PERFORMANCE & EMISSION CHARACTERISTIC OF EMULSIFIED BIOFUEL APPLICATION IN DIESEL ENGINE

by

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Thesis submitted in fulfillment of the requirements for the degree of Master of Science

June 2017

ACKNOWLEDGEMENTS

In humbleness, I thank Allah for allowing me to complete this thesis. I dedicate this work to my beloved mother; Allayarhamah Madam Fatimah Bte Ahmad who always, support and motivate me in many ways.

I would also like to express my deepest gratitude and sincere thanks to my supervisor, Dr. Mohamad Yusof Bin Idroas for his thoughtful supervision, continuous support, and stimulating critics to improve the thesis and the content of the research work. Without his invaluable inputs, I would not be able to complete my research efficiently.

Apart from that, I would like to express my appreciation to, Dr. Muhammad Khalil Bin Abdullah from School of Material and Mineral Resources for his guidance, support and critics to improve this thesis. I am also thankful to the cooperation of the staff and Ph.D. students especially Mr. Mohd Zalmi Bin Yop, Mr. Saiful Bahri Bin Abdul Jamil, Mr. Sharzali Bin Che Mat, Shukriwani Bte Sa'ad and others from School of Mechanical Engineering technical support team for their continuous support and assistance in this research.

Finally, I would like to express my indebtedness to Ministry of Higher Education, for funding my tuition fees, providing postgraduate assistance (GA) scheme and subsistence allowances

Mohd Fadzli Bin Hamid
June 2017

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LIST OF SYMBOLS

P	Pressure
T	Temperature
t	Time
N	Engine speed
ρ	Fluid density
T	Torque
ω	Angular acceleration
m	Mass
L	Litre
h_{tot}	Total enthalpy
λ	Thermal conductivity
v	Velocity
v_{max}	Maximum velocity
θ	Crank angle degree
τ	Strain rate
S_M	Momentum source
$\vec{u}$	Three dimensional flow
R	Radius
l	Length
x,y,z	Cartesian coordinates

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
EB	Emulsified biofuel
CPO	Crude palm oil
W/O	Water in oil
O/W	Oil in water
V	DC voltage
GVSTD	Guide vane swirl and tumble device
GVD	Guide vane device
BP	Brake power
BSFC	Brake specific fuel consumption
SFC	Specific fuel consumption
BTE	Brake thermal efficiency
BMEP	Brake mean effective pressure
CO_2	Carbon dioxide
NOx	Nitrogen oxide
O_2	Oxygen
TKE	Turbulence kinetic energy
GVD	Guide vane design
GVSTD	Guide vane swirl and tumble device
R_T	Tumble ratio
R_S	Swirl ratio
R_{CT}	Cross tumble ratio

CIRI-CIRI PRESTASI & PELEPASAN PENGGUNAAN BIOBAHANAPI TEREMULSI PADA ENJIN DIESEL

ABSTRAK

Pengurangan bahan api fosil dan kenaikan dan penurunan harga minyak di pasaran global telah mencetuskan kesedaran dan minat untuk membangunkan bahan api alternatif. Isu-isu bahan api fosil telah menjadi kebimbangan besar kepada pencemaran alam sekitar. Minyak sawit mentah (CPO) adalah salah satu daripada bio bahan api paling berpotensi yang boleh digunakan dalam enjin diesel, di mana sifat-sifat kimia CPO menghampiri sifat-sifat kimia bahan api diesel. Walau bagaimanapun, kelikatan yang lebih tinggi dan molekul yang lebih berat boleh menyumbangkan kepada beberapa masalah enjin seperti pengabusan rendah semasa suntikan, pembentukan mendakan karbon, penyuntik tersumbat, pencampuran rendah dengan udara dan kecekapan pembakaran yang lebih rendah. Biobahanapi terelmusi dan pengubahsuaian kepada beberapa komponen kritikal enjin termasuk peranti pandu bilah di pancaroga salur masuk dan penerokaan reka bentuk mangkuk omboh baru telah dikenal pasti sebagai penyelesaian yang menjanjikan untuk mengurangi isu-isu. Kajian ini membentangkan keputusan kedua-dua siasatan berangka dan eksperimen yang menunjukkan kesan berbeza peranti pandu bilah (GVD) dari segi variasi ketinggian 0.25R, 0.3R dan 0.35R di pancarongga salur masuk dan reka bentuk tidak serupa mangkuk omboh dengan OCB, OCC dan SCC penambahbaikan ciri-ciri aliran udara. ANSYS FLUENT 15 digunakan untuk menjalankan simulasi enjin tiga dimensi (3D) aliran sejuk pembakaran dalaman (IC). Kedua-dua simulasi dan keputusan eksperimen menunjukkan bahawa pancarongga salur masuk dengan GVD meningkatkan prestasi ciri-ciri aliran udara terutamanya pusaran, angin junam dan

nisbah angin junam melalui pancarongga salur masuk untuk enjin. GVD dengan ketinggian 0.3R didapati adalah reka bentuk yang optimum dengan peningkatan keseluruhan ciri-ciri aliran udara. Peningkatan ciri-ciri aliran udara dengan penggunaan omboh GVD dan SCC dalam enjin itu terbukti berjaya menyumbang kepada percampuran bahan api udara dan bahan api pengabusan yang lebih baik berdasarkan keputusan ciri-ciri prestasi enjin peningkatan sepanjang eksperimen.

PERFORMANCE & EMISSION CHARACTERISTIC OF EMULSIFIED BIOFUEL APPLICATION IN DIESEL ENGINE

ABSTRACT

The depletion of fossil fuel reserve and the fluctuation of oil prices in the global market have triggered global awareness and interest in developing alternative fuels. Fossil fuel has become a major environment concern due to its detrimental pollution effect. Crude palm oil (CPO) is one of the most potential biofuels that can be applied in the conventional diesel engines, since its chemical properties are comparable to that of diesel fuel. However, its higher viscosity and heavier molecules can contribute to several engine problems such as low atomization during injection, carbon deposit formation and injector clogging. An emulsification of biofuel and modifications of few engine critical components that include the incorporation of Guide Vane at the inlet manifold and the search for new piston bowl design have been identified as a promising solutions to mitigate the issues. This study presents the results of both numerical and experimental investigations showing the effects of dissimilar guide vane design (GVD) in terms of height variation of 0.25*R*, 0.3*R* and 0.35*R* at the intake manifold and dissimilar piston bowl designs with respect to OCB, OCC and SCC to the in-cylinder air flow characteristics improvement. The GVD designs and Piston modifications have been fabricated and tested to the Yanmar L70AE engine. The GVD designs and Piston modifications have been modelled using SOLIDWORK 2014, and ANSYS FLUENT 15 is employed and utilized to run a three dimensional (3D) cold flow internal combustion (IC) engine simulation. Both simulation and experimental results show that the intake manifold with GVD improved the performance of the air

flow characteristic particularly swirl, tumble and cross tumble ratios from the intake manifold to the engine. The GVD with the height of 0.3*R* was found to be the optimum design with respect to the overall improvement of the air flow characteristic. The improvement of the air flow characteristics with the application of GVD and SCC piston in the engine was proven to be successfully contribute to a better air fuel mixing and fuel atomization as based on the results of engine performance characteristics improvement throughout the experiment.

CHAPTER ONE

INTRODUCTION

1.0 Overview

In this chapter, the introduction of emulsified biofuel (EB) and its potential application in internal combustion engine is presented. Included, are the possible strategies of modifying the existing internal combustion engine to enable the EB application for the engine performance characteristic improvement to perform comparably with diesel fueled engine.

1.1 Diesel engine

Diesel engine is a major propulsion power source nowadays and has been powering for both inland and sea transportation machines due to its high thermal efficiency, reliability, high fuel economy and relative power performance. The first compression ignition (CI) engine was introduced by Dr. Rudolf Diesel where the CI engine was fueled by peanut oil for demonstration in the late 1900 (Sharma et al., 2008). However, the widespread availability and low cost of fossil fuel at that time did not help in promoting the vegetable-oil biofuel engine. It was not until the risk of depletion and the recent fluctuation of fossil fuel in the last two decades that attention began to gradually shift to vegetable-oil engine.

The demand for energy continues to rise every year and through the application of fossil fuel in CI engines, emissions of undesired gas nitrogen oxide (NO_x) and hazardous particulate matter (PM) have risen relentlessly over the years and caused great concern. Consequently, and if left unchecked, it can proved detrimental to human health and destructive to the environment. In addition to the above, more stringent regulations on emissions which were mostly implemented in European countries have motivated many researchers and scientists to continue their researches on alternative fuels and explore their potential energy.

1.1.1 Potential application of biofuel in compression-ignition engines.

Biofuel is a fuel that is produced through cotemporary biological process. Biofuel can be derived either directly from plant or indirectly from agricultural, commercialized, domestic or industrial waste. Bioethanol, simply ethanol and biodiesel are among the most commonly extracted fuel from biofuel. Biofuel, which is blended with gasoline and diesel is known as biodiesel and is a recognized alternative fuel and among the popular choices for researchers and scientist to investigation further. Indeed, burning biodiesel could reduce the emission of carbon monoxide (CO), total hydrocarbon (THC), particulate matter (PM) and polyaromatic hydrocarbon (PAH), (S. M. Palash et al., 2013). However, using biofuel did not totally solve the emission problem particularly nitrogen oxide (NO_x) since pure biofuel requires high temperature to ignite.

1.1.2 Limitation of biofuel for diesel engine application

Biofuel particularly crude palm oil (CPO), is edible vegetable oils that has great potential in replacing existing fossil fuel due to its renewability, ease of handling and lower pollution emission. CPO is naturally reddish in colour and has rich of beta-carotene content. It is one of the highly saturated vegetable fats and is semi-solid at room temperature. CPO is extracted from plants and corps. However, utilizing pure CPO as a primary fuel has been reported to shorten the engine life span, has a short-term usage, causing deposit built-up in the combustion chamber, injector coking, piston ring sticking and lubrication oil thickening (George et al., 2006), (Califano et al., 2014). These will lead to frequent engine repairs and overhauls, particularly to critical components such as fuel filter and oil filter. The main problem of biofuel is its high viscosity that contributes to several problems to the engine such as clogging of fuel lines, fuel filter and injector. Thus, a direct application of CPO in diesel engine is highly not recommended unless major modifications are to be done onto the engine.

1.1.3 Emulsified biofuel

Emulsion is defined as a mixture of two or more immiscible liquids and later become a dispersed droplet. The dispersed droplet consist of two liquid immiscible stability, an internal phase and an external phase as shown in Figure 1.1. The formation of disperse phase relies on the surfactant agent HLB number that influences the formation either to be oil or water soluble, better known as (W/O) and (O/W). In this study, the formation of (W/O) is utilized due to the water is situated in internal phase and presented as a dispersed droplet and the oil is situated in an external phase or better known as continues phase. Figure 1.2 depicts the biofuel-water droplet size and micro-explosion phenomena.

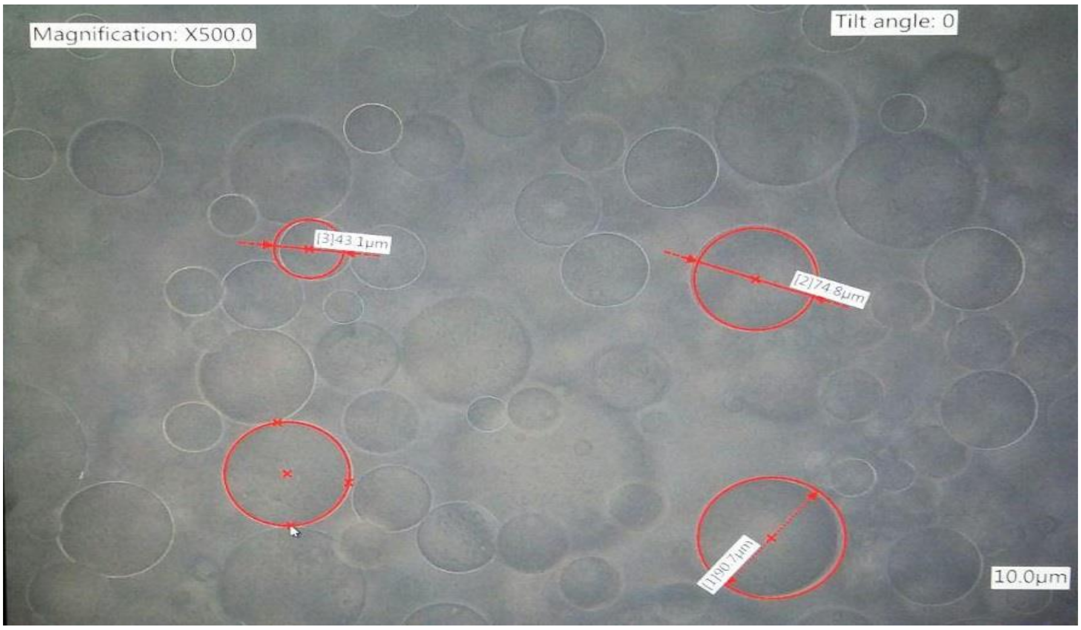

Figure 1.1: Water dispersed droplet size (red circle) into the biofuel continues phase.

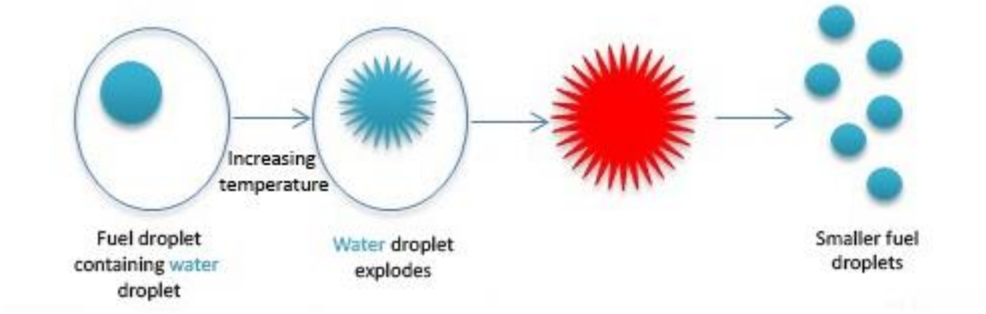

Figure 1.2: Micro-explosion phenomena (Koc et al., 2013)

The (O/W) working operation is different due the main concern on different boiling points. The huge amount of water in the external phase will initially evaporate and failure to break up the oil composition in the internal phase to become an ultra-fine droplet size. It is important to create an ultra-fine droplet size in order to rapidly assist the initial combustion. It also facilitates the heat transfer to penetrate the molecular size composition via convection and radiation. This will eventually avoid the build-up of carbon deposit at the piston resulting from inadequate heat transfer to penetrate the molecular. Emulsified biofuel produce a micro-explosion phenomena during injection which comprises primary and secondary explosions. EB working operation is dissimilar from emulsified conventional diesel. The different working operation means that there are differences in temperature between diesel fuel and biofuel, particularly CPO, during auto ignitions; 220°C at atmospheric pressure and 316°C at atmospheric pressure, respectively. When EB is injected into the engine, the molecular of spraying is exposed to higher temperature. Water, which has lower boiling point approximately 100°C, will evaporate and expand in the initial stage. Subsequently, the particles of oil will particulate and thereby dispersing the biofuel molecules to forcefully blend with surrounding air with micronization size. The micronization size of the biofuel molecules after dispersed by water evaporation has a wide excessive contact area with oxygen (hot air) and high temperature during compression as shown in Figure 1.3. Thus facilitates in initiating the ignition, enabling efficient and complete combustion. Furthermore, micro-explosion phenomenon aids in the reduction of NO_x gas emission when water vaporizes and dilutes with the reactive region thus air is cooled progressively. In addition, by adding water which has higher density than biofuel, it indirectly increases the momentum of fuel spray and improves the mixture with air. As a result, a more complete combustion is achieved thus reducing PM and soot efficiently leading to the release of green gases.

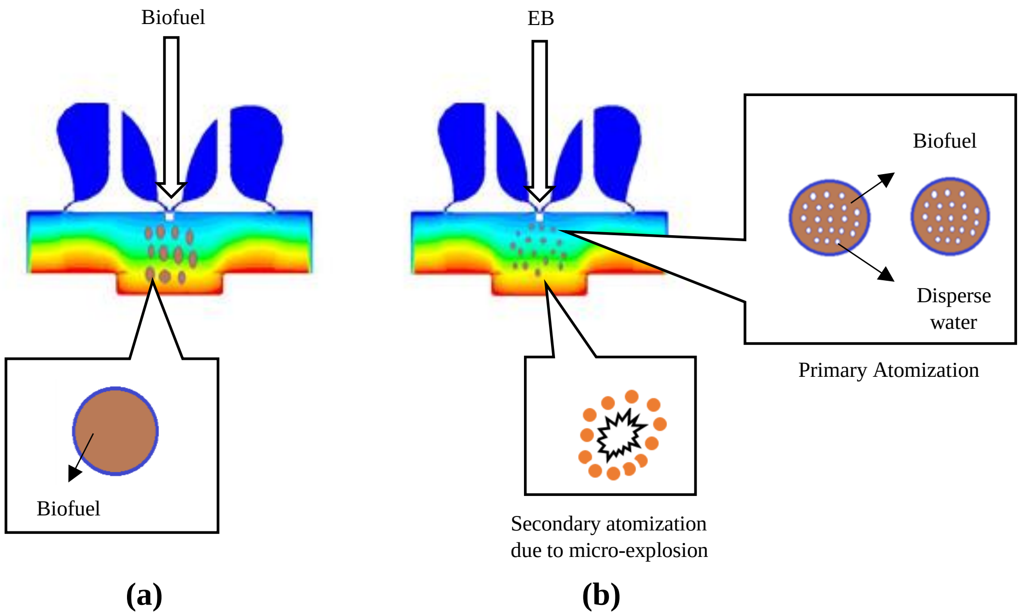

Figure 1.3: Primary and secondary atomization in spraying of EB.

1.2 EB and surfactant agent formulation.

Recently, EB has been given great attention by many researchers due to its ability to improve combustion efficiency. EB is a mixture between two or more liquids which is immiscible and present as a droplet or dispersed phase distributed throughout the others (Fingas et al., 2004). It is generated via mechanical agitation with a surfactant active agent to attain stability. Surfactant agent reacts to the fluid, weakening the surface tension. The formation between places with an oil-water mixture (O/W) or in water-oil (W/O) mixture depends on the hydrophilic-lipophilic balance (HLB) number. A surfactant is classified as non-ionic when its HLB number is from 0 to 20, while those with a HLB number above 20 is classified as ionic. Surfactant HLB value is an important stage to determine the classification of the HLB number where a low HLB number (<9) is referred to as lipophilic surfactant (oil soluble) and a high HLB (>11) is referred to as hydrophilic (water soluble) surfactant. Indeed, emulsified diesel cannot be considered as a renewable energy due to its blending with diesel fuel thus making the EB as a renewable energy due to reproducibility and replanted. In addition, EB can reduce the simultaneous higher temperature due to the presence of water in its constituent. Consequently, it will reduce the emission of NO_x and particulate matter.

1.2.1 Strategies of applying alternative fuels in diesel engine.

With the intention of obtaining comparable power performance to diesel. Many techniques had been introduced and attempted to enable CPO application in diesel engine. Among them are altering the chemical composition of biofuel via transesterification process (Fukuda et al., 2001), preheating the CPO (Kalam et al., 2004), biofuel emulsification (CPO mixed with a certain composition of water) using special techniques of emulsification and modification of few critical engine components such as piston bowl, intake manifold, injection timing, injection pressure and injection strategies (Li et al., 2014). CPO can turned into biodiesel via transesterification process of triglycerides with methanol. The product of this process is better known as palm oil methyl ester (POME). POME is recognized as a futuristic fuel because of its promising result as compared to baseline diesel performance curve (Yilmaz et al., 2012). However, producing POME is more expensive since it involves chemical and mechanical processes contributing to approximately 60% higher cost than producing CPO. Direct application of CPO in diesel engine has generated much interest since it only involves a simple production process. (Karabektas et al., 2012) had discovered that the preheated cottonseed oil methyl ester (COME) at 90°C led to favourable effect on the brake thermal efficiency (BTE) and carbon oxide (CO) emission but caused a higher production of NOx. Bari et al. (2002) had discovered that

CPO could be preheated to 60°C in order to turn its properties to be comparable with baseline diesel. It makes the combustion of CPO be more efficient resulting in lower carbon deposit. However, an auxiliary heater to preheat CPO at the fuel tank must be installed since significant heat loss can occur when the CPO is being transported from the tank to combustion chamber via pipeline. Auxiliary heater is required to heat the CPO above 60°C in order to retain its temperature at 60°C. Wang et al. (2010) studied the effect of the spray characteristic between diesel and biodiesel and discovered that biodiesel spray produces longer injection delay and smaller cone angle, thus generating larger sauter mean diameter. Its high viscosity and surface tension contributed to carbon deposit and unburned hydrocarbon in the cylinder. However, several reports had stated that using CPO directly has adversely affected the performance of the engine by lowering power output by approximately 5% to 10%, lowering torque by approximately 5% to 8% and increasing fuel consumption by 14% as compared to using diesel, Occurrences of piston ring sticking and deposit built up in the combustion chamber were also reported. These are due to CPO having higher density of 8% and lower calorific value of 10% as compared to diesel (Kalam et al., 2004), (Abu Zaid et al., 2004) and (Atmanli et al., 2013). Tiansuan et al. (2011) discovered that engine fueled by CPO produced 2.68% to 11.11% less power than engine of the same capacity fueled by diesel. It also reduced the thermal efficiency by almost 8.63% and increased specific fuel consumption by approximately 10.22%. Bari et al. (2002) had discovered that after the complete engine operation of 500 hours running on CPO, the maximum power achievable was reduced by 20% and the brake specific fuel consumption (BSFC) was increased slightly. After dismantling the engine, they found deposited of heavy carbon, worn on piston ring, and unevened spray from the nozzle.

1.3 Problem Statement

The issues of direct application of pure CPO in diesel engine still persisted even though several improvement actions had been taken by many researchers such as preheating the CPO, adding fuel additive to enhance engine performance and increasing the compression ratio to increase the volume of combustion chamber and temperature to biofuel higher auto-ignition requirement. The emulsification of biofuel is a potential strategy to improve the fuel characteristic and engine performance and help arrest emission problems. However, improper selection of surfactant agent used for the formation of biofuel emulsion will also become problematic. This is due to improper HLB setting such as an advance in mixing surfactant agent in percentage which will leads to the unfavourable HLB number and tend to form oil in the water (O/W) solution which contributes to the uneven formation of EB. This will contribute to combustion inefficiency and carbon deposit in the engine. The commercially-available diesel engines in the market have a standard piston-bowl design that caters for the best in-flow characteristic of diesel fuel. Unlike diesel fuel, the EB injection profile is different from diesel, since it has an inversed spraying characteristic that affects the spray injection and restricts the maximum fuel evaporation. Therefore, different designs of piston bowl are required to be explored in order to cater for and to enhance the air-flow circulation of the EB in the engine. The intake manifold of the diesel engine is another critical component that can be modified and characterized for the application of EB in the engine. Since the EB has higher viscosity, the in-cylinder air flow characteristics specifically swirl flow, tumble flow and cross tumble flow need to be studied. Indeed, the research of EB application in diesel engines with few modifications of the engine critical components to achieve comparable performance with diesel fuel is still at its early stage and yet to be fully explored.

1.4 Research Objective

The research objectives of this study are as follow:

1. To study and to characterize the EB properties for its application in diesel engine.
2. To characterize the dissimilar piston-bowl geometry designs via numerical simulations and to determine the optimum design for the application of EB in the engine with the improvement on the in-cylinder air flow characteristic.
3. To characterize the dissimilar guide vane designs at intake stroke via numerical simulations and to determine the optimum design for the application of EB in the engine with the improvement on the in-cylinder air flow characteristics.
4. To perform an experimental investigation on the effects of EB properties, dissimilar piston bowl geometry and guide vane designs to the overall engine performance including emission and to compare the performance with that of baseline diesel fuel.

1.5 Research Scope

In this study, the YANMAR L70AE engine model with one cylinder, one intake valve and one exhaust valve was selected as the test engine. Prior to the retrofitting of the engine, the test fuels comprising of pure diesel, pure biofuel and EB with 1-5% percentage water and 2% percentage hybrid surfactant were investigated throughout the engine dynamometer evaluation and emission tests. In the following stage, the test engine was retrofitted in order to cater for the EB application. The modification focused on the piston-bowl geometry design and guide vane design at the intake manifold. The dissimilar piston-bowl geometry designs which had been considered in this study were; open cylinder bowl (OCB), shallow depth re-entrance combustion chamber (SCC), and omega combustion chamber (OCC). The guide vane design (GVD) with respect to height variation was considered for the test at the intake manifold. The guide vane height variation which had been considered was in the increment of 0.25R, 0.3R and 0.35R while the vane length and angle were remained constant. The dissimilar piston-bowl and guide vane designs were studied for their effects to the in-flow characteristics in the engine using ANSYS FLUENT 15 specifically for the analysis of air swirl flow, tumble and cross tumble intensity. Eventually, the optimum designs of the piston-bowl and GVD for EB application in the diesel engine were determined. The simulation results were validated by the experimental investigation and tests on the retrofitted engine for determining the overall performance characteristics improvement.

1.6 Thesis Outline

This thesis contains five chapters. Chapter One presents the introduction of EB, its potential application in CI engine and expected performance. The problem statement, objective and scopes of this research are also presented in this chapter. Chapter Two consists of literature review related to this study. This chapter, outlines the latest knowledge and previous works that had been conducted by many researchers relating to the application of biofuel in the CI engine, characterization of chemical properties, engine modification and emulsification process of biofuel. Chapter Three reports the significant methodology in delivering the research, the experimental procedure relating to HLB setting, emulsification process, chemical properties testing, numerical setup, engine performance and emission test. In this chapter, every experiment procedure and analysis technique are explained in details. All the results, obtained from the methodology conducted in Chapter Three are analysed and discussed in Chapter Four. Finally in Chapter Five, the conclusion of the research work are presented together with recommendations for future work.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

Biofuel is one of the promising alternative fuels that can be applied in the CI engine due to the comparability of its chemical properties to that of diesel fuel. Biofuel has the advantages of renewability and lower emission of pollutant gases as compared to fossil fuels. However, there are still few outstanding issues being associated with biofuel application in the compression-ignition engines such as the condition of diesel engines during and after long period of operation. The main drawback of biofuel is its higher viscosity and low volatility that can contribute to a poor atomization and combustion characteristics of fuel in the engine. This literature review reports the details of many researches concerning the emulsification of fuel, the significant effect of water in fuel emulsion, specification of material used for fuel emulsification, engine performance assessment and includes the investigation of wear and tear, lubricity and durability, emission and few modifications of CI engine parts for the application of the EB application to improve the engine performance characteristics.

2.1 Emulsification of fuel

2.1.1 EB as a dispersed system

Dispersed system is a homogenous system that occurs between heterogeneous macroscopic system and molecular solution in an intermediate system. It has the possibilities to formulate the dispersed phase by two conditions; by condensation of the actual solution (formation by condensation) and by dispersion of the macroscopic phase (formation by dispersion). EB is included from a dispersed systems and can be defined as a mixture of two or more immiscible liquids and become a dispersed droplet. Dispersed droplets consist two liquid immiscible stabilities, an internal phase and an external phase. The formation of dispersed phase relies on the surfactant agent HLB number whereby it influences the formation to be either oil or water soluble better known as (W/O) and (O/W). (W/O) represents the water in the dispersed phase and the oil in the continues phase and for (O/W) is vice versa. The formation of (W/O) happens due to the location of water is which is situated in internal phase and is presented as a dispersed droplet and the location of oil which is situated in an external phase or better known as continues phase. Because of that, the (O/W) working operation is different with that of (W/O) due to the large amount of water at the external phase that will evaporate initially and failure to break up the oil composition in internal phase to become an ultra-fine droplet size. It is important to create an ultra-fine droplet size due to rapid assisted initial combustion. It also facilitates the heat transfer penetration to the molecular size composition via convection and radiation.

However, emulsion and micro emulsion are technically different even though they are both in the same dispersed systems group. The differences between micro emulsion and emulsion is not only merely on the droplet size, but most importantly on their thermodynamic stability (Eastman et al., 2009). The determination of emulsion properties such as stability, viscosity, density and specific gravity depends more on the droplet size and distribution size (Kumar et al., 2009). Emulsion in general is thermodynamically unstable and requires energy to form (Eastman et al., 2009). This is due to their Gibb free energy solution (ΔG_f) which has positive value ($\Delta G_f>0$). Gibb free energy solution which has positive value indicates that they have a spontaneous tendency for phase separation. In order to increase the emulsion thermodynamic stability, several techniques have been utilized and the most popular technique is via emulsifier agents formulation. The droplet diameter size dispersed phase produced by this technique usually measured above 0.1 µm (between 1-10µm). This emulsion liquid are physically opaque and milky in color (Yang et al., 2012).

As mention above, emulsion is thermodynamically unstable. Therefore, breakdown process was introduced to solve this problem. Breakdown process is a technique to improve the stability system through delay process of emulsion via surfactant agent formulation and solvents. Various techniques to process regarding to breakdown of emulsion may occur on storage, depending on the particle size distribution and density of the droplet, the magnitude of the attractive against repulsive (determined flocculation), the solubility of the disperse droplets and the particle size distribution (determine Ostwald ripening) and the stability of the liquid film between the droplets (determine coalescence and inversion phase). Emulsion breakdown process has multistage variations such as gravitational settling, decreasing of the interfacial area and free energy of the system. Gravitational settling is a particle emulsion process that cause the particle to fall to the bottom of the vessel forming sediment. Decreasing of interfacial area is a stability for a period of time with application of kinetic energy through surfactant agent reduce the interfacial tension in between two layers. The different breakdown processes are shown in Figure 2.1.

The breakdown process phenomena occuring in each process necessitates an analysis to determine the surface force involved. The process may take place simultaneously, complicating the analysis. Every single part of the breakdown process has been summarized by Rousseau et al. (2000) focusing on breakdown process, detailed of each process and methods on its prevention. Micro emulsion is basically a formation system in spontaneous and display nano-dispersed system. Micro emulsion is thermodynamically stable (Israelachvili et al., 1994), isotropic liquid mixture of oil, water and surfactant (Gutiérrez et al., 2008), large interface area, ultralow interfacial tension and optical transparency (Dantas Neto et al., 2011). The micro emulsion in the Gibbs free energy has shown either negative or zero value ($\Delta G_f \leq 0$) officially indicating the stability of emulsion formation. The droplet in micro emulsion is considered much smaller and fine crystalize size. Ramadhan et al. (2004) and Agarwal et al. (2007) had discovered that in general the micro emulsion size is between the range of 0.001 – 0.15 µm.

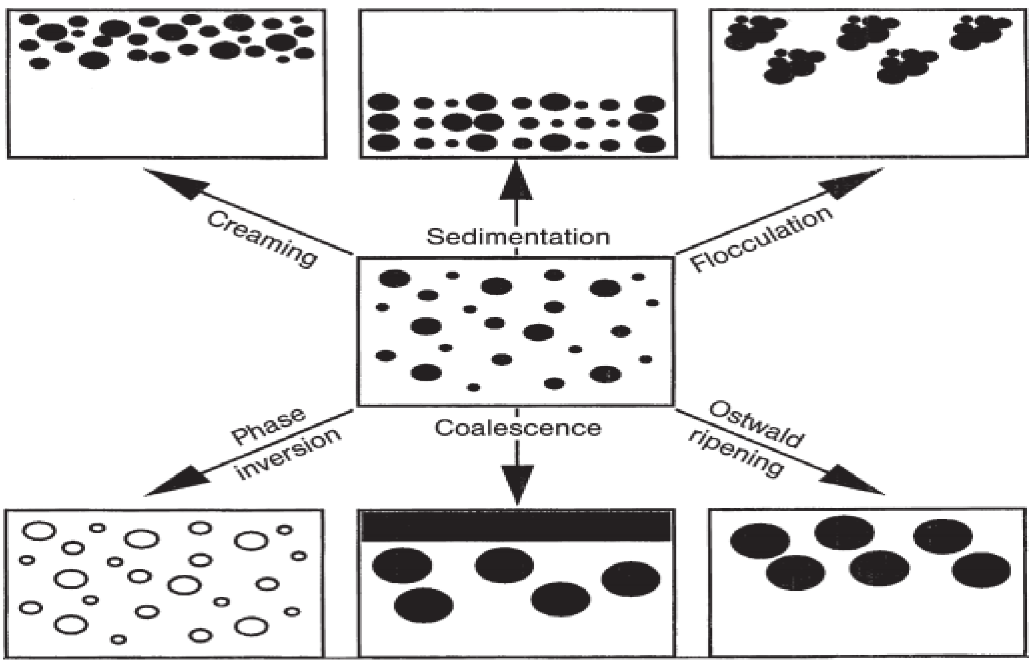

Figure 2.1: Numerous techniques of breakdown process in emulsion (Ramadhan et al., 2004)

2.1.2 Effects of water in EB; micro explosion phenomenon

Water is one of the vital components used to formulate an emulsified fuels. However, the presence of water in the engine system gives a negative impact and therefore, special attention must be given to stabilize the emulsified fuels. The foundation of emulsified fuels, which contain water, can cause the formation of rust and hydroproxides through fuel oxidation and can leads to corrosion (Graboski et al., 1998). This has been given full attention since the water feature consists of the salt content (Leung et al., 2009).Tap water, bottled water, dietary reference intake consist natural salts and might affect the function of emulsifier agent and emulsifier fuel's properties. Several researchers had investigated and reported that inorganic salts content in water compound would affect the dispersed system and stabilized with different types of surfactant agent by (Leung et al., 1987), (Ariyaprakai et al., 2010), and (Balcan et al., 2014). (Balcan et al., 2014) discovered that an electrolyte result of 0.5wt% NaCl in water is least effective in system containing ethoxylated surfactant. For this reason, the selection of surfactant and the combination of surfactant and co-surfactant characteristic are necessary to be investigated thoroughly in order to improve the stability of dispersed system.

Some researchers had suggested that to improve the EB, the use of demineralized water is necessary because it is more stable in emulsion as compared to ordinary tap water. Therefore, to remove salt content in water composition, water treatment need to be done. However, it is important to take into account the higher energy that water treatment requires an additional energy consumption, increasing cost and resources necessary to formulate EB. The presence of water in EB supposed to replace specific amount of fuel. Its presence is to improve the mass of fuel injection, to advance the atomization process in the cylinder before the combustion process occurs. It reduces the fuel heating value and decreases the total energy of unit mass of fuel. From this matter, it reduces the formation of NO_x inside the combustion chamber due to excessive water in the hot combustion chamber environment via radiation and convection. It significantly reduces the temperature of combustion chamber.

Additionally, it shows that the water presence in EB has increased the engine performance curve close to the that of conventional fossil fuel diesel (Kumar et al., 2005), (Lin et al., 2004) and (Moka et al., 2014).

The increased engine performance is cause by the improvement of atomization and mixing characteristic due to the effect of water dispersed phase in the fuel. Mofijura et al. (2012) reported that during injection, emulsified fuel that was sprayed through the nozzle inside the cylinder combustion chamber had been atomized into fine droplet size. Since water and fuel have different boiling points first, it is observed that water has reach their boiling point initially and soaked enough reaction heat. From this emulsified fuel process, it could be extended to EB, vegetable oil and animal fats application. The combustion of EB is characterized by the differences between the water and fuel volatility according to Tran et al. (2005). The droplet was excessively superheated via convection and radiation heat transfer in the enclosure cylinder environment. Inside the droplet, a rapid bubble nucleation effect followed and then continued with internal formation of vapor bubbles. The effect of vaporization that initially consisted water blew up the oil layering and caused the oil droplet to become fine atomization or volume ratio. Crookes et al (1997) named this phenomenon as micro-explosion.

In early 1965, two researchers named Ivenov and Nevedov. (1994) discovered the micro-explosion process. Micro-explosion effect in combustion has brought many benefits to the environment and the engine performance itself. Selim et al. (2009) discovered that the micro-explosion caused primary and secondary explosion. For instance, as EB, a primary explosion is a water composition in the internal phase atomization content due to different boiling points effect and heat transfer transmit their heat via rapid nucleation to the internal phase of atomization composition. Mura et al. (2012) investigated the effect of secondary explosion in terms of performance and found that the secondary explosion was very rapid and as a result it dispersed over a large volume, enhancing fuel/ air premixed and improving overall combustion efficiency. Furthermore, Jiao et al. (2003) summarized that this mechanism is a fundamental in reducing particulate matter (PM) emission in medium and heavy oils atomization. Figure 2.2 shows the dispersed system atomization prior to the combustion process.

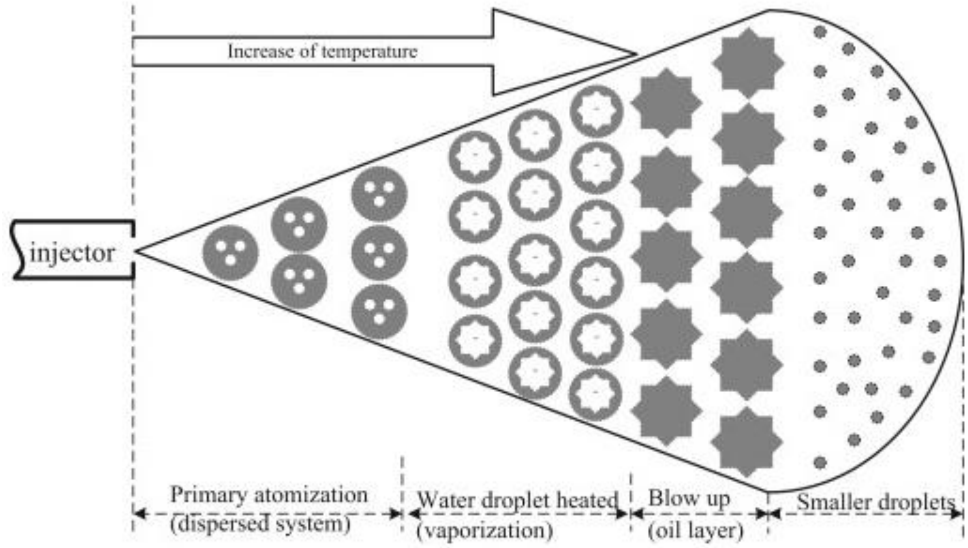

Figure 2.2: Dispersed system atomization in sequence (Yang et al., 2013)

Alahmer et al. (2013), Armas et al. (2005) and Cui et al. (2009) claimed that the presence of water in a micro-explosion effect is also possible to reduce a nitrogen oxides during exhaust gas emitted. According to Nazha et al. (1998), the improvement via emulsified fuel led to a shorter combustion reaction. This improvement principal leads to diminish of soot, particulate matter (PM), carbon oxides (CO), and hydro carbon (HC) formation. The water vapour aids in the formation of particulate to produce CO and H_2 in the region with less oxygen. Therefore, fewer amount of particulate was emitted as investigated (Husnawan et al., 2009). Attia et al. (2014) reported that, there were still debates the discrepancy, particularly on CO and unburned hydrocarbon emission. Leung et al. (2009) had discovered that engines which fueled by emulsified fuel on CO emission are mainly depend on the engine speed and load and compromised the decreased temperature into combustion chamber and consequently increased viscosity. Researchers such as Yang et al. (2013), Barrera et al. (2001) and Lif et al. (2010) had discovered that emulsified fuel had improved especially during the start of injection and the start of combustion of the fuel i.e. ignition delay.

Several studies found that the existence of water in emulsified fuel reduced the temperature due to heat absorption by water vaporization over fuel jet in the superheated environment. According to Zhang et al. (2013), it is endothermic vaporization (water absorbing heat energy via vaporization) in combustion chamber that consequently reduced significant local temperature. In addition, it will enlarge the ignition delay and improves combustion efficiency better than conventional diesel fossil fuel. The experimental method was a huge scientific contribution in evaluating the micro-explosion phenomenon. Califano et al. (2014) had testified that the micro-explosion phenomenon occurrence highly depended on a number of parameters and did not always occur. Samec. (2002) had identified that the coalescence or phase separation as an important factor affecting water droplets dispersed into the continues phase. However, the water presence in emulsified fuel had indirectly influenced the physic and chemical kinetics of combustion which is beneficial to combustion especially on the rate of heat release, reduction on the flame of temperature, changing of the chemical composition which result in higher OH radical concentration that can control NO_x formation and soot oxidation. Furthermore, it dilutes the rich zone in the combustion chamber.

Table 2.1: List of surfactant used in the EB formulation (Califano et al., 2014)

Chemical Type	Chemical Formula	HLB Number
Sorbitan monopalmitate (Span 40)	$C_{22}H_{42}O_6$	6.7
Sorbitan monostearate (Span 60)	$C_{24}H_{46}O_6$	4.7
Sorbitan monooleate (Span 80)	$C_{24}H_{44}O_6$	4.3
Sorbitan sesquiolate (Span 83)	$C_{66}H_{130}O_{18}$	3.7
Sorbitan trioleate (Span 85)	$C_{60}H_{108}O_8$	1.8
Polyoxyethylene sorbitan monooleate (Tween 80)	$C_{64}H_{124}O_{26}$	15
Tetraethylene glycol dodecyl ether (Brij 30)	$C_{20}H_{42}O_5$	9.7
Sodium bis-[2-ethylhexyl] sulfosuccinate (AOT)	$C_{20}H_{37}O_7SNa$	10.2
Oleic acid	$C_{18}H_{34}O_2$	1.0
Triton X-100	$C_{14}H_{22}O$	13.5

2.2 Material and methods used in the formation of EBs.

Complying accurately with the methodology to formulate EBs is difficult since the oils are derived from different feedstock (Vegetable oils/ animal fats and emulsifier agent formulation). Also, there are different methods of preparation i.e.: mechanical agitation and alteration of the physical-chemical compounds. Mechanical agitation is among the popular technique in preparing biofuel blended with water and surfactant agent via mechanical stirrer and membrane emulsification. In the last few decades, the ultrasonic vibration technique was given significant attention since it has the capability to break up the water dispersion into tiny size particle in a solution at high speed (Kannan et al., 2011). Several researchers had found that, for the purpose of braking up the water dispersion to the smallest droplet size, the rotational speed of stirrer needed to be increased (Bibette et al., 2006), (Kumar. 1996) and (Kerihuel et al., 2006). Kerihuel et al. (2006) had experimented on varying the stirrer speed from the range of 500 rpm to 1500 rpm, but no water droplets size variations were observed in their experiments.

There are several factor that could influence EB stability such as type of surfactant, co-surfactant characteristic, volume ratios, physical properties (viscosity, density, surface tension, and specific gravity), intensity and duration of the method used, preheating effect and etc. Surface tension and viscosity are functions of temperature and from this statement, the intention to deform the interface might be possible since the temperature can decrease the energy used by executing via proper heating temperature. Balcan et al. (2014) had claimed that the water in ambient temperature is the suitable solvent used is non-ionic amphiphiles. In the elevated temperature, the non-ionic amphiphiles becomes poor solvent and is replaced by an ionic surfactant.

The purpose of utilizing a surfactant agent is to reduce the surface tension of water or oil, to activate their surface layer and to maximize the contact area to obtain emulsion or microemulsion. The ability of surfactant agent to stabilize the dispersed system depends on the molecular structure and energy from interaction with the system (polar and nonpolar). The direction of surfactant orientation is the hydrophilic is more toward to water soluble and the hydrophobic is more toward to oil soluble. According to Kerihuel et al. (2006), in order to realize stable EB, the selection of surfactant to formulate EB must be dissolved in the oil (continues phase). The surfactant agent can be categorized with variant (hydrophilic-lipophilic balance) HLB number based on its formulation. Ozsezen et al. (2009) defined that HLB number is commonly in the range of 0 to 20 and non-dimensional value. The hydrophobic molecules tend to be oil soluble and interact with dissolvent in fats, oils, non-polar solvents and lipid. According to Qi et al. (2010), for the purpose formulating the dispersed system, the emphasis is that the surfactant agent used must be based on the HLB number. He suggested that emulsion tended to be (W/O) dispersed system that represented lipophilic more than hydrophilic. Kerihuel et al. (2006) suggested that the HLB number should be in between 4 to 8 for water in oil system.

Opawale et al. (1998) and Calabria et al. (2007) had specified that a mixture between two components HLB number which consist of low HLB number and high HLB number of surfactants yielded more stable emulsion. In order to straighten the homogeneity of EB, the formulation based on mathematical equation was proposed by Tadros et al. (2009) can be used. From this equation, the mass percentage of the surfactant involved in the mixture is possible to obtain. Co-Surfactant is becoming a more popular technique to increase the water amount and further stabilize of the EB. Salager et al. (2005) had explained that a co-surfactant is a smaller amphiphile with reduced tail size and head compared to surfactant i.e.: an amine, an acid, or phenol. Most of the cases is an alcohol.

2.3 Performance assessment of diesel engines fueled by EB

2.3.1 Engine performance and exhaust emission.

Emulsification fuel is not new, but has been used long time ago since the process of combustion and emission polluted the environment with NO_x, HC, CO, PM and Soot. Recently, a lot of researchers started to focusing on EB investigation, engine performance, engine durability, and gas exhaust emission, providing promising to replacing fossil fuel (Kumar et al., 2006); (Muralidharan et al., 2011; Atmanli et al., 2013; and Kerihuel et al., 2006). Most of the results depend on the engine operating mode, type of injection system and tuning method, system modification design in the engine profile and finally optimization of the combustion chamber configuration. The physiochemical of EB is also a determinant to the engine performance and exhaust emissions. However, based on the cetane number and heating value, the EB together with surfactant agent performed lower than baseline diesel fuel. Due to this, the profile performance curve testing table towards engine and exhaust emission between diesel, pure biofuel and EB has been carried out (Moka et al., 2014).

Alcohol and Co-Surfactant might be the finest agent formulation in order to reduce the viscosity and surface tension of EB. Previous study by Ziejewski et al. (1984) had shown that the use of higher volume of short chain of alcohol can possibly reduce the ignition quality of fuel due to their lower cetane number and consequently decrease engine performance. To accommodate this, Kumar and Khare. (2004) used the cetane improver as another component in their EB formulation. The differences in performance characteristic specifically on ignition delay had been reported by researchers (Crookes et al., 1997; Kumar et al., 2005; and Ghobadian et al., 2009). Nevertheless, shorter ignition delay had been achieved when using EB instead of using pure biofuel. Experiment to determine the ignition delay using EB was conducted by Crookes et al. (1995). They found that, inconsistency of ignition delay was not always obtained with increasing water percentage per volume of EB. According to Senthil et al. (2005), the emulsified of animals fats with ethanol had a longer ignition delay as compared to the methanol based system.

The physiochemical properties of EB is quite an interesting substance discovery, especially the behavior and influences of premixed combustion phase, peak