Faculty of Mechanical Engineering

OPTIMIZATION OF BORON-BASED NANOLUBRICANT FOR DIESEL ENGINE

Muhammad Ilman Hakimi Chua Bin Abdullah

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.

Signature : ……

Name : ……

Date : ……

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.

TABLE OF CONTENTS

		PAGE
DECLARATION		
DEDICATION		
ABSTRACT		**i**
ABSTRAK		**ii**
ACKNOWLEDGEMENTS		**iii**
TABLE OF CONTENTS		**v**
LIST OF TABLES		**vii**
LIST OF FIGURES		**viii**
LIST OF ABBREVIATIONS		**xiii**
LIST OF PUBLICATIONS		**xiv**
CHAPTER		
1.	**INTRODUCTION**	**1**
1.1	Background	1
1.2	Problems Statement	3
1.3	Objective of the thesis	5
1.4	Contribution of this study	6
1.5	Scope of Work	7
1.6	Thesis Flow Structure	8
2.	**LITERATURE REVIEW**	**11**
2.1	The Search for Better Lubricant	11
2.2	The Theory of Lubricant	16
2.3	The Coefficient of Friction (COF)	20
2.4	Nanoparticles as Solution Additives	22
2.5	Design of Experimental (DOE)	27
2.6	Physico-Chemistry Properties	30
2.7	Lubricant Dilution by Fuel	32
2.8	Engine Performance	35
2.8.1	Dynamometer	36
2.8.1.1	Detailed Dynamometer Description	37
2.8.2	Power and Torque over Speed	39
2.8.3	Brake Specific Fuel Consumption (B.S.F.C)	42
3.	**METHODOLOGY**	**46**
3.1	Experimental method	46
3.1.1	Design of Experiment (DOE)	48
3.1.2	Material and Sample Preparation	49
3.1.3	Friction Test	50
3.1.4	Surface Morphology and Chemical Composition Observations	51
3.2	Physico-chemical Characterization	53
3.2.1	Viscosity/Viscosity Index test measurement	53
3.2.2	Total Acid Number (TAN) and Total Base Number (TBN) measurement	54
3.2.3	Flash Point Measurement and Flash Temperature	55

Parameter Calculation
3.2.4 Stability Test (pH control) 56
3.3 Dilution Method for Optimized Nano-oil 58
3.4 Engine Performance Testing Method 59
3.4.1 Engine Performance and Emission Test 59
3.4.2 Fuel Consumption Measurement 60
3.4.3 Surface Morphology Observation 60

4. RESULT AND DISCUSSIONS 61
4.1 Quantitative Analysis based on Taguchi Method 61
4.1.1 Analysis of the S/N ratio and Mean for COF 61
4.1.2 Analysis of Variance (ANOVA) for COF 64
4.1.3 Confirmation Test 65
4.2 Friction and Wear Mechanisms 67
4.3 Physical-Chemical Properties 73
4.3.1 Kinematic Viscosity and Viscosity Index 73
4.3.2 TAN/TBN Residual 75
4.3.3 Flash Point and Flash Temperature Parameter (FTP) 77
4.3.4 FTIR Analysis 78
4.3.5 Stability Analysis 81
4.4 Fuel Dilution on the Nano-Oil 87
4.4.1 Effect of Diluted Nano-oil on Coefficient of Friction (COF) 87
4.4.2 Effect of Diluted Nano-oil on Wear Properties 90
4.5 Engine Performance Validation of the Optimized Nano-Oil 92
4.5.1 Torque and Power 92
4.5.2 Brake Specific Fuel Consumption (B.S.F.C) 94
4.5.3 Emissions Characteristic 95
4.5.4 Piston Ring Wear 96

5. CONCLUSIONS 99
5.1 Summaries of conclusions 99
5.2 Recommendation for Future Research 102

6. REFERENCES 103
7. AWARDS 117
8. APPENDICES 118

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Relationship between λ and the lubricant regime	17
2.2	Physical property of hBN and Al_2O_3 nanoparticles	27
2.3	Representative petroleum lubricating oils	31
3.1	The hBN/Al_2O_3 vol.% and experimental condition: three parameters and three levels	48
3.2	DOE with L_9 (3^3) orthogonal arrays	48
3.3	Sample composition assign to each pH value	57
3.4	Mixing ratio for each sample	57
3.5	Properties of Standard and B100 biodiesel at room temperature	58
3.6	Engine specification as referred to engine details catalogue	59
4.1	ANOVA for COF S/N ratios	64
4.2	ANOVA for COF Means	65
4.3	Summarized calculation for 95% CI for COF	66
4.4	Lubrication regime for conventional diesel engine oil and optimized nano-oil	68
4.5	Nano-oil pH controls image screening for 60 days observation	86

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Thesis flow structure	10
2.1	Schematic structure of the ZDDP tribo-film according to the multi-technique approaches	14
2.2	Layer structure of surface formed from ZDDP	15
2.3	TEM image recorded onto an anti-wear film particle and corresponding electron diffraction pattern. (b) X-ray spectrum (EDX). The anti-wear film is composed of iron (from contacting surfaces) and elements present in the ZDDP additive (O,P,S,Zn). (c) and (d) FE and Zn Radial Distribution Function (RDF uncorrected from phase shifts) extracted from EXAFS experiments on ZDDP anti-wear film particles.	15
2.4	Summaries types of common lubricants	17
2.5	Schematic diagrams of Stribeck Curve	19
2.6	Schematic diagram for geometry cap calculation	21
2.7	Chemical bonding of (a) hBN, (b) Al2O3, and SEM shapes of (c) hBN nanoparticle, (d) Al2O3 nanoparticles	26
2.8	Fuel blow by (a) compression stroke and (b) power stroke	34
2.9	Schematic diagram for dynamometer setup of engine, torque	38

	measurement arrangement and tachometer	
2.10	Brake power and torque of Yanmar 170F single-cylinder reciprocating engine as a function of engine speed and displacement	41
2.11	Brake specific fuel consumption as a function of engine speed	42
2.12	(a) Jaguar V12 HE power, torque and B.S.F.C curve over speed, (b) Difference B.S.F.C for different engine loads	44
2.13	Power output at quarter throttle, half throttle and full throttle	45
3.1	Details thesis methodology flow chart	47
3.2	Schematic diagram sample preparation by using ultrasonic method	49
3.3	Schematic diagram of a four-ball tester	50
3.4	(a) Cross sectional area for 4-ball test cup and (b) wear scar diameter (WSD)	51
3.5	Schematic diagram of SEM concept	52
3.6	Schematic diagrams of the flash point apparatus	56
3.7	Schematic diagrams for overall engine performance test setup	59
4.1	Main effect plots for S/N ratio's effect on COF	62
4.2	Main effect plots for means effect on COF	63
4.3	The percentage comparison obtain by ANOVA for S/N ratio and mean	65
4.4	COF by 0.5 vol.% composition of hBN nanoparticle and Al_2O_3 nanoparticles with 0.3 vol.% surfactant	66
4.5	COF repeatability tests of nano-oil and conventional engine oil	68
4.6	Comparison coefficient of friction between optimized nano-oil and	69

	conventional engine oil	
4.7	SEM image and EDS analysis for debris from nano-oil	69
4.8	SEM image (a) worn generated tested by SAE 15W40, (b) worn generated tested by Nano-oil, (c) Wear track/tribofilm of nano-oil and (d) EDS image of tribofilm	70
4.9	Wear rates of ball materials lubricated under conventional diesel engine oil and optimized nano-oil	71
4.10	SEM micrograph of the worn surfaces of the material lubricated by (a) conventional diesel engine oil and (b) optimized nano-oil	72
4.11	Kinematic viscosity and viscosity index comparisons between nano-oil (with 0.5 vol.% hBN) and conventional engine oil (SAE 15W40)	74
4.12	Viscosity-temperature characteristics of selected oils	74
4.13	TAN/TBN side by side comparisons between optimized nano-oil with SAE 15W40 conventional engine oil	76
4.14	FTP and flash point temperature of nano-oil and SAE15W40	77
4.15	FTIR spectrum of the BN-nanostructured material showing the bands corresponding to a mixture of hexagonal and cubic BN particles	79
4.16	The FTIR transmittance wavelengths for SAE15W-40 before/after performance test and nano-oil before/after performance test	80
4.17	The absorbency curve of nano-oil with time	81
4.18	Photograph of oil solution with different nanoparticles after (a) 24 hours, (b) 168 hours and (c) 720 hours	83

4.19	Nano-oil pH controls UV-spectrometer absorbance for 60 days observation	84
4.20	Schematic illustrations for (a) electrical double-layer, (b) attractive force between double –layer and (c) repulsive force between double –layer	85
4.21	COF of diluted SAE15W40 and diluted nano-oil at 1800s	88
4.22	COF of diluted SAE15W40 and diluted nano-oil at 3600s	88
4.23	Dynamic Viscosity vs. percentage of dilution for diluted SAE15W40 and diluted Nano-oil	89
4.24	Lubricant thicknesses vs. percentage of dilution for diluted SAE15W40 and diluted Nano-oil	89
4.25	Average wear rates vs. percentage of diluted SAE15W40 and optimized Nano-oil	90
4.26	SEM images of the worn surfaces on the ball bearing tested by Nano-oil diluted with 15 vol.% B100 biodiesel fuel with clear grooves formed by minor abrasive wear	91
4.27	SEM images of the worn surfaces on the ball bearing tested by SAE 15W40 oil diluted with 15 vol.% B100 biodiesel fuel with (a) major adhesive wear and, (b) pitting and scuffing surfaces	91
4.28	Optimized Nano-oil effectively improve both maximum (a) power and (b) torque of a small diesel engine	93
4.29	Trend of BSFC over speed for SAE 15W40 with and without hBN nanoparticles	94
4.30	Gas emission Hydrocarbon, HC and Carbon dioxide, CO_2 produce	95

again speed

4.31 Wear rate (mass losses) of piston ring tested by conventional engine oil and optimized nano-oil 96

4.32 SEM micrograph of piston ring surfaces (a) new piston ring, (b) lubricated with 15W40 diesel engine oil and, (c) lubricated with nano-oil 97

4.33 Mending effect occurred due to the boron element entrapped and deposited in the contact areas of piston ring when lubricated with nano-oil 97

4.34 Illustrated of mending effect of hBN nanoparticles occur at the asperities on the piston ring contact area 98

LIST OF ABBREVIATIONS

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

LIST OF PUBLICATIONS

JOURNALS

Abdullah, M.I.H.C., Abdollah, M.F.B., Amiruddin, H., Tamaldin, N., Mat Nuri, N.R., 2015. The Potential of hBN nanoparticles as friction modifier and antiwear additive in engine oil. *Mechanics and Industry,* 17, pp. 104. (ISI Indexed).

Abdullah, M.I.H.C., Abdollah, M.F.B., Amiruddin, H., Tamaldin, N., Mat Nuri, N.R., Accepted for publication, 2015. Effect of Diluted Nano-Oil on the Anti-wear and Friction Properties. *Advanced Materials Research,* (Scopus indexed).

Abdullah, M.I.H.C., Abdollah, M.F.B., Amiruddin, H., Mat Nuri, N.R., Tamaldin, N., Hassan, M., Rafeq, S.A., 2014. Effect on hBN/Al_2O_3 Nanoparticles on Engine Oil Properties. *Energy Education Science and Technology Part A,* 32 (5), pp. 3261-3268. (Scopus indexed).

Abdullah, M.I.H.C., Abdollah, M.F.B., Amiruddin, H., Mat Nuri, N.R., Tamaldin, N., Hassan, M., Rafeq, S.A., 2014. Improving Engine Oil Properties by Dispersion of hBN/Al_2O_3 Nanoparticles. *Applied Mechanics and Materials,* 607, pp. 70-73. DOI: http://dx.doi.org/10.4028/www.scientific.net/AMM.607.70. (Scopus indexed).

Abdullah, M.I.H.C., Abdollah, M.F.B., Amiruddin, H., Tamaldin, N., Mat Nuri, N.R., 2014. Effect of hBN/Al_2O_3 Nanoparticles Additives on the Tribological Performance of Engine Oil. *Jurnal Teknologi* (Sciences and Engineering), 66 (3), pp. 1-6. DOI: http://dx.doi.org/10.11113/jt.v66.2685. (Scopus indexed)

Abdullah, M.I.H.C., Abdollah, M.F.B., Amiruddin, H., Tamaldin, N., Mat Nuri,

N.R., 2013. Optimization of Tribological Performance of hBN/Al_2O_3 nanoparticles as Engine Oil Additives, *Procedia Engineering,* 68, pp. 313-319. DOI: http://dx.doi.org/10.1016/j.proeng.2013.12.185. (Scopus indexed)

PROCEEDINGS

M.I.H.C. Abdullah, N. Tamaldin, M.F.B. Abdollah, H. Amiruddin, N.R. Mat Nuri, The Effect of hBN Nanoparticles on The Extreme Pressure Lubrication, Proceeding of 1st International Conference on Tribology, TURKEYTRIB'15, Istanbul, Turkey, 7~9 October 2015.

M.I.H.C. Abdullah, M.F.B. Abdollah, N.R. Mat Nuri, H. Amiruddin, N. Tamaldin, Evaluations of Piston Ring Wear Using Nano Lubricant Oil in Small Diesel Engine, Proceedings of Malaysian International Tribology Conference 2015, Penang, Malaysia, 16~17 November 2015.

M.I.H.C. Abdullah, M.F.B. Abdollah, N.R. Mat Nuri, H. Amiruddin, N. Tamaldin, Comparison of the Frictional Properties of nano-Oil and SAE 15W40 Oil Diluted with Biodiesel Fuel, Proceedings of Malaysian International Tribology Conference 2015, Penang, Malaysia, 16~17 November 2015. (Accepted for publication).

H. Amiruddin, M.F.B. Abdollah, A.M. Idris, M.I.H.C. Abdullah, N. Tamaldin, Stability of nano-Oil by pH Control in Stationary Conditions, Proceedings of Mechanical Engineering Research Day 2015, Melaka, Malaysia, 31 March 2015.

M.F.B. Abdollah, M.I.H.C. Abdullah, H. Amiruddin, N. Tamaldin, N.R. Mat Nuri, The hBN Nanoparticles as Effective Additives in Engine Oil to Enhance the Durability and Performance of a Small Diesel Engine, Proceedings of 41th Leeds-Lyon Symposium on Tribology 2014, Leeds, United Kingdom, 2~5 September 2014.

M.F.B. Abdollah, M.I.H.C. Abdullah, H. Amiruddin, N. Tamaldin, N.R. Mat Nuri, Drive to Greener Future: Tribological and Engine Performances of Nano-oil, Proceedings of JAST Tribology Conference 2014 (International Forum on Front-line of Tribology is Asia Region), Tokyo, 19~21 May 2014.

M.I.H.C. Abdullah, M.F.B. Abdollah, H. Amiruddin, N.R. Mat Nuri, Optimized Nanolubricant for Friction Reduction, Proceedings of 40th Leeds-Lyon Symposium on tribology & tribochemistry Forum 2013, lyon, France, 4~6 September 2013.

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