UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL INVESTIGATION ON PERFORMANCE OF HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINE FUELED WITH PALM OIL BASED BIODIESEL

HASYUZARIZA BINTI MUHAMAD TOBIB

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By

HASYUZARIZA BINTI MUHAMAD TOBIB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

September 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chair : Associate Professor PhD Abdul Aziz Bin Hairuddin, PhD
Faculty : Engineering

Fossil fuel is the main resource to fuel Internal Combustion Engine (ICE). High gases exhaust emission and finite resources of fossil fuel are the major problems in ICE industry. Biodiesel fuels with Homogeneous Charge Compression Ignition Engine (HCCI) have the potential to replace the current conventional engine, which can reduce the emissions levels and also the dependency towards fossil fuel. The objectives of the study are to improve the performance and emissions levels of HCCI engine fuelled with palm oil-based biodiesel. For this purpose, single cylinder diesel engine with a port fuel injector and heated intake air was used to operate the HCCI engine at 2700 rpm. The fuels used for this study were diesel and palm oil-based biodiesel with four different blends of 5%, 10%, 15%, and 20% (POB5, POB10, POB15, and POB20, respectively). The parameters varied for the study were different air fuel ratio (lambdas,λ) of 3.1, 2.9, 2.6, 2.4 and intake air temperature of 70, 80, and 90°C. When using diesel fuel on HCCI mode, engine power, torque, brake thermal efficiency (BTE) were lower and brake specific fuel consumption (BSFC) was higher compared to compression ignition direct injection (CIDI) mode. The in-cylinder pressure pattern and heat release rate (HRR) for HCCI mode shows the combustion is advanced and the peak is higher at rich mixture compared to CIDI mode. The power and torque produce from HCCI mode is lower compared to CIDI mode by 12%. On both engine mode, the power produce for POB is reduced by 6% than diesel fuel. The BSFC for HCCI was higher than CIDI mode, however, BSFC reduced by 13% as increased POB. The BTE in HCCI reduced by 5% than the CIDI mode. The BMEP reduced when operated in HCCI mode by 13% whereas, increase by 7% when increased air intake temperature. Nitrogen dioxide (NO_x) emission of HCCI reduces drastically while hydrocarbon (HC) and carbon monoxide (CO) are higher than CIDI mode. NO_x emissions at HCCI mode reduce by over 90%. By increasing the amount of biodiesel will increase the NO_x emissions but NO_x at

HCCI mode still lower than that of CIDI. When the amount of POB increased HC and CO were improved (decrease) by 15% and 18% respectively. The emission of carbon dioxide (CO_2) was also decreased by 25%. This means that biodiesel fuel improved the emission of HCCI. Therefore, it can be concluded that POB was one of potential alternative fuel to replace the conventional diesel fuel in HCCI engine, as it provides the alternative way to reduce the dependency to fossil fuel, thus decreasing the percentage of emission levels.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

EKPERIMEN MENGKAJI PENGGUNAAN CAMPURAN MINYAK SAWIT BIODIESEL KEATAS ENJIN PENCUCUHAN MAMPATAN CAS HOMOGEN

Oleh

HASYUZARIZA BINTI MUHAMAD TOBIB

September 2019

Pengerusi : Profesor Madya Abdul Aziz Bin Hairuddin, PhD
Fakulti : Kejuruteraan

Bahan api fosil merupakan sumber utama digunakan dalam industry pembakaran dalaman enjin (ICE). Pertambahan pembebasan ekjos gas dan kekurangan bahan api fossil merupakan masalah besar dalam industri ICE. Minyak biodiesel dengan Enjin Pencucuhan Mampatan Cas Homogen (HCCI) berpotensi menggantikan konvensional diesel enjin dimana dapat mengurangkan kadar pembebasan gas ekjos dan juga dapat mengurangkan kebergantungan kepada bahan api fosil. Objektif dari kajian ini adalah untuk menambahbaik prestasi dan pembebasan gas ekjos dari enjin HCCI menggunakan biodiesel kelapa sawit. Untuk tujuan ini, sebuah enjin diesel satu silinder dengan penyuntik bahan api liang dan udara masukan terpanas digunakan untuk mengendalikan enjin HCCI pada kelajuan enjin 2700 rpm. Bahan api yang digunakan untuk kajian ini ialah campuran diesel dan minyak kelapa sawit dengan empat campuran yang berbeza iaitu 5%, 10%, 15% dan 20% (POB5, POB10, POB15 dan POB20). Parameter yang digunakan untuk mengkaji prestasi, ciri pembakaran dan pelepasan adalah menggunakan perbezaan nisbah bahan api dan udara (lambda,λ) = 3.1, 2.9, 2.6, 2.4 dan suhu udara masukan pada 70°C, 80°C dan 90°C untuk mengkaji prestasi enjin keadaan HCCI yang berbeza. Apabila menggunakan bahan api diesel pada mod HCCI, kuasa enjin, tork, kecekapan terma brek (BTE) adalah lebih rendah dan penggunaan bahan bakar brek spesifik (BSFC) lebih tinggi berbanding mod suntikan langsung penyalaan mampatan (CIDI). Corak tekanan dalam silinder dan kadar pelepasan haba (HRR) untuk mod HCCI menunjukkan pembakaran maju kehadapan dan puncaknya lebih tinggi pada campuran yang kaya berbanding mod CIDI. Kuasa dan tork yang dihasilkan dari mod HCCI adalah lebih rendah berbanding dengan mod CIDI sebanyak 12%. Pada kedua-dua mod enjin, kuasa yang dihasilkan deangan menggunakan POB berkurang sebanyak 6% daripada bahan api diesel. BSFC untuk HCCI adalah lebih tinggi daripada mod CIDI, bagaimanapun, BSFC berkurang sebanyak 13% apabila POB meningkat. BTE pada HCCI berkurang

sebanyak 5% daripada mod CIDI. BMEP berkurang sebanyak 13% apabila dikendalikan dalam mod HCCI manakala, meningkat sebanyak 7% apabila suhu udara meningkat. Pembebasan nitrogen dioksida (NOx) menurun secara drastik sementara hidrokarbon (HC) dan karbon monoksida (CO) lebih tinggi daripada mod CIDI. Pelepasan NO_x pada mod HCCI berkurang sebanyak 90%. Apabila jumlah biodiesel ditingkatkan. akan meningkatkan pelepasan NO_x tetapi NO_x pada mod HCCI masih lebih rendah daripada mod CIDI. Apabila jumlah POB meningkat, HC dan CO menjadi bertambah baik (menurun), masing-masing sebanyak 15% dan 18%. Pembebasan karbon dioksida (CO_2) juga menurun sebanyak 25%. Ini bermakna bahan bakar biodiesel meningkatkan pelepasan HCCI. Oleh itu, dapat disimpulkan bahawa POB adalah salah satu bahan bakar alternatif yang berpotensi untuk menggantikan bahan api diesel konvensional dalam enjin HCCI, kerana ia memberikan cara alternatif untuk mengurangkan ketergantungan pada bahan bakar fosil, sehingga menurunkan peratusan tingkat pelepasan.

ACKNOWLEDGEMENTS

First of all, I would like to thank the Al-Mighty God whom give me mercy and blessing to finish my study. I am grateful to have a group of very supportive supervisors. A special thanks to my main supervisor, Associate Professor Dr. Abdul Aziz Hairuddin, for his continuous guidance to enlighten the overall part of the study and his over limit spend time to make sure I achieve the target. To my first co-supervisor, Associate Professor Ir. Dr. Nuraini Abdul Aziz for his endless cooperation. Also, to my second co-supervisor, Dr. Muhamad Mat Noor whom always keep me in track and ease my study.

I would also like to thank my experiment group, which comes from different postgraduate backgrounds who always come to setup and maintaining the engine test bed. I always feel grateful to have sharing sessions with them to share the idea in technical part which improves my hands-on skill. I want to thanks to technical staff Mr. Azmi for his help in allowing my group to conduct the experiment throughout the years.

I have not forgotten my parents and siblings for their endless support throughout my studies. My friends and colleagues who gave me full cooperation to finish my writing. My beloved husband Mr. Abdul Rahman Bin Khasim who give full support and motivation to proceed with my study. Last but not least, I would like to express my greatest appreciation to the Ministry of Education Malaysia and Universiti Putra Malaysia which provided a research grant to facilitate me with all the equipment. Without them, I would not have been able to achieve my goal.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Abdul Aziz Bin Hairuddin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Nuraini Binti Abdul Aziz, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Muhamad Bin Mat Noor, PhD
Senior Lecturer
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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Signature: ______________________________
Name of Chairman of Supervisory Committee: Associate Professor Dr Abdul Aziz Bin Hairuddin

Signature: ______________________________
Name of Member of Supervisory Committee: Associate Professor Dr Nuraini Binti Abdul Aziz

Signature: ______________________________
Name of Member of Supervisory Committee: Dr Muhamad Bin Mat Noor

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LIST OF ABBREVIATIONS

4S	4 Stroke
AC	Air Cooled
BMEP	Brake Mean Effective Pressure
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
BTDC	Before Top Dead Center
BTE	Brake Thermal Efficiency
CA	Crank Angle
CI	Compression Ignition
CIDI	Compression Ignition Direct Injection
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CR	Compression Ratio
DEE	Diethyl Ether
DI	Direct Injection
EGR	Exhaust Gas Recirculation
HCCI	Homogeneous Charge Compression Ignition
HRR	Heat Release Rate
IMEP	Indicated Mean Effective Pressure
IP	In-cylinder Pressure
ISFC	Indicated Specific Fuel Consumption
LTC	Low Temperature Combustion
NA	Naturally Aspirated
NO_x	Nitrogen Oxides
PFI	Port Fuel Injection
POB	Palm oil biodiesel
POB10	10% palm oil 90% diesel
POB15	15% palm oil 85% diesel
POB20	20% palm oil 80% diesel
POB5	5% palm oil 95% diesel
PW	Pulse Width
RP	Rated Power
RS	Rated Speed
SOI	Start of Ignition
TDC	Top Dead Center
ULSDF	Ultra Low Sulphur Diesel Fuel
WC	Water Cooled
λ	Lambda

CHAPTER 1

INTRODUCTION

1.1 Background of Research

The increasing numbers of vehicles contribute to the rise in greenhouse gases and air pollutants, which increase the earth surface temperature over the years (Meinshausen et al. 2009). Many studies from different countries have taken a serious concern about the global warming issue (WAZA 2016). One of the biggest contributors to this matter is smoke fumes from the oxidation of fuel during combustion process of engine which produces a large amount of toxic emissions, such as nitrogen oxide (NO_x), carbon dioxide (CO_2), unburned hydrocarbon (UHC) and particulate matter (PM) (Great Minster House 2008). These emissions are considered to be the main cause of global warming. In addition, continuing and increasing use of petroleum will magnify the global warming problems and cause depletion of fossil fuel.

Figure 1.1 shows the world oil consumption in transportation and other. The transportation sector is the primary user of petroleum. Since 1997 to 2020 was about 10.7 million barrels per day are attributed to the transportation sector. Most of the gain in worldwide oil consumptions is due to the transportation sector. Figure 1.2 shows the historical data of the new discovery of oil reserves grow slowly, while the consumption shows a high growth rate. If oil discovery and consumption follow the current trends, the world oil resource will be used up by 2038 (Ehsani et al. 2004). Concern on energy efficiency and toxic emissions such as NO_x and PM encouraged the efforts to achieve implementation of the new technology of internal combustion engines that able to achieve higher energy efficiency and lower emissions levels.

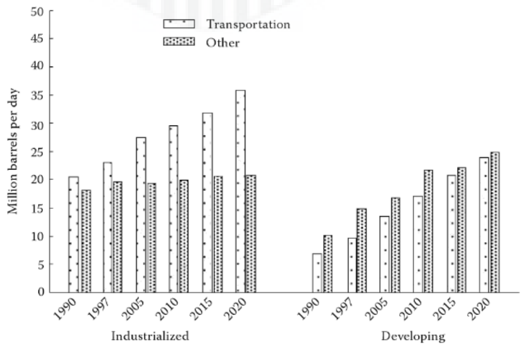

Figure 1.1 : World oil consumption in transportations and others (Ehsani et al. 2004)

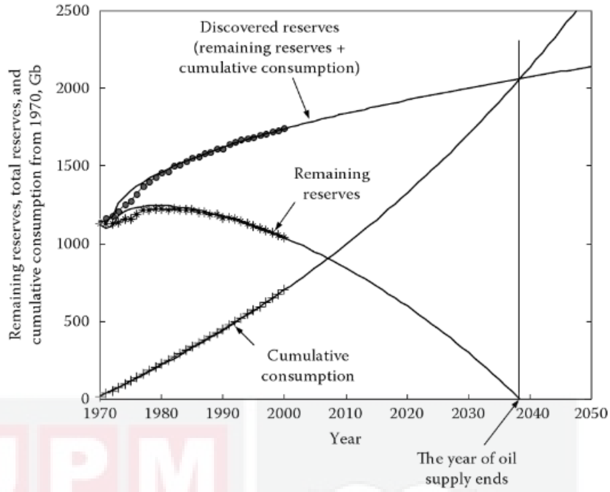

Figure 1.2 : World oil discovery, remaining reserves and cumulative consumption (Ehsani et al. 2004)

1.2 Introduction of HCCI engine

The advancement of internal combustion (IC) research area has introduced an alternative engine mode, which is called Homogeneous Charge Compression Ignition (HCCI) engine. HCCI is a hybrid technology of compression ignition (CI) and sparks ignition (SI) operations. HCCI engine operation is able to maintain fuel efficiency relatively the same as compared to that of compression ignition direct injection (CIDI) engine, but the NO_x and PM emissions are reduced (Gan, Kiat, and Mun 2011; P. Kumar and Rehman 2014). The operation principle of the HCCI engine is based on the preheat intake charge, where the charge is instantaneously burnt when it reaches its chemical activation energy.

The HCCI engine has the advantages of both CI and SI engines. This is because CI engine uses high compression process to ignite the charge with no throttle loss, resulting in high engine efficiency, while SI engine will premix the charge, hence generated low NO_x and PM emission (Alexandros G. Charalambides 2013a). However, unlike CI and SI engines, the HCCI combustion process occurs simultaneously along the volume rather than in a flame front. This is an important feature of the HCCI engine, which allows the combustion to occur at much lower temperatures, hence reduces the emissions of NO_X (Farrukh 2018). Figure 1.3 illustrates the comparison between the combustion characteristic of SI, CI, and HCCI engines.

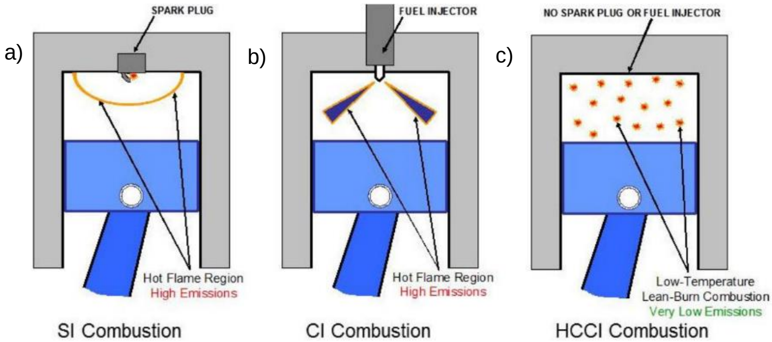

Figure 1.3 : Combustion characteristic of a) SI b)CI c) HCCI engines
(Alexandros G. Charalambides 2013a)

HCCI engine differs significantly in their operation from SI engine. The SI engine uses a spark plug to initiate combustion, while the CI engine uses high-pressure fuel injector at the end of the compression stroke. In order to achieve autoignition, CI engines are designed to operate at a higher compression ratio than the SI. For the HCCI engine, the fuel-air mixture was mixed either in the intake system or in the cylinder with controlled direct injection. The premixed fuel-air mixture is compressed until the mixture has enough chemical energy to trigger the combustion instantaneously. The hot intake air charge will increase the chemical reactions rate, which yields fast combustion process. Table 1.1 shows the difference in operating condition between SI, CI, and HCCI engines.

Table 1.1 : Comparison between conventional SI, CIDI, and HCCI engines
(P. Kumar and Rehman 2014)

Engine Type	**SI**	**CIDI**	**HCCI**
Fuel	Gasoline	Diesel	Flexible fuel
Air fuel ratio, λ	≈1.0	=1.2-2.2	>1.0
Mixture preparation	(Port Fuel Injection (PFI), Gasoline-Direct (GDI)	Direct Injection (DI)	DI, PFI, and DI+PFI
Ignition	Spark ignition	Auto-ignition	Auto-ignition
Combustion form	Premixed	Diffusion	Premixed but dominated by chemical kinetics
Combustion rate limitation	Flame propagation	Mixing rate	Multipoint or spontaneous
Flame front	Yes	Yes	No
Combustion temperature	High	Partially High	Relatively low

HCCI engines are part of the low-temperature combustion (LTC) technologies that are widely investigated worldwide. Low emissions engines with relatively higher combustion efficiency are achieved when the engine is operated in the region of low equivalence ratio. Therefore, lean combustion engines have low heat release temperature, hence becoming the main factor in reducing the emissions levels (Dec 2009). Furthermore, HCCI engines are known to be operated with different types of fuels. Biodiesel is considered as an environmentally friendly and sustainable alternative to fossil fuels and can be operated in HCCI mode. One of the properties of biodiesel is non-toxic fuel, which significantly reduce toxic emissions when burned. Among the new technologies, such as hybrid and electric vehicles, the HCCI engine can be considered as one of the future candidates to be implemented with the benefit of biodiesel. The problems related to fossil energy utilization have promoted worldwide research on renewable energy technologies.

1.3 Problem Statement

There were some problems that may allow this study to be carried on. The first problem was the high exhaust emission from the ICE. Many studies reported high emissions levels in conventional CI engines fuelled with diesel fuel (Acharya et al. 2017; Aldhaidhawi, Chiriac, and Badescu 2017; O. M. Ali et al. 2016; Chen et al. 2017; Emiro, Keskin, and Mehmet 2018; Kaisan et al. 2017; A. Kumar, Shukla, and Tierkey 2016; Mccarthy, Rasul, and Moazzem 2011; Qi et al. 2009; Thirumal and Gunasekaran 2015; Zhu et al. 2016). The CI or diesel engine is highly used in the mechanical industry due to their high capability and efficiency. The second problem was the fossil fuel has finite resources that are running low dramatically.

As mentioned on previous sub-topic, the world oil reverse will end by year 2040 because of increasing of transportation with high demand of fossil fuel over the years (Ehsani et al. 2004). Therefore, one of the most appropriate energy resources substitute for engines are biodiesel driven from renewable bio-materials. Biodiesel can reduce CO_2 level significantly, whereas the levels of exhaust emissions are influenced by the properties of the biodiesel (D´Agosto et al. 2017). Palm oil-based biodiesel is one of the edible oils and has been considered to be used in vehicles and other machinery (Petron 2012), thus it has a huge potential to be used in HCCI engine.

Palm oil based biodiesel also is the most potential alternative renewable fossil fuels in Malaysia because the country is one of the main palm oil producers in the Asian region (Pacheco et al. 2017). The last problem needs to be solved was the uncertainty of the efficiency of HCCI engine fuelled with palm oil biodiesel. The HCCI engine have potential to overcome the drawback of both SI and CI as well as it is low emission combustion. In the meantime, the study on HCCI engine using vegetable oil such as pine oil (Huang et al. 2016), hone oil methyl ester (Hiremath et al. 2017) and rapeseed methyl ester (Mancaruso and Vaglieco 2010). Jatropha oil is one of the edible oils and successfully operated on HCCI engine as reported by Ganesh, Nagarajan and Ganesan (Ganesh, Nagarajan, and Ganesan 2014). However, palm oil-based biodiesel has not yet been investigated in an HCCI engine. Therefore, the study focusses on the HCCI engine fuelled with palm oil-based biodiesel.

1.4 Objectives of Study

The main objective of this study is to improve the performance and emissions levels of an HCCI engine fuelled with palm oil-based biodiesel. The specific objectives are:

1. To improve the performance (power, torque, BSFC, BTE and BMEP) of an HCCI engine using palm oil-based biodiesel.
2. To improve the combustion behaviour (in-cylinder pressure and heat release rate) of HCCI engine fuelled with palm oil-based biodiesel.
3. To reduce the emissions levels (NO_x, HC, CO and CO_2,) of palm oil-based biodiesel in HCCI engine.

1.5 Scope of Study

This study focuses on the HCCI engine mode with some modification on the CI engine. The engine model used was Yanmar L48N6, a single-cylinder four-stroke diesel engine with a capacity of 192.3 cc. The engine tank has a fuel capacity of 2.5 litres and the engine used an electrical starter. Implementation of heater and port fuel consumption (PFI) at the intake section of the engine have enabled the conversion to HCCI mode of combustion. The palm oil with blend of 5% (POB5), 10% (POB10), 15% (POB15), and 20% (POB20) was used in HCCI and compression ignition direct injection (CIDI) engine mode. This range of blend ratio was chosen because of the possibility to be used in the near future as the current market is limited to 7% (POB7) blend. As we know, POB7 has been commercialised used in Malaysia. Vehicles can use the fuel blend up to POB20 without any modification required (Alptekin and Canakci 2009).

During the experiment in the HCCI mode, the engine operated in partly closed room. Room temperature is about 27- 30°C The is no specific relative humidity need for this experiment. The engine speed, pulse width (PW), and intake pressure were kept constant at 2700 rpm, PW= 2.5 ms and 1 bar, respectively. Meanwhile, intake temperature was varied at 70°C, 80°C, and 90°C. The atmospheric condition was about 1 atm as the experiment held in a closed laboratory room. The injection pressure of the HCCI engine was up to 120 to 180 bar. Lastly, the lambda (λ) is varied between 2.4, 2.6, 2.9, and 3.1. The possible condition to run this experiment was limited at intake temperature of 70 - 90°C. This range of temperature was able to operate at given engine speed and at all λ conditions without making the engine ringing.

1.6 Thesis Outline

The thesis has five chapters. Chapter 1 is the Introduction. In this chapter, a background of this study has been presented regarding the exhaust emission emits from the transportation. Then, HCCI engine concept, features, and comparison between SI, CI, and HCCI are discussed. A problem statement is presented to identify the problems related to current issues in HCCI engines. Finally, followed by the objectives and scope of study.

Chapter 2 is the Literature Review. This chapter discusses previous studies related to CI and HCCI engines as well as the proposed method to achieve HCCI mode. The purpose of the literature review in this study is to obtain a comprehensive understanding of HCCI performance with various types of fuels and methods used to achieve HCCI mode and also the emissions characteristics.

Chapter 3 is the Research Methodology. This chapter presents the experimental methodology of this study which describes how to convert a commercially available single-cylinder CI engine to an HCCI engine. Then, describe about the modification of the engine such that the used of the intake air heater and PFI, where the PFI is then controlled by the electronic control unit (ECU). This chapter also includes the flow chart of the study and details about the procedures and equipments used in the experiment.

Chapter 4 is the Results and Discussions. This chapter discusses the results of the study in HCCI modes fuelled with different palm oil blend. HCCI engine was directly compared with the CI engine using the same engine operating. The engine performance comparison discusses the in-cylinder pressure, engine power, fuel consumption, engine efficiency, and emissions levels.

Chapter 5 is the Conclusion. This chapter highlights the main findings of the experimental study. The goals included the main parameters that affect the engine performance and emission levels in different engine modes. Besides, there are several recommendations for consideration of future works.

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LIST OF PUBLICATIONS

Hasyuzariza M. Tobib, A. Aziz Hairuddin, Nuraini Abdul Aziz, M.M. Noor, J. Zulkiple, Muntasser A.A Mossa 2018, 'An Experimental Investigation on the Combustion and Performance of an HCCI-DI Engine' published in AIP Publishing in the Automotive Innovation Green Energy Vehicle (AIGEV) Conference, 25-26 July 2018, Kuantan Malaysia

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