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PERFORMANCE OF HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINE FUELLED WITH USED COOKING OIL-BASED BIODIESEL

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By

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May 2019

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Energy is increasingly used around the globe daily for transportation purposes whether in air, land, or sea. The majority of energy used in the transportation sector is extracted from the combustion process in engines. The amount of energy extracted during the combustion process to create necessary power produces undesired amounts of emission levels as by-products. Many countries have strengthened their energy policies and proposed more stringent emission standards to tackle this issue. To decrease engine emissions, many researchers are investigating the effects of using biodiesel in conventional spark ignition (SI) or compression ignition (CI) engines and its effect on engine performance. Some have developed biodiesel fuels to suit these engines, while others have modified the engines instead giving rise to the Homogeneous Charge Compression Ignition (HCCI) engine. In this study, a CI engine was modified to operate in HCCI mode and used cooking oil (UCO)-based biodiesel was used as fuel. The UCO was obtained from the market and was transesterified in the Institute of Biotechnology, Universiti Putra Malaysia`. The purpose of this study is to investigate the performance of a HCCI engine fuelled with biodiesel and its effect on emissions levels and engine power. It is expected that the HCCI engine will have improved emission levels compared to the conventional CI engine. Furthermore, using biodiesel as a fuel can further improve emission levels. In this study, the engine used was a single-cylinder, 4-stroke diesel engine, air-cooled, and with a rated speed of 3600 rpm and displacement of 0.219 liters. The engine was then converted to operate in HCCI mode using a pre-heating method. The engine was run at different speeds of 1600 rpm, 1800 rpm, 2000 rpm, and 3600 rpm in direct injection (DI) mode, followed by the HCCI mode, run at one engine speed of 2700 rpm, with different biodiesel blend rates and intake temperature. The engine was fuelled with UCO biodiesel blends of B5, B10, B15, and B20, where B5 indicates a blend of 5% UCO and 95% diesel. The results showed that when the engine was run in diesel mode with UCO as fuel, the engine torque and brake power reduced and fuel consumption increased. The

emission level of NO_x, CO, and UHC was also reduced but CO_2 emission increased. When the engine operates in HCCI mode using UCO biodiesel with different blend ratio, improved emission level was observed, where the CO emission levels decrease with increased blend ratio that because more oxygen with lower carbon is present in biodiesel blends compared to diesel fuel, which has better combustion. The amount of oxygen in UCO biodiesel helped create better combustion, leading to a reduced CO emission level. In DI mode, the engine yielded high NO_x of 142 ppm with diesel fuel, however, this value decreases to 10 ppm when the engine was run in HCCI mode at temperature of 70ºC. The NO_x emission was further decreased to 5 ppm with increased intake air temperature to 90ºC, that because the intake temperature was controlled in HCCI mode. The NO_x emission level decreased when run in HCCI engine and when increased the intake temperature that due to improvement in the combustion. It can be concluded from the findings that when the engine operated in HCCI mode fuelled with UCO-based biodiesel, the emissions levels were improved without sacrificing the engine performance significantly, which the main aim of this thesis.

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

PRESTASI ENJIN PENCUCUHAN MAMPATAN HOMOGEN DENGAN BERBAHAN API BIODIESEL BERASASKAN MINYAK MASAK TERPAKAI

Oleh

MUNTASSER ABDULABBAS MOSSA

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Penggunaan tenaga global setiap hari untuk tujuan pengangkutan di udara, tanah dan laut semakin meningkat dengan ketara. Kebanyakan tenaga yang digunakan dalam sektor pengangkutan diekstrak daripada proses pembakaran dalam enjin. Jumlah tenaga yang diekstrak semasa proses pembakaran untuk memberikan kuasa yang diperlukan menghasilkan tahap pelepasan yang tidak diingini sebagai produk sampingan. Justeru,banyak negara memperketatkan dasar tenaga mereka dan mencadangkan piawaian pelepasan yang lebih ketat untuk mengatasi masalah ini. Untuk mengurangkan kadar pelepasan enjin, ramai penyelidik kini menyiasat kesan penggunaan biodiesel terhadap prestasi enjin konvensional pencucuhan bunga api (SI) atau pencucuhan mampatan (CI). Sesetengah daripada mereka membangunkan bahan api biodiesel manakala beberapa yang lain menggunakan enjin yang diubah suai termasuk enjin pencucuhan mampatan cas homogen (HCCI). Dalam kajian ini, enjin CI diubahsuai untuk beroperasi dalam mod HCCI dan biodiesel berasaskan minyak masak terpakai (UCO) digunakan sebagai bahan api. UCO diperolehi daripada pasaran tempatan selepas proses transesterifikasi di Institut Bioteknologi, Universiti Putra Malaysia. Tujuan kajian ini adalah untuk mengkaji prestasi enjin HCCI yang menggunakan bahan api biodiesel dan kesannya ke atas tahap pelepasan dan kuasa enjin. Dijangkakan bahawa penggunaan enjin HCCI dapat memperbaiki tahap pelepasan berbanding enjin konvensional SI dan CI. Selain itu, penggunaan biodiesel sebagai bahan bakar dapat memperbaiki tahap pelepasan dengan lebih lanjut. Dalam kajian ini, enjin yang digunakan ialah enjin diesel silinder tunggal, 4 lejang, penyejukan udara, dengan laju kadaran 3600 rpm dan sesaran 0.219 liter. Enjin ini kemudiannya ditukar kepada mod HCCI menggunakan kaedah prapemanasan. Enjin ditetapkan pada kelajuan 1600 rpm, 1800 rpm, 2000 rpm dan 3600 rpm dalam suntikan terus (DI), manakala dalam mod HCCI hanya menggunakan satu kelajuan enjin, iaitu 2700 rpm, dengan kadar campuran biodiesel dan suhu masukan yang berbeza. Enjin diisi dengan biodiesel UCO mengikut campuran B5, B10, B15, dan B20, di mana B5 menandakan campuran 5% UCO dan 95% diesel. Keputusan menunjukkan bahawa apabila enjin dijalankan pada mod diesel dengan UCO sebagai bahan api, tork enjin dan kuasa brek berkurang manakala penggunaan bahan api meningkat. Tahap pelepasan NO_x, CO, dan UHC juga dikurangkan tetapi tahap pelepasan CO_2 meningkat. Apabila enjin beroperasi dalam mod HCCI menggunakan biodiesel UCO dengan kadar campuran berbeza, tahap pelepasan menunjukkan penambahbaikan. di mana tahap pelepasan CO menurun dengan peningkatan kadar campuran biodiesel. kerana lebih banyak oksigen dengan karbon rendah hadir dalam campuran biodiesel berbanding dengan bahan api diesel yang menyumbang ke arah pembakaran yang lebih baik. Jumlah oksigen dalam biodiesel UCO membantu menghasilkan pembakaran yang lebih baik, yang membawa kepada tahap pelepasan CO yang berkurangan. Dalam mod DI, enjin menghasilkan tahap pelepasan NO_x tinggi 142 ppm dengan minyak diesel, tetapi nilai ini mengurang kepada 10 ppm apabila enjin dijalankan dalam mod HCCI pada suhu 70ºC. Tahap pelepasan NOx dikurangkan lagi kepada 5 ppm dengan kenaikan suhu udara masukan kepada 90ºC kerana suhu masukan yang dikawal dalam mod HCCI, di mana tahap pelepasan NO_x berkurangan apabila dijalankan pada enjin HCCI dan dengan peningkatan suhu masukan yang meningkatkan pembakaran. Tahap pelepasan NO_x mengurang lagi kepada 5 ppm dengan kenaikan suhu udara masukan kepada 90ºC. Kesimpulan daripada kajian ini menunjukkan bahawa apabila enjin beroperasi dalam mod HCCI dan diisi dengan biodiesel UCO, tahap pelepasan dapat diperbaiki tanpa mengurangkan prestasi enjin secara ketara, ini merupakan tujuan utama thesis ini.

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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:

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Date:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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

Signature: ______________________________
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LIST OF ABBREVIATIONS

A/F	Air fuel ratio
B.P	Brake Power
BDC	Bottom Dead Center
BMEP	Brake Mean Effective Pressure
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CAD	Crank Angle degree
CI	Compression ignition
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DI	Direct Injection
EGR	Exhaust Gas Recirculation
EGT	Exhaust Gas Temperature
HC	Hydrocarbon
HCCI	Homogenous Charge Compression Engine
HRR	Heat Release Rate
IC	Internal combustion
LTC	Low Temperature Combustion
NOx	Nitrogen Oxide
PFI	Port Fuel Injection
PW	Pulse Width
SI	Spark ignition
TDC	Top Dead Center
UCO	Used cooking oil
λ	1/Air fuel ratio

CHAPTER 1

INTRODUCTION

1.1 Background

The rising concern surrounding environmental pollution nowadays is a major motivation for studies to investigate cleaner sources of energy and usage optimization of present energy sources. Internal combustion engines have been a major source of air pollution for more than one century, and are still an issue of concern to this day. Emissions from these engines mainly consist of soot and exhaust gases such as carbon dioxide (CO_2), nitrogen oxide (NO_x), carbon monoxide (CO), and unburned hydrocarbon (UHC). CO_2 emission levels are a major environmental problem that has given rise to the greenhouse effect. Some researchers have shown that NO_x and UHC also promote greenhouse gas emissions, in the form of smog. Presently, research and development on automotive vehicles is controlled by environmental regulations, so new technologies should satisfy all customer requirements, such as improved performance, fuel economy, and the ability to be driven within acceptable costs.

In previous studies, the depletion and demand in fossil fuel had led to researchers improving bio-waste and organic-based fuel [1]. Diesel fuel and gasoline are the most common fuel used in internal combustion engines. Some gases are released from the engine due to the combustion of hydrocarbons in fuels, and these affect human health and the environment. This has led to studies attempting to decrease different kinds of emissions as part of compliance with regulation, mainly in developing countries. On the other hand, alternative fuel is a good new source of energy that can be used in different ways. The engine needs good fuel to obtain enhanced performance, low emission levels, and low fuel consumption. Biodiesel is a good renewable fuel that can be produced and used with diesel engine in different blend rates. Many researches and studies have found promising technologies to improve engine performance and reduce emission levels. One of these technologies is the Homogenous Charge Compression Ignition (HCCI) engine, which operates based on lean combustion and a more homogenous air-fuel mixture [2]. The advantages of a HCCI engine include its ability to use many types of fuels, low emissions levels of NO_x, ability to operate in a high-compression ratio engine, and having efficiencies close to that of CI engines. However, the HCCI engines also have some disadvantages such as control of combustion, cold start, knocking, and low to medium load operations.

1.2 Overview

Most internal combustion engines produced around the world are used in different fields such as in ships, planes, trains, automobiles, and in some electric power generators. In the last decade, various efforts have been done to improve upon these existing technologies. Researchers are now focusing on how to decrease emission levels such as UHC, CO_2, NO_x, and CO while simultaneously improving engine performance by increasing its efficiency. Currently, many new technologies are being developed such as electric vehicles, and fuel cell and hybrid engines to achieve low emission levels for the engine. All of these studies and different technologies are moving away from combustion and several electric vehicles for one have even completely eliminated the need for an internal combustion engine. These hybrid vehicles have many disadvantages, however, such as high maintenance cost and limitation in driving distance. One technology to improve the efficiency of the internal combustion engine introduced the use of low temperature combustion such as the Homogenous Charge Compression Ignition engine (HCCI), Premixed Charge Compression Ignition engine (PCCI), and Reactivity Charge Compression Ignition engine (RCCI). An engine that is based on the principle of gasoline and diesel engines, but is more efficient and produces lesser emissions, is known as the Homogeneous Charge Compression Ignition engine (HCCI). Figure 1.1 shows a comparison between the Spark Ignition (SI), Compression Ignition (CI), and Homogenous Charge Compression Ignition (HCCI) engines.

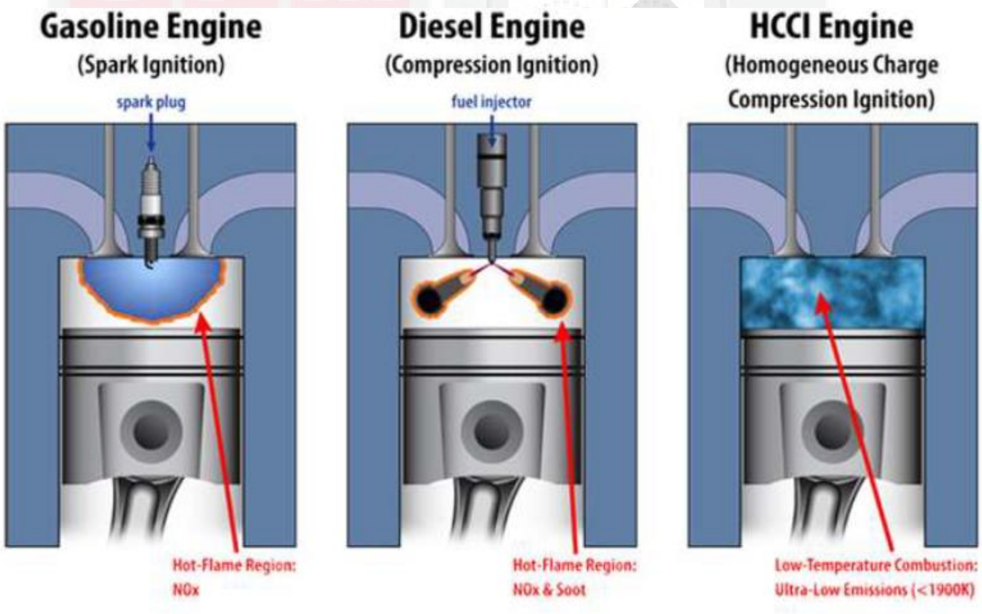

Figure 1.1 : The difference between from left to right SI, CI, and HCCI engines [3]

The HCCI engine has some advantages including the fact that it can run as a CI engine with a higher compression ratio. The engine can achieve 30% efficiency, which is higher than the SI engine efficiency, and promote lower emission levels. Some disadvantages of the HCCI engine are its cold-start capability, the pressure increase and high heat release rate, difficulty to control auto ignition, small power range (low load), and higher HC and CO emissions levels [4]. The study of the HCCI engine is principally based on a combination of the CI and SI engines. In the Spark Ignition engine, the air and fuel mixes before the ignition, where the spark plug is used to initiate the combustion.

Also, in a CI engine, the combustion occurs by injecting diesel mist into hot compressed air by using an injector. The HCCI engine, on the other hand, works like a CI engine, which has a high compression ratio, where the mixture of fuel and air is compressed initially until it reaches the chemical activation energy required to trigger combustion. The combustion is controlled by an auto ignition phenomenon and occurs at several points in the cylinder spontaneously. Its lean mixture and fast combustion could decrease the in-cylinder temperature, which will reduce the production of NO_x and other emissions. HCCI engines are a comparatively new mode of combustion process, and have generated great interest as an interim solution for hybrid vehicles. The control system of the HCCI engine is complex, as it involves complex chemistry for controlling its combustion. The method of control and understanding of chemistry are the main challenges faced for this type of engine technology. [5]. Figure 1.2 shows the different working principles of the CI and SI engines up until now and in the future. It also shows the advantage and disadvantage of both engines. This engine is a possible candidate for future engines, if solutions for some of its challenges such as control of temperature, knocking, and low operation load, can be found.

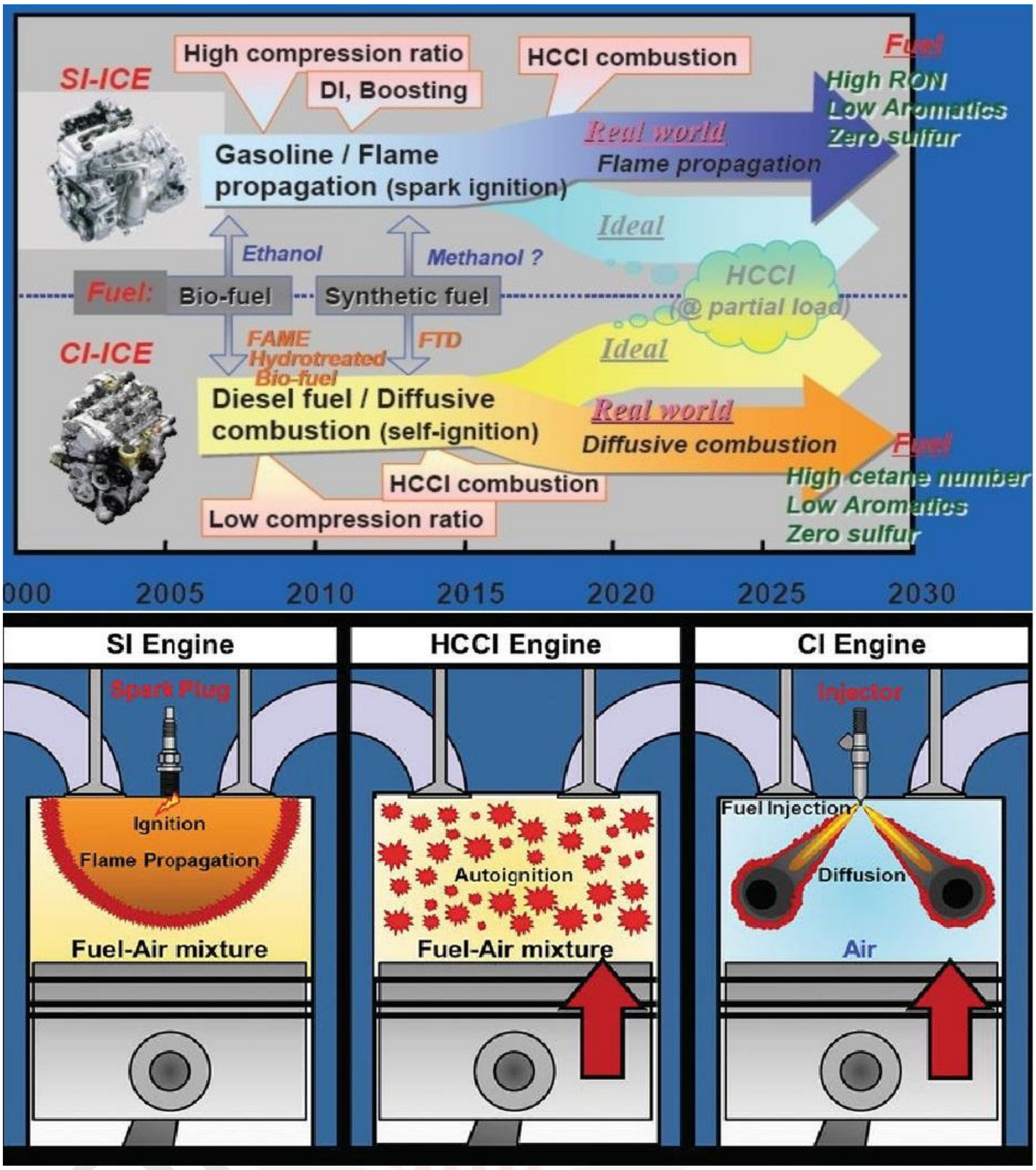

Figure 1.2 : Development of internal combustion chamber [6]

Figure 1.3 shows the emission levels of the HCCI engine and effect of temperature. CO and UHC are reduced when the temperature is less than 1400 K. When the temperature increases to a range between 1400 K and 2000 K, the engine creates soot, but when the temperature goes beyond 2200 K, NO_x will be created.

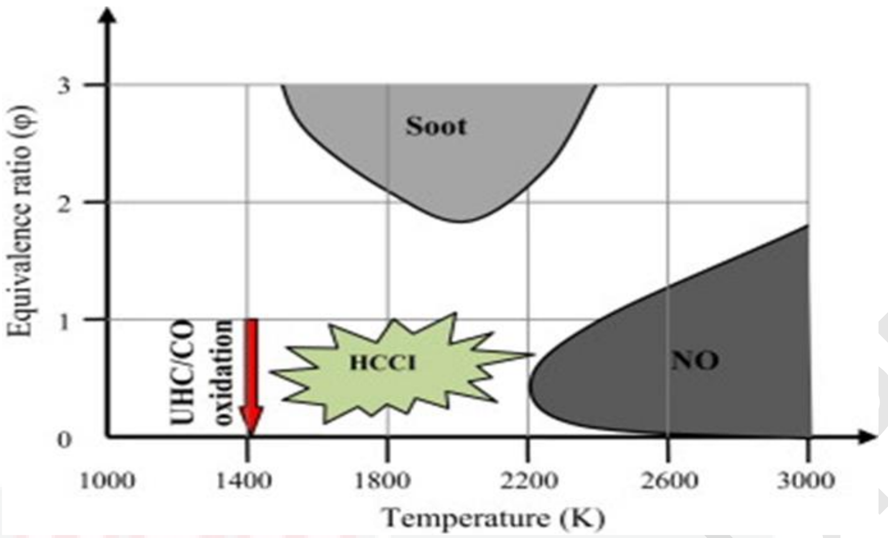

Figure 1.3 : Homogeneous Charge Compression Ignition (HCCI) combustion: mixture preparation and control strategies [7]

Furthermore, the use of alternative renewable energy affects engine performance and emission levels [8]. There is high interest in using the engine in different modes and thus, many researchers are now focusing on investigating the performance of biodiesel based on algae, palm oil, jatropha, and used cooking oil. These biodiesels have the advantage of reducing emission levels without compromising engine performance. Thus, when biodiesel is used in a HCCI engine, it can further improve the engine's emissions levels. Used cooking oil (UCO)-based biodiesel has the potential to be used as biodiesel fuel because of its ease of production, fair prices, and the lack of environmentally harmful exhaust emissions created by the oil [9]. Also, the biodiesels in a HCCI engine can limit NO_x emissions [2]. In a nutshell, the HCCI engine is considered a promising engine for the future if solutions to controlling its internal temperature and spontaneous combustion were found.

1.3 Problem Statemen

The homogeneous blend of air and fuel mixture in the HCCI engine leads to cleaner combustion with lower emission levels. This study focuses on the possibility of solving some of the problems of the HCCI engine, which are stated in detail below:

1. High emission levels in the CI engine.
2. High emission levels in the HCCI engine.

In present day, traditional engines have a low thermal efficiency and high NO_x levels; however, the HCCI engine faces several major difficulties. These problems include limited power, control of combustion, cold start, and high emissions levels of HC and CO [5] [8]. The high emission levels of HC and CO in HCCI engine can be improved by using biodiesel [4]. In order to reduce emission levels, biodiesels have been used with the CI engine in different studies [6] [7]. Biodiesel is one of the most promising renewable energies for reducing CO_2, while the HCCI engine can use biodiesel to reduce NO_x and soot emission levels. NO_x emission levels can be reduced using low temperature combustion; in this case, the HCCI engine is a good possible candidate. Many biodiesels used in the CI engine are based on palm oil, algae, and biodiesel from cooking vegetable oil waste (Used Cooking Oil) or even soybean and animal fat waste biodiesel, all of which have been shown to reduce emissions levels [9]. Also, in many studies such as in [10], [11], and [12] biodiesel was used to run a diesel engine to investigate the effect of biodiesel on engine emission and performance. Many researchers have focused on various methods to reduce emissions levels, such as using biodiesel with the CI engine and also running the engine in HCCI engine mode [8]. Many studies have also investigated the performance of biodiesel in HCCI engines to further reduce emissions [13] [14]. The CI engine can be operated to run with UCO-based biodiesel to reduce emission levels without compromising engine performance [15]. The engine can be operated in good condition when used with fuel of low oxygen and nitrogen content as well as low cetane number [16] [17]. Additionally, the diesel engine can run without modification by using biodiesel, as some studies investigated the environmental effect of biodiesels on emission levels [1] [2] [3]. However, the use of UCO-based biodiesel in a HCCI engine has still not been investigated until now, and from the previous study of using the UCO biodiesel in CI engine shows that the properties of this biodiesel that can used in HCCI mode. The CI engine produces a high NO_x emissions levels and to solve this problem, the used of HCCI engine is able to reduce the emission [18]. Therefore, this study focuses on the performance of CI and HCCI engines fuelled by UCO-based biodiesel. The biodiesel will have different blended ratios.

1.4 Hypothesis

The world needs to improve the environment by reducing the greenhouse gases. From the previous studies the best way to solve some problems of CI engine is by using the HCCI engines. The good method to run HCCI engine by using a heater and with biodiesel. It is the best method to decrease the emission levels. Assuming diesel engine was fuelled with renewable used cooking oil-based biodiesel, it has the possibility to decrease the exhaust emissions levels to minimum level as stated in previous studies by researchers [1-4]. The NO_x will be decreased to minimum level when using HCCI engine. The HCCI engine is still under study and therefore it contains some challenges to be solved. In this study the effectiveness of study by using the used cooking oil-based biodiesel and during operation in HCCI engine was investigated.

1.5 Objectives

The main objective of this study is to investigate the performance and emission levels of a HCCI engine fuelled by UCO-based biodiesel. The specific objectives of this study are:

1. To analyze the performance of a HCCI engine using UCO-based biodiesel (Brake Power, Torque, Brake Mean Effective Pressure, Brake Specific Fuel Consumption and Brake Thermal Efficiency).
2. To investigate the combustion behavior of HCCI engines fuelled with UCO-based biodiesel (in-cylinder pressure and Heat release rate).
3. To reduce the emission levels of UCO-based biodiesel in a HCCI engine (NO_x, UHC, CO and CO_2)

1.6 Scope of Study

This section explains all conditions and limitations of the experimental work conducted in this study. The scopes of this study are:

- Understand the work of two engine modes: CI and HCCI engines.
- Two types of fuel used: conventional diesel and UCO-based biodiesel.
- Using the UCO-based biodiesel (properties and advantage)
- Engine speed is 2700 rpm for both the CI and HCCI engines (had run the engine for different engine speed to find the speed that investigate the HCCI operation).
- Engine load from 0%–15%, (HCCI engine run with low load conditions)
- Lambda (λ) from 2.4-3.1, (tested engine with a wide range of lambda to find the stable lambda that can run on HCCI engine).
- Engine temperatures are 40˚C–50˚C.
- Intake temperatures of HCCI engine are 70˚C, 80˚C, and 90˚C and that because the HCCI engine run with limited range of combustion between misfire and knocking and these temperatures are the best range to run this engine.
- Intake pressure of 1 bar.
- Injection pressure of HCCI engine is 180–220 bars by use PFI in HCCI mode.
- Used cooking oil blends are B5, B10, B15, and B20 and that because these blends are the best ratio to run HCCI engine to investigate all performance and emissions.
- Pulse width of injection is 2.5 ms that can run on the HCCI mode.

1.7 Thesis Outline

This thesis contains five chapters. This first chapter explains the background of this study. The literature review of previous studies on the HCCI engine, operations, and comparisons between the SI and CI engines is discussed in depth in the second chapter. Also, studies of different biodiesels are also discussed. This chapter also reviews the methodologies used in developing HCCI engines.

The third chapter in this thesis outlines the methodology of the study. This chapter mainly discusses the HCCI modes using the pre-heating method to convert a CI into a HCCI engine. Furthermore, the temperature of the engine was monitored so that the engine would conform to the right conditions before converting it to HCCI mode. Chapter 4 discusses the results collected from experimental work. Chapter 5 is the last chapter and presents the conclusions and recommendations of the study. In this chapter, the objectives of the study are summarized. The challenges of the study that have affected the results are also highlighted. This chapter concludes with recommendations for future study.

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LIST OF PUBLICATIONS

Muntasser A.A Mossa., Abdul Aziz. Hairuddin, Nuraini A. A., J. Zulkiple, Hasyuzariza M. Tobib, 'The Effects of Hot Exhaust Gas Recirculation (EGR) on the Emission and Performance of a Single-Cylinder Diesel Engine' International Journal Automotive Mechanical Engineering (IJAME), (accepted).

Pshtiwan M. Sharif, A. Aziz Hairuddin, A. As'arry and K.A.M. Rezali, M.M. Noor, M. Norhafana, Muntasser A. A Mossa, S.M. Shareef, 'International Regulation of Vehicle Emissions Control Rules And Its Influence on Academic Engine Development Experimental Study And Vehicle Manufacturing' accepted in Conference Series: Materials Science and engineering in the 1st International Postgraduate Conference Mechanical Engineering (IPCME), 31st October 2018, Pekan, Malaysia.

Hasyuzariza M Tobib, Rostam Hamzah, Muntasser A.A Mossa, A. Aziz Hairuddin, M.M. Noor, 'The Performance of an HCCI-DI Engine Fuelled with Palm Oil-Based Biodiesel' accepted in OIP Conference Series: Meterailes Science and engineering in the 1st International postgraduate Conference Mechanical Engineering (IPCME), 31st October 2018, Pekan, Malaysea.

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

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