Fundamental Characteristics of Microbubbles in Water and Diesel Fuel

Afiza Erny[1,*], *Dzharudin* Fatimah[1] , and *Izhar* Muhammad[1]

[1]Fakulti Kejuruteraan Mekanikal, Universiti Malaysia Pahang, 26060 Pahang, Malaysia

Abstract. Recently, the usage of oxygenated fuel has emerged as a reliable way to enhance engine performance. Due to this matter, the potential of microbubbles (MB) mixed fuel in improving engine performance is anticipated. Being small in size, MB are characterized by having unique characteristics such as low rising speed and self-pressurization which can contribute to fuel oxygenation. In this study, the fundamental characteristics of MB in diesel and water medium were investigated. The MB are produced by shearing air into the high pressurized fluid. Then the life span as well as the size distribution of the MB in both mediums were observed. MB in water shrink faster compared to MB in diesel despite the differences in size range. As for size distribution, no significant tendency can be seen between both mediums.

1 Introduction

Diesel engines are indispensable in power generation and transportation sector due to their efficiency and durability over gasoline engines. However, high emission has always been an issue as diesel engines exhaust a significant harmful chemical to the air. This noxious emission brings negative affects to human health as well as the environment. Strict regulation has been imposed on the diesel-powered engine in recent years in order to reduce the exhaust emission. Thus, engine with low emissions has been developed by adopting pre formation and post formation emission control techniques like the introduction of biodiesel, particulate filters, catalytic converters and many more. Continuous efforts and study have focused on the diesel fuel as it is regarded as an economical solution that can be adapted in the existing diesel engine without engine modification.

Among those studies, recently, water-mixed fuel has emerged as one of the most popular method [1]–[5]. There are four primary methods of introducing water into the diesel engines: water injection into the cylinder using a separate injector, spraying water into the inlet air, intake manifold fumigation and water-diesel emulsions. The emulsification technique is the most effective technique as it can reduce nitrogen oxide (NO) emissions and particulate matter (PM) emission while simultaneously promote the combustion efficiency.

Another eminent additive in diesel fuel is alcohol[6], [1]. Ethanol named to be one of the most prominent alcohols as a fuel additive and have been widely used in many countries. It is a form of renewable energy produced by feedstock and their wastes. The usage of ethanol-blended fuel in compression ignition engines produce lower smoke, sulfur particulates and improve the fuel properties. Main disadvantages of ethanol to be used in diesel engine are low cetane number and the solubility problem in the petroleum diesel fuel. When ethanol fuel is mixed with the diesel fuel, problems usually occur in fuel phase separation which can be solved by using other alcohol such as isopropanol. Isopropanol is another oxygenated fuel which can also be produced from biomass like ethanol. Alcohol mixed fuel is refer to

* Corresponding author: erny@ump.edu.my

oxygenated fuel or oxygen enrich fuel also recognized as a method to improve fuel efficiency[3].

Therefore, in this project, engine performance as well as fuel efficiency will be investigated using air mixed with fuel by injecting micro-sized bubbles prior to injection stage. Unlike the macro bubbles, MB are characterized by having unique characteristics such as low rising speed, self-pressurization, electrical charges, and many more. Furthermore, owing to the small size, they tend to collapse and dissolves more oxygen to the liquid. This particular characteristic has caught many researcher's attentions to utilize it in enhancing combustion rate. Fuel improvement has been demonstrated experimentally by Yasuhito et al by using gas oil mixed with micro bubble[7]–[9]. As the results, the fuel consumption was reduced by 2-14% and reduction in pollutant emissions were confirmed. This achievement has shade many lights in the upcoming studies. Therefore, in this paper, preliminary experiments were done, where the characteristics of MB in diesel fuel and water were compared.

1 MB Characteristics

2.1 Small size

The definition of MB size is highly controversial. In the terminology of fluid physics, bubbles having diameter few hundred μm or less are consider as microbubbles while in the physiological activity studies, bubbles with diameter range between 10 – 40 μm known as micro bubbles [10]. Li et al. express that microbubbles as bubbles with diameters of a few tens of micro meters and have a lot of different characteristics from common mill bubbles with diameters order of milli meters [11]. Ishii et al. justify that microbubble as bubbles having diameter scale from several tens of μm to several hundreds of nm [12].

2.2 Low rising speed

Being small in size, the terminal velocity of the MB is extremely low. Therefore, MB has a longer life span compared to normal-sized bubbles. This phenomenon causes MB to be able to transfer their momentum to the liquid and to drag along the gas within them.

2.3 Shrinking and dissolution

B Ohnari interpret the shrinking process of microbubbles is due to the difference in pressure (ΔP) between inside and outside surrounding liquid of the microbubble[12]. It has influence in the internal pressure of microbubble as it increased and the radius decreases (as pressure is inversely proportional to radius). Because of the high pressure inside the bubble, gas inside the microbubbles tends to diffuse outside from a region of high pressure to a low pressure of surrounding. As a result, the microbubbles shrink and finally collapse, thus causes high mass transfer rate of gas microbubble to the surrounding liquid[13].

3 MB application in diesel engine

Heywood J.B stated that, the engines must operate in excess air to assure complete combustion. If the air carrying more than 21% O2 by volume to pass through the intake valve than the chemically required (stoichiometric), it will ensure nearly all fuel molecules receive the required oxygen for complete combustion[14]. Besides assuring complete combustion, excess air boost up the mixing process of fuel and air, but it also wastes heat energy by carrying it to the exhaust gases. Insufficient amount of oxygen during combustion process will cause incomplete conversion of carbon and hydrogen. This phenomenon will lead to formation of particulates and carbon monoxide increased in exhaust emissions.

A various of analytical and experimental studies have demonstrated the essential of using oxygen enriched combustion in diesel engines[15][16]. The results of all these observation show a considerable decrease in unburned hydrocarbon, carbon monoxide emissions and smoke while oxides of nitrogen emissions increased pro-rata with the increment of oxygen. Cole et al. reported the reduction in nitrogen oxide emission due to oxygen enrichment by injecting water into the combustion chamber[17].

Study by Chin has found that the increment in oxygen level cause a reduction in energy needed for combustion processes[15] [18]. Enriching the air intake with oxygen lead to a large reduction in ignition delay and combustion noise. Furthermore, by increasing the oxygen level to a reacting fuel oxidizer mixture leads to an efficient burn rates and the ability to burn more fuel at the same stoichiometry (oxygen to fuel ratio).

The oxygen level in the combustion chamber can be increased by mixing the oxygen with the air intake or by using oxygenated fuels. Both techniques have almost similar impact on the combustion, as mentioned by Donahue and Foster [19]. One of the promising advantages of using oxygen enhanced combustion is that low quality fuels can be used in the engines without influencing the overall performance of the engines as it was described by Marr et al.

Being small in size, MB is convenient to be used as fuel additive. As the diameter of the holes in injector in diesel engine, is around 0.12~0.2mm (120~200 μm), MB will be small enough to supply additional oxygen for combustion process. As mentioned in the previous chapter, unlike macro bubble, MB has a low rising speed as well as the tendency to shrink and dissolute. By mixing MB in fuel, it can be either suspend in the fuel and being supplied to the combustion chamber as it is, or it can be dissolute to the fuel, and supply the extra oxygen in form of fuel. Therefore, in this study, preliminary experiments were done, where the characteristics of MB in diesel fuel and water were compared.

4 Methodology

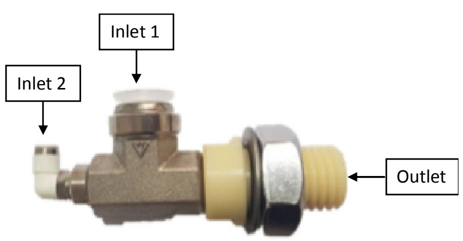

Fig. 1. MB generator

In this experiment, MB were generated by using MB generator (AWATARO) from Nitta company in a tank as shown in fig. 1. High-pressurized fluid is supplied to the inlet 1 by using pump which force the air to suck into the inlet 2 due to low pressure within the generator. The formation of micro bubbles is induced by the shear stress from the turbulent mixing flow of the air and fluid. The generator was keep running for 10 minutes before collecting the samples to assure the uniformity of the bubbles distribution. The samples were collected using a petri dished and the bubbles were observed using a digital microscope. In the first experiment, the bubbles were observed every 2 hours for 12 hours per day to capture the size difference with time. In the second experiment, total of 5 samples were collected from the tank and the size of bubbles within the bubbles were recorded to analyse the distribution.

5 Results and conclusions

5.1 Bubble's life span

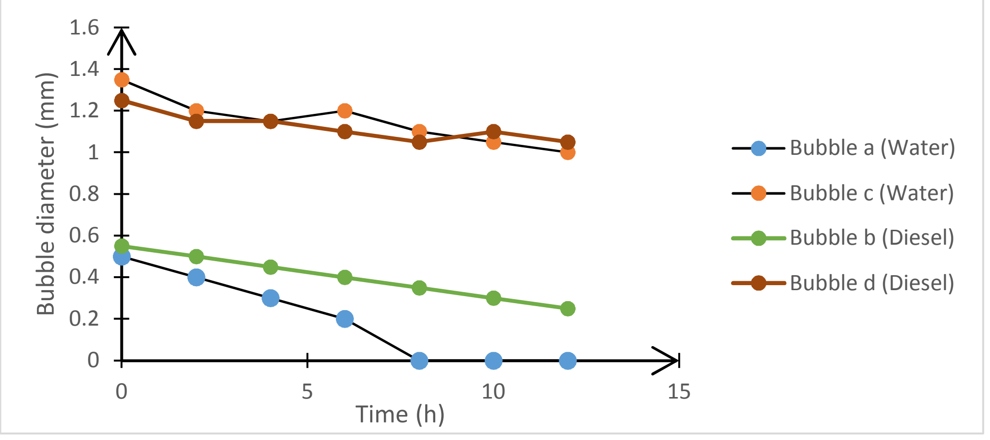

Fig. 2. MB life span in water and fuel

In Fig. 2, bubbles in both water and diesel were compared at different size range. One bubble from each medium which possess almost similar size were observed for 12 hours. There are 2 ranges of size were compared, bubbles between 0.4-0.6mm and 1.2-1.4mm. Overall, all bubbles show a similar tendency where the size decreased as the time goes by. As for the comparison between both mediums, MB in water shrink faster compared to MB in diesel despite the differences in size range. MB less than 0.5mm dissolve into the water within the 8 hours of suspension. Meanwhile, MB in fuel was still shrinking within the 12 hours observation.

5.2 Size distribution

Figure 3 illustrates the size distribution of MB in water and diesel fuel. Based on the graph, the MB were highly produced within range 0.2 mm – 0.4 mm, in both mediums. Out of 312 bubbles, less than 20 bubbles with diameter of more than 1mm were observed. Regarding the comparison between MB size distribution in water and diesel fuel, no significant tendency can be seen from the above graph.

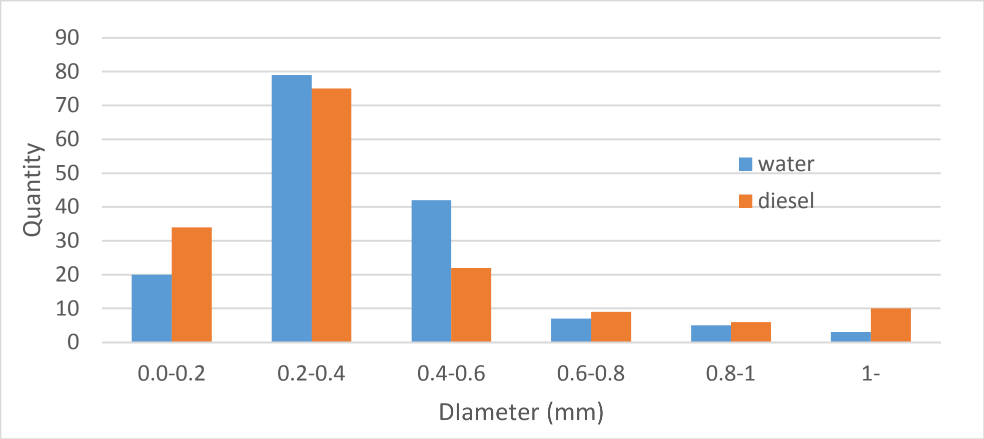

Fig. 3. MB size distribution

6 Discussions

This project attempts to enhance engine performance by introducing MB to diesel fuel. Thus, fundamental experiment was performed in this paper, where, MB characteristics in water and diesel fuel were observed and analysed.As the results, regarding the life span, the generated MB show ow a similar tendency where the size decreased as the time goes by. The surface tension of a micro bubble is higher than the internal gas expansion which causes it to shrink as the time goes by. On the comparison between both mediums, MB in water shrink faster compared to MB in diesel despite the differences in size range. This phenomenon might due to the difference in medium properties, such as density, viscosity and many more.

In terms of size distribution, no significant tendency can be seen between both mediums. However, the limitation of this experiment the USB microscope that have been used is only able to visualize MB with 100µm and above. In future, an advanced microscope is needed to observe smaller bubbles. Furthermore, in further experiments, more aspects will be taken into consideration such as temperature, dissolute oxygen level and many more. As for the conclusion, by using MB mixed fuel, positive developments on the engine efficiency and emission are anticipated. This is due to the ability of MB to supply excess oxygen by suspending within the fuel for a long time as well as able to dissolute within the fuel.

This research was supported by Universiti Malaysia Pahang, Malaysia (RDU1703155 and RDU160398) and Ministry of Education, Malaysia (FRGS/1/2017/TK03/UMP/03/1).

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