosilah Binti Abdollah and Nur Alisha Balqis. The unconditional love both of your share every single day turns my work to single words of inspiration that help to finish this dissertation. Both of you are the gift that I treasure the most.

I would like to give my special thanks to my parents, Chua Eh Jee and Tan Bee Seyok, no existed words can describe my gratitude toward you. Both of you have lay deepness love and trusted in every decision that I have made. From you, I learn about life, courage, empathy, hope and forgiveness. Thank you for your continuality care and support. To my sibling, it's was miracle to be with you all. Special thanks extended to my dearest sisters, Chua Yuk Lin, Chua Yuk Thing and Chua Yuk Nee, for their encouragement and source of motivation.

Last but not least, to my research colleagues who are still working on their Master study in UTeM: Mr. Mohd Adli Zil Ikram Bin Abdullah, Mr. Mohd Zakwan Bin Mohd Razi, Mr. Ashapi'e Bin Mustafa, Miss. Noor Ayuma Binti Mat Tahir, Miss. Fairuz Binti Suhimi, Mr. Mohammad Nazry Rosley and Miss. Humairak Binti Mohamad Yusof, my sincere thanks for your constant support for all the ups and downs, joy and sadness, laughter and tears. Many years have passed and our friendship never ends. Continual thanks to others who are not listed here for the friendship and hospitability.

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| | | |
|---|---|---|
| $Al_2O_3$ | - | Alumina/Aluminum oxide |
| ANOVA | - | Analysis of variant |
| B.S.F.C | - | Brake specific fuel consumption |
| B100 | - | B100 biodiesel fuel |
| bmep | - | Brake mean effective pressure |
| $CO_2$ | - | Carbon dioxide |
| COF | - | Coefficient of friction |
| CuO | - | Copper oxide |
| DOE | - | Design of experimental |
| DPF | - | Diesel particulate filters |
| EDX | - | Energy dispersive X-ray spectroscopy |
| EEV | - | Energy-efficient vehicles |
| EHD | - | Elastohydrodynamic |
| FTiR | - | Fourier-transform infrared spectrometer |
| hBN | - | Hexagonal Boron Nitrite |
| HC | - | Hydrocarbon |
| $M_oDTC$ | - | Dithiocarbamate molybdenum |
| PSD | - | Power stroke diesel |
| RBDPO | - | Refined Bleached and Deodorized Palm Oil |
| RSM | - | Respond Surface Method |
| SAE | - | Society of Automotive Engineers |
| SEM | - | Scanning electron microscopy |
| SFC | - | Specific fuel consumption |
| TAN | - | Total Acid Number |
| TBN | - | Total Based Number |
| $TiO_2$ | - | Titanium oxide |
| VI | - | Viscosity index |
| ZnDTP, ZDDP | - | Zinc dithiophosphate |
| SiO2 | - | Silica |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Lubricant technologies currently were developing progressively to cater the demand of the industries need mostly in automotive, aircraft, marine transportation and others. There are many types and brand of lubricant can be found in the local or international market nowadays, impressive additives were added to the lubricant especially into the engine oil lubricant which gives better lubricating performance. Based oil became one of the main sources to develop most of these common lubricants, but year by year the statistic shown that the mineral sources of the lubricant (petroleum) significantly decay due to the limited sources.

The counter measure of this issue, researchers tend to move on developing for the biolubricant which mostly granted the nobility on the biodegrability factor which claim to be more environmental friendly. There are a lot of works currently conducted on this particular area, Kalam et al. (2012) shown that bio-lubricant infuses waste vegetable oil can lower the coefficient of friction (COF) as lubricant substitute (maximum 4%) with normal lubricant and amine phosphate additive. However, palm oil based lubricant still shows higher total acid number (TAN) value. More issues rose prominently not only due to the lack of the key oil properties, but also the material sources, handling and extraction. Bio-lubricant seems need much more effort, time and development so that, these lubricant can competed with the standard conventional lubricant. But with current demand, time was the main figure that limit to producing better lubricant.

Nanolubricant currently been pop up in tribological fields, the idea was by mixing the nano-size solid particle into the lubricating oils. Result from the combination, several researchers found out that, COF and wear reduce significantly with this nanolubricant, some tribological mechanism also were found and explored. A lot of techniques and method then were introduced to stable these solid particles between the lubricating molecules. The finding of nanoparticles that can reduce the friction and wear become more challenging due to the limitation size of the nanoparticles, but the results are always promising for better lubricating properties. The development of this nanolubricant has not been up to commercialization yet due to the current investigation only up to lab scale test only. Hsiao et al. (2009) found out that, diamond nanoparticle impressively reduce the COF tested together with several lubricating oil. But the cost of nano-size diamond is much more expensive compared to the cost of replacing the engineering component, which are not cost effective to solve the current industrial issue.

## 1.2 Problems Statement

The need to increase the performance of engine to obtain maximum output (power, torque) while improving fuel economy and reducing emissions is constantly sustaining the demand for research into combustion, fuels and lubricants. As a matter a fact, no less than one third of vehicle fuel consumption is spent in overcoming friction. These friction losses cause a huge direct impact on both fuel consumption and emissions. Moreover, the component wear rate increases year by year due to raw material limitation. Materials become more expensive and the process becomes more challenging. Along with maximizing the output power, another concern related to this issue is regarding air pollution. A better lubricant can be a major factor in reducing the impact of the transportation system to the environment. The failure to properly address this problem could lead to many problems which could prove to be disastrous, be it towards global health, or the environment as a whole.

A lot of lubricant currently been developed with several new formulation been introduced. Logically the lubricating properties should be improved but in realistic it was not up to expectation. The search for new formulation and new additives begin with the occurrence of nano-technology. There are many works conducted involved with this nano-size additive which been details discuss in the section 2.3 and the research gap are clearly been defined.

Nowadays, a study on the effect of hexagonal boron nitrite (hBN) nanoparticles as lubricating oil additive on tribological performance, emissions and fuel consumption of a diesel engine has not yet been studied especially on SAE 15W40 grade conventional diesel engine oil which is cheap and easy to get in the market. The friction loss in a vehicle has a direct impact on both fuel consumption and emissions; and nano-based lubricants are effective in decreasing level of friction and wear of components; therefore, it would be