INVESTIGATION OF SYNTHETHIC DIESEL FUELS AND COMBUSTION CHARACTERISTICS USING RAPID COMPRESSION MACHINE (RCM)

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DEDICATION

To my cherished wife,

Mdm. Nurul Nabilah Binti Ramli

For been a constant source of support and encouragement during the challenges throughout the study and life.

To my beloved mother and father,

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ABSTRACT

In a compression ignition engine, the fuel/air mixing process affects the combustion process. The study mainly investigates the effects of blending ratio, injection pressure (P_{inj}), and ambient temperature (T_i) on ignition delay and heat recovery process during the combustion process. The fuel was blended using a fuel blending machine at three different blending ratios of 10%, 15%, and 20% using the Tire Pyrolysis Oil (TPO) and Plastic Pyrolysis Oil (PPO). Each oil was tested by using a Rapid Compression Machine (RCM). The ambient temperature was varied from 750 K until 1050 K and P_{inj} at 80 MPa to 130 MPa. The data obtained was compared to Euro 5 as reference. The ignition delay of TPO10 was 1.61 ms at 80 MPa compared to 0.9 ms when the pressure was 130 MPa. For T_i, the ignition delay of PPO10 at 750 K reached 1.34 ms, but at 1050 K, the ignition delay shortened to 0.64 ms. Such increment in the P_{inj} and T_i helps in the atomization and combustible of mixture formation by lengthening the spray tip penetration, which also produces finer fuel droplet spray and reduces ignition delay. Whereas, the increase in blending ratio is found to increase the ignition delay while the increase in T_i and P_{inj} decrease the ignition delay, hence improving the combustion's performance. The increment in ignition delay increases the mixing time available, which usually results in a more uniform mixture, substantial reductions in the overall cylinder pressure, and maximum HRR.

ABSTRAK

Proses pencampuran bahan bakar/udara dalam sebuah enjin pencucuh mampatan mempengaruhi proses pembakaran. Kajian ini menyiasat kesan nisbah pencampuran, tekanan suntikan (P_{inj}), dan suhu persekitaran (T_i) terhadap penundaan penyalaan dan penyerepan semula haba semasa proses pembakaran. Bahan bakar dibancuh menggunakan mesin pembancuhan bahan bakar pada tiga nisbah pencampuran yang berbeza, iaitu 10%, 15%, dan 20%, menggunakan minyak pirolisis tayar (TPO) dan minyak pirolisis plastik (PPO). Setiap minyak diuji menggunakan mesin pemampatan pantas (RCM). T_i diletakkan pada variasi 750 K hingga 1050 K manakal tekanan suntikan antara 80 MPa hingga 130 MPa. Data yang diperoleh juga dibandingkan dengan Euro 5 sebagai rujukan. Kelewatan pencucuhan TPO10 adalah 1.61 ms pada 80 MPa berbanding 0.9 ms pada tekanan 130 MPa. Untuk T_i, kelewatan pencucuhan PPO10 pada 750 K mencapai 1.34 ms, tetapi pada 1050 K, kelewatan pencucuhan menjadi lebih pendek iaitu 0.64 ms. Peningkatan P_{inj} dan T_i membantu dalam pengatoman dan pembakaran campuran dengan memanjangkan penembusan hujung semburan, sekaligus menghasilkan semburan titisan bahan bakar yang lebih baik dan merendahkan penundaan pecucuhan. Manakala, peningkatan nisbah pencampuran telah meningkatkan kelewatan pencucuhan, sementara kenaikan T_i dan P_{inj} merendahkan penundaan pencucuhan, sekaligus meningkatkan prestasi pembakaran. Peningkatan kelewatan pencucuhan juga meningkatkan masa pencampuran sedia ada, yang kemudiannya menghasilkan campuran bahan bakar yang lebih seragam, penurunan besar pada tekanan silinder, dan HRR maksimum.

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LIST OF SYMBOLS AND ABBREVIATIONS

%wt	-	Weight percent
API	-	American Petroleum Industry
ASTM	-	The American Society for Testing and Materials
C	-	Carbon
CC	-	Combustion Chamber
CI	-	Compression Ignition
CL	-	Cylinder Liner
DCN	-	Derived Cetane Number
DF	-	Diesel Fuel
dP	-	Rate of Pressure
dQ	-	Rate of Heat Release
DTPO	-	Distilled Tire Pyrolysis Oil
EA	-	Activation Energy
EN	-	European Standard
H	-	Hydrogen
HC	-	Hydrocarbon
HHV	-	Higher Heating Value
HP		Horse Power
ICE	-	Internal Combustion Engine
IS	-	Indian Standard
N	-	Nitrogen
NO_2	-	Nitrogen Dioxide
NOx	-	Nitrogen Oxide
O_2	-	Oxygen
P_{inj}	-	Injection Pressure
PAH	-	Polycyclic aromatic hydrocarbons

PM	-	Particular Matter
PPO	-	Plastic Pyrolysis Oil
RCM	-	Rapid Compression Machine
S	-	Sulphur
SA	-	Spark Advance
T_i	-	Ambient Temperature
TDC	-	Top Dead Centre
TPO	-	Tire Pyrolysis Oil
TPO-DF	-	Tire Pyrolysis Oil-Diesel Fuel
VE	-	Volumetric Efficiency

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The depletion and carbon dioxide emission of petroleum fossil fuel have become an alarming issue as many modes of transportation depend on petroleum fossil fuel (Gad et al., 2018). Concern about the depletion of oil resources has been raised throughout the past years as the consumption and demand for fuel increase with population growth and the rising number of vehicles used daily. Researchers around the world have been searching for ways to solve this concerning issue. This includes the proposal of using synthetic diesel fuel as a recommended alternative to conventional fuel in order to mitigate problems such as scarcity of fossil fuel, carbon dependence, and greenhouse gas emission. However, the costs involved in processing biofuels are significantly higher, thus putting a question on its potential to substitute fossil fuel.

In response to the issue, a number of governments have started the initiative to produce synthetic diesel fuel and biofuels from different feedstock. This includes obtaining biofuels (biodiesel and bioethanol) via fermentation and transesterification (Cherubini, 2010) as well as producing synthetic diesel fuel through the advance processes of thermochemical treatment such as combustion, hydrothermal liquefaction, gasification, and pyrolysis (Bain, 2004). Any fuel formed via hydrogen gas synthesis (e.g., gasoline, diesel, kerosene) is considered as synthetic diesel fuel, which is often derived from non-crude oil sources like tires, plastic, natural gas, or biological sources like corn. The most popular way to obtain gasoline and diesel is by distilling crude oil into specific size molecules and molecular weight. Synthetic diesel fuel is formed by hydrogen gas and carbon monoxide extracted from the source, which then become the desired petroleum end products (Jung et al., 2018).

A number of studies have also investigated the potential of converting wastes such as plastics, biomass, and rubber tires into crude oil via the pyrolysis process. Such process is believed to be capable of producing biofuel that can replace the conventional fossil fuel. The majority of these studies were focused on plastic and tires as these wastes can be converted into oil through the pyrolysis process (Kalargaris et al., 2017a). Furthermore, the pyrolysis process can also synthesize plastic waste into three different products of solid, liquid, and gas (Kalargaris et al., 2017b). The consistency of a pyrolysis product is determined by the physicochemical properties of the plastic waste and the operating conditions of the pyrolysis process such as the catalyst, time of residence, and temperature (Williams et al., 1997). Therefore, the liquid product, also known as crude Plastic Pyrolysis Oil (PPO), has comparable characteristics to those in conventional fuels and can be used in internal combustion engines (ICE). The types and properties of fuel used will greatly influence the combustion process such as the ignition delay and heat recovery process.

Delay in ignition is closely linked to engine output as well as fuel emission. It plays a crucial function in the mechanism of combustion (Bannister et al., 2009). In diesel engines, the ignition delay of a fuel refers to the time duration that begins from the first droplet of fuel spray reaches the combustion chamber to the point that the first blaze is seen in the fuel or air mixture. The ignition delay of a diesel spray is deemed as critical in the context of preparing the fuel before its injection into the engine and choosing the optimum injection timing (Heywood, 1988). Ignition delay is strictly related to the air temperature and the pressure of the injection. Furthermore, the change in fuel properties can also influence ignition delay (Abed et al., 2019). In general, the beginning of fuel injection accounts for the moment when the injector needle lifts from its position, and the beginning of combustion (SOC) can be described by the shift in the HRR slope that occurs at ignition (Qate et al., 2013). Ignition delay and HRR can be measured with the aid of normal diesel engine or a compression machine.

The compression machine background for combustion research can be divided into three generations. Falk (1906) developed the first-generation compression machine where fuel and oxidizer mixtures were instantly compressed using a piston powered by a weight dropping mechanism. In the first-generation compression machine, the ignition temperature was observed without ignition delay. Hence, second-generation compression machine was developed by creating a constant volume chamber reaction where the piston was kept at the chamber to resemble the top dead center (TDC) condition in an engine. This prompted Cassel (1917), Tizard et al. (1920, 1922, 1926), and Aubert (1925) to create a compression machines that was capable of calculating ignition delays. In the late 1960s, Affleck et al. (1968) created a rapid compression machine (RCM) using a pneumatic propelled piston system. This resulted in greater extent of compression ratio studies with lesser compression times of around 20 ms. Meanwhile, another RCM was created by Carlier et al. (1994), Griffiths et al. (1993), and Mittal et al. (2007) using a comparable design where a rod-less piston was designed and high driving forces were involved to stop the piston at stroke end, which was solved by designing the piston stopper. Thus, RCM is seen as a tool to study the mechanism of mixture forming and combustion as it is created to stimulate a single compression event of an internal combustion engine cycle. By using external forces, this unit produces a high-speed piston motion (Goldsborough et al., 2017).

Therefore, the aim of this study is to conduct a test on TPO and PPO with different blending ratios in an RCM. The blending ratios involved are 10%, 15%, and 20%. Previous studies have reported promising results on the relationship between lower blending ratios and pyrolysis oil. However, scarce investigations have been conducted on higher percentage of blending ratio due to fact that common diesel engine cannot function properly when using pure pyrolysis oil or also known as bio-crude oil. The blending ratios selected in this study are aligned with the steps taken by the Malaysian government to implement biodiesel into the market, which starts from low ratio and raising it periodically. B5 and B7 had been successfully implemented in Malaysia despite facing the price fluctuation of palm oil. The current biodiesel ratio used in Malaysia is B10 (Zulqarnain et al., 2020). The percentage below 10% are considered low as it has been successfully implemented in Malaysia and the percentage 50% and higher would be considered as high blending ratio. 50% of ratio are considered high as Malaysia had sufficient supply to support until B50 for transportation (Masjuki et al., 2013).

Several experiments have been conducted involving various diesel engines from laboratory research units to large adapted dual-fuel engines (Shihadeh et al., 2000; Suppes et al., 1997). The findings show positive engine efficiency outcomes for smooth operation. Nevertheless, there are several issues that need to be addressed when using synthetic fuel to replace diesel, particularly given its soot formation and re-polymerization rate. Using pure pyrolysis oil requires the alteration of different engine components particularly the fuel pump, linings, and injection system. The parameters that were manipulated in this research are the pressure of fuel injection, ambient temperature of the combustion chamber, and blending ratio of the synthetic diesel fuel. Results of the ignition delay and HRR from the combustion chamber will be reported as the end result of the experiment by translating the pressure graph. It suggests that fuel volatility and properties influencing spray break-up have limited effect on the ignition process (Pickett et al., 2009). Ignition time data indicates strong agreement with prior observations by other researchers in a Rapid Compression Machine.

1.2 Problem Statement

The current fuel price is continuously increasing, owing to the scarcity of natural resources around the world (Chandra, 2013). Thus, alternative fuels are highly required to replace the need of the commercial fuel. In response to the issue, there are many substances in human daily life that can be used or converted into the fuel required to run a vehicle (Vaccaro, 2017). Among the potential substances are tires and plastic wastes which pose significant threats to the environment as they are non-degradable materials.

One of the critical global issues contributing to economic and environmental complications is the handling of solid waste. There has been an increase in the volume of rubber and tires wastes in the industrial and automobile sectors. This is a dilemma that needs a sustainable solution. It has been estimated that around 1.51 billion tires wastes are created per year (Verma et al., 2018). Furthermore, plastic demand has also undergone exponential growth and has grown by up to 129 million tons per year. This type of plastic waste can be used effectively as a potential supply of energy. The main solution for waste disposal of rubbers and tires is the landfills (Wongkhorsub et al., 2013). Although some has resorted to recycling these wastes, there is still much more to be disposed. Tires are not preferred in landfills as it is space consuming and has 75% of empty space (Liu et al., 1998). It also accumulate methane gases, which allows them to rise to the surface. This ‘bubbling’ effect will affect landfill liner designed to help prevent pollutants from contaminating local groundwater and air (Price et al., 2006). It can also be a mosquito breeding spot and cause toxic fires that emits high pollutant emission (Williams et al., 2016).

Plastic and tires wastes can undergo the pyrolysis process in order to convert it into crude oil before blending it with Euro 5 to produce PPO and TPO. However, the real potential and problems of TPO and PPO with blending ratio higher than 10% are yet to be identified. The investigation, observation, and argument reported in this thesis represent an exploration of the synthetic diesel fuel combustion fundamentals in order to achieve better ignition delay using synthetic diesel fuel. Through the experiment, the effect of blending Euro 5 and synthetic diesel fuel on endothermic, heat recovery process, ignition, and combustion characteristics associated with the reduction of maximum HRR will be better understood.

1.3 Research Objectives

The following goals are rooted in this research:

(i) To investigate the effect of fuel properties and blending ratio on heat recovery process and ignition delay of diesel combustion using synthetic diesel fuel.

(ii) To analyze the effect of injection pressure (P_{inj}) and ambient temperature (T_i) on ignition delay and heat recovery process.

(iii) To compare the effect of injection pressure (P_{inj}) and ambient temperature (T_i) on ignition delay and heat recovery process for Euro 5 and synthetic diesel.

1.4 Scope of Study

There are several scopes of analysis that need to be pursued in order for the research to accomplish its primary objectives.

(i) The properties for each type of blended pyrolysis oil used were tested for its flash point, water content, viscosity, and density.

(ii) The injection pressures used were 80 MPa, 90 MPa, and 130 MPa.

(iii) The ambient temperatures used were 750 K, 850 K, 950 K, and 1050 K.

(iv) The fuels used for the experiment were Euro 5, TPO10, TPO15, TPO20, PPO10, PPO15, and PPO20.

(v) The study was conducted using the RCM to investigate the ignition delay,and heat recovery process.

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