OPTIMISATION OF PALM OIL BIODIESEL COMBUSTION IN COMMON RAIL FOR SMALL CAR ENGINE

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To my beloved mother and father

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ABSTRACT

Operating a diesel engine with biodiesel increases fuel consumption and NOx emission while producing significantly low black smoke. This is due to the inherent chemical and physical properties of biodiesel which results in un-optimised engine operating parameters. This study presents the investigation on the effects of palm oil biodiesel on the performance and emissions of a common rail passenger car engine and proposes a simplified control strategy for fuel economy optimisation for biodiesel operation. Firstly, the effects of the biodiesel on the emissions and fuel economy of a Euro2 1.5 litre engine was mapped by conducting extensive engine dynamometer and emissions testing across all operating regions. The region with significant difference between conventional and biodiesel fuels was identified for optimisation. Secondly, the effects of the fuel injection parameters to the performance and emission was studied by conducting fuel rail pressure and injection timing sweep at each speed and load region. Finally, the optimised injection parameters were determined by Multiple Response Weighted Signal to Noise Ratio techniques. It was found that the low to medium engine speed and load region, from 2000 rpm to 3000 rpm and 25% to 50% load, is where the difference between conventional and biodiesel is most significant with increased NOx and fuel consumption while the smoke emission is reduced by as much as 56%. The adopted fuel injection control strategy involved the adjustment of the end of injection timing and the fuel rail pressure. It was demonstrated that the optimised injection parameters were at the nominal end of injection settings while the rail pressure at 3% to 9% lower than nominal. Fuel economy improvement of as high as 5% was demonstrated while the NOx and smoke emissions were kept within the diesel values. At medium speed and load for 20% biodiesel, brake specific fuel consumption of 2% lower than diesel was achieved. In conclusion, a new, simplified fuel injection parameters optimisation strategy for palm oil based biodiesel was successfully developed and demonstrated, which could be applied via piggyback system for immediate application.

ABSTRAK

Penggunaan biodiesel boleh meningkatkan penggunaan bahan api dan pelepasan NOx disamping mengurangkan asap hitam. Ini kerana sifat fizikal dan kimia biodiesel menyebabkan operasi enjin dan sistem pancitan bahan api yang tidak optima. Tesis ini melaporkan kajian yang dijalankan untuk mengkaji kesan penggunaan biodiesel sawit terhadap prestasi enjin dan pelepasan asap enjin 1.5 liter dengan sistem rel sepunya, dan seterusnya mengusulkan satu strategi mudah untuk pengoptimuman prestasi enjin tersebut. Ia bermula dengan pemetaan perubahan pelepasan asap dan penggunaan bahanapi untuk enjin berkenaan yang berkait dengan penggunaan biodiesel melalui ujian dinamometer dan pelepasan gas pada seluruh kawasan operasi enjin. Dari peta tersebut, kawasan operasi enjin yang paling terkesan oleh biodiesel dikenalpasti untuk pengoptimuman. Seterusnya, kesan pengubahan parameter sistem pancitan bahanapi terhadap prestasi dan pelepasan asap diukur dan kaedah *Multiple Response Weighted Signal to Noise Ratio* digunakan untuk menentukan parameter yang paling optima. Selanjutnya strategi pengoptimuman sistem pancitan bahanapi melalui tekanan dan pemasaan pancitan diusulkan. Hasil kajian ini mendapati operasi enjin pada tahap kelajuan enjin dan bebanan yang sederhana, sekitar 2000 rpm ke 3000 rpm dan bebanan dari 25% ke 50%, adalah paling terkesan dengan penggunaan biodiesel di mana pelepasan NOx dan penggunaan bahanapi meningkat dengan ketara sementara pelepasan asap hitam turun sehingga 56%. Penggunaan strategi pelarasan system pancitan bahanapi yang dicadangkan berjaya menurunkan penggunaan bahanapi sementara mengawal pelepasan asap pada tahap yang sama seperti minyak diesel. Penjimatan penggunaan bahanapi sehingga 5% dapat dicapai dibandingkan dengan operasi sistem pancitan yang asal. Pada kelajuan dan bebanan yang sederhana, penggunaan bahapi 2% lebih rendah daripada diesel dapat diperolehi untuk bahanapi 20% biodiesel. Sebagai kesimpulan, satu strategi pengoptimuman sistem pancitan bahanapi yang mudah telah berjaya dibangunkan dan ditunjukkan serta sedia digunapakai di kenderaan diesel dengan sistem pancitan rel sepunya.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	-	Analysis of Variance
ATDC	-	After Top Dead Centre
BMEP	-	Brake Mean Effective Pressure
BSFC	-	Brake Specific Fuel Consumption
BTDC	-	Before Top Dead Centre
CA	-	Crank Angle
CLCC	-	Closed Loop Combustion Control
CO	-	Carbon Monoxide
DI	-	Direct Injection
ECU	-	Electronic Control Unit
EGR	-	Exhaust Gas Recirculation
EOI	-	End of Injection
FBP	-	Final Boiling Point
FC	-	Fuel Consumption
GCV	-	Gross Calorific Value of the fuel
HC	-	Hydrocarbon
HSDI	-	High Speed Direct Injection
IBP	-	Initial Boiling Point
IDI	-	Indirect Injection
MRWSN	-	Multiple Regression Weighted Signal to Noise
$\dot{m}_f$	-	Fuel mass flow rate
N	-	Engine speed, rpm
NEDC	-	New European Driving Cycle
NOx	-	Oxides of Nitrogen

OBD	-	Onboard Diagnostics
P	-	Rail Pressure
P	-	Engine Power
PAH	-	Polyaromatic Hydrocarbons
PWM	-	Pulsewidth modulation
SN	-	Signal to Noise Ratio
SOI	-	Start of Injection
STB	-	Smaller the Better
T	-	Engine Torque
T50	-	Temperature at 50% evaporation
T90	-	Temperature at 90% evaporation
TDC	-	Top Dead Centre
w	-	Weightage for each target response in Taguchi method
WSN	-	Weighted Signal to Noise
η_{th}	-	Brake Thermal Efficiency

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CHAPTER 1

INTRODUCTION

1.1 Background

Due to economic and socio-political reasons, biodiesel use has been gaining popularity since its introduction into the transportation industry. In Malaysia, the use of palm oil biodiesel has been mandated since 2007 by the introduction of its Malaysian Bio-fuel Policy (Ministry of Plantation Industries and Commodities, 2006). The biodiesel use in Malaysia could be increased in the near future to 10% blending with conventional diesel fuels. While the application of biodiesel could be used to serve as a price control mechanism for the palm oil commodity, it also has several technical advantages in terms of emissions, being carbon neutral and reducing dependency on fossil fuels.

It is important to note however, that the use of biodiesel in an engine is not without issues. A well-known fact about the disadvantage of biodiesel use is in the increased fuel consumption as a result of its lower calorific values. Although biodiesel could significantly reduce the soot emissions, the NOx emissions from biodiesel has generally been reported to increase particularly at some operating conditions at part load. In addition, running an engine on biodiesel fuel has some effects on the fuel system response. For example, the higher bulk modulus and viscosity of biodiesel could change the injection behaviour by advancing the injection and altering the spray pattern. For common rail engine, the low energy density of biodiesel would force the engine to operate at a different region on the map in the ECU for the same power output. All these would result in un-optimised operation of the engine.

It has been shown that different types of biodiesel could result in significantly different response towards its performance and emission. The inherent difference in the fuel properties related to the origins of the plant oil contributes to these changes in performance. Palm oil for example, has more saturated chain components in comparison to other biodiesel that leads to higher cetane number and higher oxidation stability, however, gives poor cold flow properties. The high cetane number has contradictory effects on the emissions – on one hand, reduction of premixed combustion phase could reduce NOx emissions, but increase soot formation. On the other hand, high cetane leads to advanced combustion timing that could increase NOx and reduces soot. Other physical properties of biodiesel such as viscosity, density and bulk modulus could change the behaviour of the injection and the atomisation. This may lead to simultaneous positive and negative effects to the performance and emissions of a diesel engine. It is thus important to measure and study the compounded effects of these properties of biodiesel.

Optimising this performance and emissions trade-offs is possible by a variety of means – including mechanical approach such as nozzle design and locations, compression ratio optimisation and fuel injection control parameter adjustments. With the introduction of electronically controlled common rail fuel injection system, optimising engine performance and emission becomes more flexible. This is due to the ability for independent adjustment of the injection parameters and the possibility to revert to diesel operation when there is a fuel switch-over.

Review of existing literatures found that previous works on palm oil biodiesel study, especially on common rail passenger car technology, are limited. Most of the study involved either the low pour point palm oil methyl esters (which had lower cetane numbers), or focused on medium to heavy duty engines. Particularly, the study involving optimisation of palm oil biodiesel combustion in an engine are limited to low pour point biodiesel and mostly on mixture of biodiesels which has lower cetane numbers. Given the unique properties of palm oil methyl esters as well as the lack of available literatures, necessitates a study on its common rail fuel system response, the effects in small high speed passenger car engine, and its optimised operation.

1.2 Problem Statement

Biodiesel combustion in an engine has trade-offs in terms of its performance, fuel economy and emissions. Generally, operating with biodiesel yield significantly reduced soot emissions but at the expense of increased fuel consumption and higher NOx emissions. Unique fuel properties of different origins of the biodiesel contributes to the varying response in terms of performance and emissions. Palm oil methyl esters has more saturated chains hydrocarbons, higher iodine values, higher cetane but poor low temperature properties in comparison to other biodiesel. Thus, it is important to study the compounded effects on the engine performance and capitalize on the desirable properties of this biodiesel for use in warm climate regions. In addition, running an engine with biodiesel when the engine parameters are set for diesel operation is expected to result in poor performance and/or emissions. Hence, it is envisaged that there is a need for optimising the engine for palm oil biodiesel that provide minimum fuel consumption without sacrificing the emissions. This would eventually lead to true fuel flex vehicles where switching from conventional diesel and biodiesel is seamless.

In addition, there is inadequate assessment of palm oil biodiesel in common rail engine technology. Most of the previous works dealt with conventional mechanical type fuel system. Some efforts on common rail are focusing on emissions and focusing on low concentration of biodiesel and using other biodiesel than palm oil based. Thus, there is a need to comprehensively study the performance, emissions and combustion characteristics of palm oil biodiesel, particularly the high pour point biodiesel.

1.3 Research Hypothesis

Base palm oil methyl esters has high cetane number which could offer interesting opportunity for emissions and performance of diesel engine. However, most of the previous works done on palm oil biodiesel in common rail diesel engine uses low pour point biodiesel. This biodiesel has lower cetane and less unsaturated

components, as a result of distillation process required to reduce the pour point. This may have markedly different combustion behaviour than the base palm oil biodiesel. Note that for Malaysia, high pour point palm oil methyl ester pose no problem for application in transportation sector. This is because Malaysian climatic temperature is consistently high throughout the year. Thus, there is a need to study the effects of this biodiesel in common rail settings on the performance, emissions and fuel system response.

As shown by literatures, fuel properties may have positive or negative effects on the engine performance and emission. High cetane number of palm biodiesel for example, would possibly increase smoke and reduce NOx emissions for its shorter premixed burn, but at the same time advance the ignition which could results in increased NOx. On the other hand, the high oxygen content of biodiesel would help soot oxidation. These contradicting effects points to the need to study the effect on combustion of high cetane palm biodiesel and looks for opportunity of optimising the combustion. In short, there is a need to optimise the common rail engine operation for biodiesel use.

The adjustment of the engine and fuel injection settings such as the injection timing, injection pressures, EGR, engine designs, have significant, well known impact on the performance and emissions. One could expect that by using different fuels such as biodiesel, changes in the fuel injection parameters settings could help improve the drawbacks inherent to that type of biodiesel. Each parameters need to be checked and optimised for each fuel types if the lowest emissions are to be achieved at best performance. Common rail engine offers unique opportunity for optimisation as it is a flexible system whereby independent adjustment of the fuel injection parameters are possible. Thus, there is a need to study the effects of changing the fuel injection parameters on the palm oil based biodiesel performance and emissions.

Although a number of research had been done on optimisation of biodiesel combustion on common rail engines, the effects on high cetane biodiesel such as palm oil is not available. Optimisation with close loop combustion control system allows for putting the emissions in check, but without optimising the fuel economy. Hence this

study deals with the optimisation of the common rail operation for palm oil biodiesel with the aim of minimising the fuel consumption while keeping the emissions in check. Given the optimisation would involve multiple response problem, a statistical approach is required to minimise the number of engine tests and calibration work.

From the review of the previous works, a research hypothesis can be drawn. Given the high cetane number of palm oil based biodiesel, it is expected that the NOx emissions increase is minimized due to its altered ignition behavior. Besides, the inherent properties of oxygenated fuels provide significant smoke emission reduction. Hence, the unique properties of palm oil based biodiesel would allow for optimized operation by means of altering the fuel injection strategies of a common rail engine.

1.4 Objectives of the Study

The objectives of the study are as follows:

i. To investigate the effects of palm oil methyl ester on the performance, fuel consumption, emissions and fuel system response of a passenger car with common rail fuel injection system.
ii. To investigate the effects of fuel injection parameters on the performance and emissions of palm biodiesel and its blends
iii. To develop and validate the optimisation strategy for palm oil biodiesel on common rail passenger car engine through fuel injection parameters adjustment.

1.5 Significance and Scopes of the Study

The study will shed some light on the trade-off between performance and emissions of palm oil biodiesel operating in modern common rail diesel engine. The

best settings for injection strategy will be highlighted. The results would be beneficial in control strategies development for the future fuel flex vehicle for biodiesel.

The research will be covered by the following scope of work:

i. The assessment and optimization is to be conducted on common rail passenger car engine that meets Euro 2 emissions standards.
ii. Baseline performance and emissions study of neat diesel and palm oil biodiesel blended fuels shall be carried out with measured parameters of power, fuel consumption, fuel system response, NOx and soot emissions. The baseline performance shall be carried out at full span of engine speeds and at 25%, 50%, 75% and100% load.
iii. The optimization of fuel injection parameters shall be carried out at the speeds and load selected based on the significant difference in terms of performance and emissions in comparison to diesel fuel.

1.6 Organisation of the Thesis

This thesis comprises of five chapters which covers the introduction, literature review, methodology and experimental setup, results on engine performance and emissions, optimisation of fuel injection parameters, the validation of the optimisation strategy and finally the conclusion and recommendations.

Chapter 1 provides the background of the study by describing the trade-offs of biodiesel combustion in an engine. It also gives the motivation for this study and describes the objectives and scope of work.

Chapter 2 discusses the previous works on the biodiesel performance, emissions and fuel system response and explains the current position of the research in these areas. Mainly it describes the issues and challenges including the trade-offs of biodiesel and their properties effects on engine performance and emissions.

Chapter 3 details the experimental setup and the methodology adopted for this study. It describes the equipment used, the modification to the engine, and data acquisition and the methods implemented for the engine tests.

Chapter 4 presents the results of the study. This chapter discusses the performance, emissions, fuel consumption and the fuel system response of the palm oil biodiesel and provides the comprehensive map of the parameters measured. Here, the best operating region for optimisation in obtaining maximum benefit is identified. Subsequently it elaborates the effects of changing the fuel injection parameters on the fuel economy, thermal efficiency and the smoke and NOx emissions. Trends in terms of the response with respect to biodiesel use is presented here. Finally, it discusses the optimisation effort for the fuel injection parameters to achieve minimum fuel consumption while keeping the emissions to within diesel values. Statistical method adopted for the optimisation is presented and a simple control strategy is proposed here, followed by the validation of the strategy using palm oil biodiesel as well as yellow grease biodiesel

Chapter 5 concludes the study based on the results and recommend further areas for study of this type of biodiesel.

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