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Liquid Fuel Combustion in a Burner System: A Short Review

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Abstract: Fossil fuels have been the major energy resource of the world. However, the gaseous that produced by combustion of fuel is poisonous and it can lead to health problems for living things. This paper review the main factors which contribute to the combustion of the burner system. The main parameters considered are flame length, flame height, flame area, flame temperature and emission of gases. The first part of this study recaps on the flame characters. The second part discuss the effects of on the flame temperature of the burner system. The final section discusses the emission characteristics on emissions of nitrogen oxide, carbon monoxide, sulphur dioxide and carbon dioxide. The outcome of this paper provides an understanding of the combustion characteristics towards the performance of burner system.

Keywords: Burner, Liquid fuel, Flame, Combustion

1. Introduction

Fossil fuels have been the major energy resource of the world in the past century. However, fossil fuels have been the significant vitality asset of the world in the previous century. It is estimated that the oil reserves will be exhausted within 40 years if consumed at the current rate [1]. Therefore, there is a need to look for renewable and sustainable energy resources. Burner and combustion are two terms which cannot be separated. As known, heat is an energy source. Combustion occurs when the fuel is reacted with oxygen and heat energy and flame is released. Combustion process occurs by reacting with carbon, hydrogen and sulfur oxygen in fuel. As a result, the hydrocarbons and water vapor are revealed. The main aim is to heat up after converting chemical energy to thermal energy. It is a source of energy that we use in many aspects of our lives, including heating and production.

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Among the many different energy forms, diesel fuel plays an important role in the industrial and economic growth of a country because it contributes to a major portion of the transportation and power generation sectors. On the other hand, major concerns on depletion of fossil fuels and negative impacts on the environment have called for the development and use of an alternative fuel to substitute diesel. Currently, one such fuel that can be substituted for diesel engine application is fatty acid methyl esters (FAME) or more commonly known as biodiesel. According to the American Society of Testing Methods (ASTM), biodiesel is defined as a domestic, renewable fuel derived from the transesterification of animal fats and vegetable oils [1]. Biodiesel derived from waste cooking oil (WCO) can be viewed as potential feedstock for biodiesel production because it is non-consumable and it can change over waste to energy.

Human activities have produced a 45% increase in the atmospheric concentration of carbon dioxide since the beginning of the industrial revolution, from 280 ppm in 1750 to 415 ppm in 2019 [2]. This increase occurred despite the absorption by various natural sinks involved in the carbon cycle of more than half of the emissions. Majority of anthropogenic carbon dioxide emissions are from fossil fuel combustion, primarily coal, oil, and natural gas, with additional contributions from deforestation, land use changes, soil erosion, and agriculture. The combustion of fossil fuel releases hazardous emissions such as carbon dioxide (CO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), oxides of sulphur (SO_x), unburned hydrocarbon (UHC), and particulate matter (PM). These gaseous emissions deteriorate the environment quality and thus risking the human health. This paper discuss the combustion characteristics and its relation to the flame length, flame height, flame area and flame temperature. In addition, emission characteristics will also be presented.

2. Flame and Combustion

A flame is the gaseous component of a fire which is visible. This is due to a strongly exothermic reaction in a thin zone. Flame involves the chemical reaction between a chemical substance called a fuel and an oxidizing chemical. The chemical reaction between the fuel and the oxidant is known as combustion. It is accompanied by heat release and usually by light emission in the visible region of the spectrum.

Flame length is the length of flames measured along their axis at the fire front. In other words, the distance between the flame height tip and the midpoint of the flame depth. Flame angle is defined as the angle between the leading edge of the flame and the horizon with origin at the base of the flame's leading edge [3]. According to Kumaran, Gopinathan, & Kantharrajan [4], flame length is an important parameter which needs to be considered before application of gas turbine. The longer post flame in the combustion chamber will cause damaging effects on turbine components. This current work has deployed an infrared thermal imager for viewing the flame and measuring the length of each fuel manually. The combustion characteristics of improved biodiesel or Second Generation Biodiesel (SGB) were evaluated using a diffusion burner which has similar combustion dynamics to a gas turbine combustor.

In terms of flame length and emissions, the combustion characteristics of the improved biodiesel were assessed. The results were subsequently compared to unimproved biodiesel or First Generation Biodiesel (FGB) and distillate diesel (DD). The results are shown in Figure 1. SGB50 has the highest flame length reported, and SGB20 has a flame length comparable to DD. However, the pattern for both SGB and FGB is similar whereas the percentage of the blend increases the length of the flame becomes shorter except for SGB50. Kumaran et al. (2014) reported similar results, where DD was recorded as the longest flame and followed by FGB20, FGB50, FGB80 and FGB100. On the other hand, compared with FGB100, SGB100 has a longer and stable flames. This could be correlated with the fuel burning rate as there is greater capillary flow than FGB due to change in physical properties induced by SGB. Thus, during combustion more SGB absorbed and burned consistently than FGB.

Correspondingly, the Figure 2 thermal images show that the SGB100 flame is more stable and longer than the FGB100 flame. Furthermore, yellow smoke formation is lower for SGB which is an indicator of full combustion compared with FGB100. This is because the production of soot dropped when the amount of unsaturated fatty acid in the fuel composition decreased [4]. SGB20 is proven to be suitable to replace distillate diesel in terms of flame length. In the meantime, further investigation for SGB50 is recommended as it may not be suitable for microgasturbine due to longer flame and limited combustor design. However, it may be considered for gas turbine applications because gas turbine has greater combustor than microgasturbine [4].

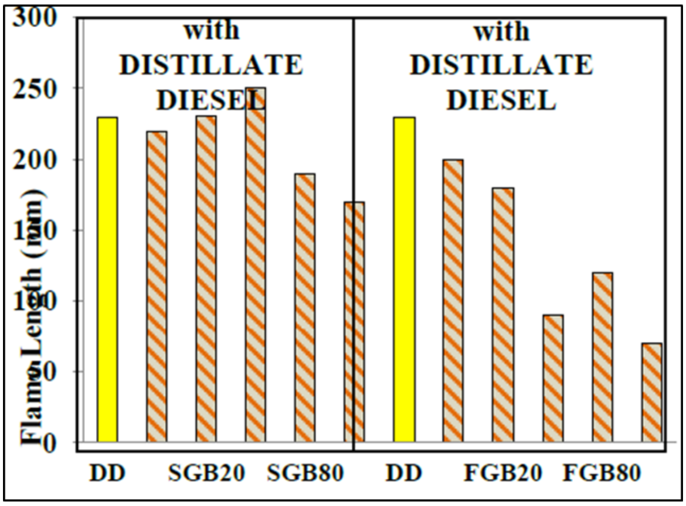

Figure 1: Flame length versus fuel sample [4]

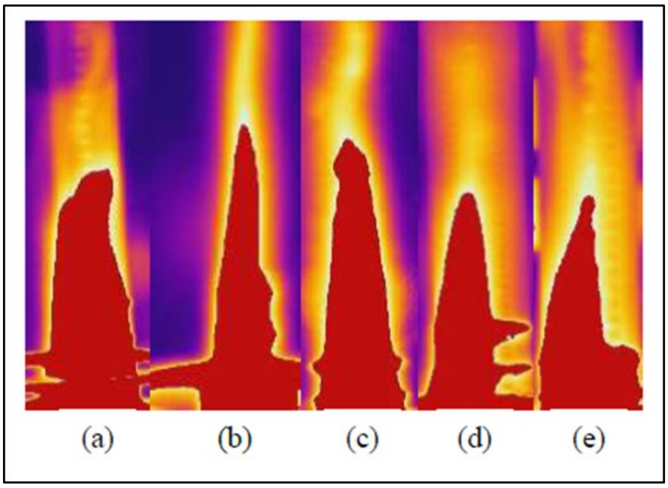

Figure 2: Thermal images for different fuels: (a) distillate diesel; (b) SGB50; (c) SGB100; (d) FGB50; (e) FGB100 [4]

A fundamental study on the characteristics of diesel combustion was conducted in this research using a burner system by changing the water content and the equivalence ratio [5]. Discussions were made during burning process on the relationship between water-emulsified into mixture formation and flame development. The concept of diesel and water emulsification was studied with a focus on controlling the process of combustion to minimize harmful emissions. The main purpose of this research is to investigate the effects of diesel-water emulsification on the formation of mixtures, the burning process and the development of flames within the burner system. The influences of the water-emulsified on the point of ignition and the development of flame were investigated.

Figure 3 shows diesel flame developments with different water content. The diesel misfire for W0 and W5 is going up to the equivalence ratio of 0.6 (lean). However, with the water content the misfire will increase. The higher water content diesel such as W10 and W15 will ignite on an equivalence ratio of 1.0 (stoichiometric). Because of the low content of the diesel molecule within the spray, the flame cannot be formed at the equivalence ratio. For W0, the flame is brighter, and the flame height is higher than those diesel fuels combined with water. The diesel and water combination were shown to have lower flame height. It is observed that flame height for W0 is higher for an equivalence ratio of 2.0 (rich) than other diesel flames due to inactive combustion which can lead to high gas temperature occurrence. Besides that, the flame area produced for all water contents from an equivalence ratio of 2.0 has a larger flame area compared with other equivalence ratio. This is the point where the rich combustion takes place. Moreover, the flame structure for all fuels and all equivalence ratios expands its flame area at 0.06 seconds after start of ignition and then shrinks at 0.09 seconds and then becomes constant and developed flame pattern. According to [5], the flame penetration of the pure diesel combustion is greater than other diesel-water mixtures. In addition, if a larger flame area is created by a higher equivalence ratio, this can be used as a qualitative measure of fuel-air mixing enhancements.

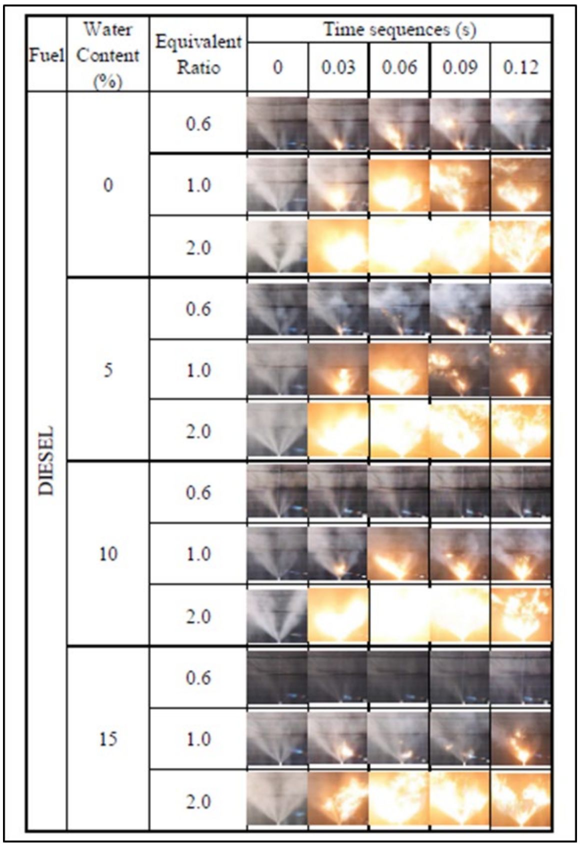

Figure 3 : Effects of water-emulsified on ignition point and flame development [5]

3. Flame Temperature

Temperature is a physical property of matter which expresses hot and cold in quantitative terms. This is the representation of thermal energy present in all matter which is the cause of heat incidence and a flow of energy when a body is in contact with a colder one. Arizal *et al.* [6] presents the combustion performance of Jatropha oil-derived biodiesel in an oil burner designed for conventional diesel. Biodiesel used in this study is a blend of diesel with Jatropha Methyl Ester (JME) and combustion efficiency was calculated and compared with conventional diesel fuel (CDF). The performance of Jatropha biodiesel in combustion is based on wall temperature profiles.

Biodiesel derived from Jatropha has been shown to be comparable with CDF's combustion properties and has high potential to be used as alternative fuel for diesel machines. Nine stations are located along the external wall of the combustion chamber where wall temperatures were measured and recorded. Temperature profiles at equivalence ratios of 0.72, 1.0 and 1.34 for CDF and Jatropha biodiesel blends are shown in Figure 4, 5 and 6, respectively. The similarity observed from the graphs is because the temperature profiles for all fuel blends are almost similar. From the graphs, the temperature rises from the inlet of the combustion chamber (100 mm) to the distance of 400 mm, then begins to decrease until the outlet of the combustion chamber (900 mm).

For B10 the highest temperature of 960°C was recorded at 400 mm from the combustion chamber inlet, at an equivalence ratio of 0.72. Besides that, the temperatures reported for B15 and B20 have been lower. Theoretically, as the percentage of Jatropha biodiesel volume increases, the Lower Heating Value (LHV) and the blends' calorific values will decline. This will cause the temperature of the flame to decrease as the Jatropha biodiesel increased from B5 to B20 (Arizal et al., 2015). The temperature profiles for all the blends were nearly similar at stoichiometry except for B5, which recorded lower temperature along the length of the combustion chamber. The wall temperature profiles of the blends recorded lower temperatures as compared to CDF at the higher equivalence ratio of 1.34 [6].

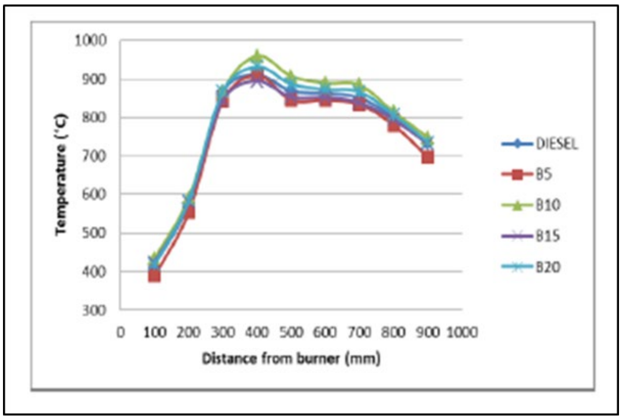

Figure 4: Wall temperatures at equivalence ratio 0.74 [6]

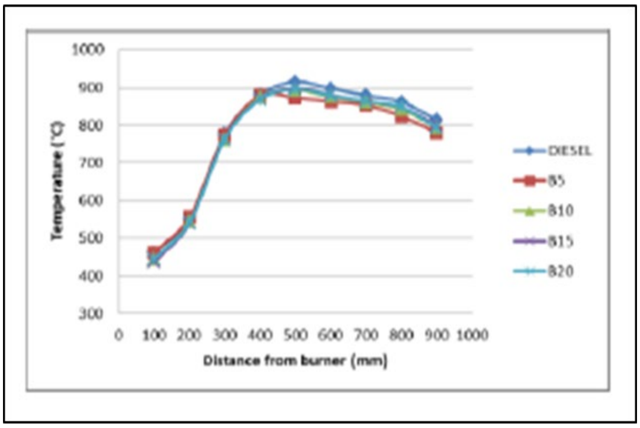

Figure 5: Wall temperatures at equivalence ratio 1.0 [6]

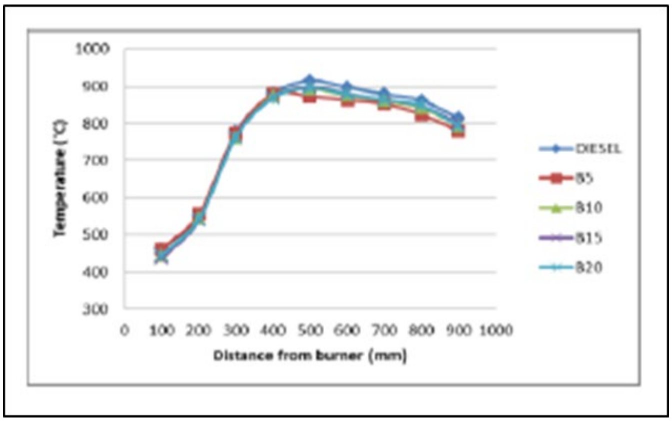

Figure 6: Wall temperatures at equivalence ratio 1.34 [6]

The flame temperature is the principal factor in the rate of heat transfer. It can be seen in Figure 7 that the flame temperature of the diesel oil is higher than the flame temperature of the biodiesel. This explains the higher heat transfer rate of the diesel oil in furnace parts near the body of flame (Sies et al., 2014).

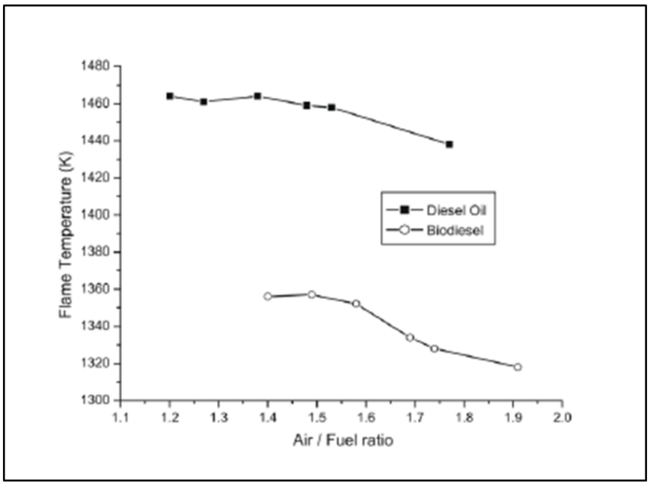

Figure 7: Flame temperature [6]

Sies *et al.* [7] presented the results of droplet combustion for ethanol, diesel, castor oil biodiesel, and their blends. The results shows that adding biodiesel to diesel significantly reduces soot formation while reducing burning 21rate slightly. Besides that, higher soot production of methyl oleate than castor biodiesel was observed suggesting strong oxidation propensity of the function group hydroxide (OH) in castor biodiesel. Figure 3.8 shows representative flame streaks of a burning diesel droplet stream (Figure 8-a), castor oil biodiesel (Figure 8-e), and its mixtures (Figure 8 b-d). A strong yellow brightness of the diesel flame indicates the presence of soot, which is mainly due to the presence of aromatic components in the fuel blend. If the biodiesel ratio increases, the yellow luminosity decreases visually, the reduction becomes drastic and yields a smaller blue flame [7].

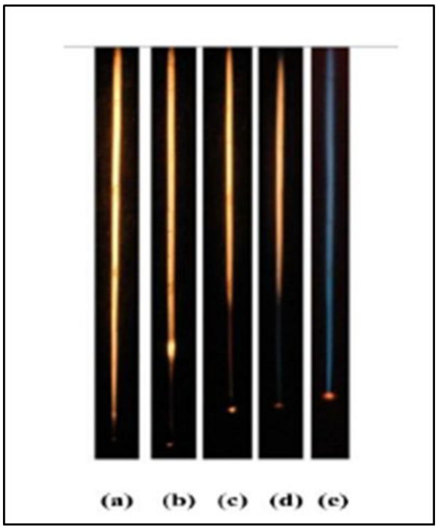

Figure 8: Flame streak images of blends of diesel and (castor oil) biodiesel: (a) diesel, (b) D75B25, (c) D50B50, (d) D25B75, (e) biodiesel [7]

According to Sies et al. (2014), analysis of the flame temperature of biodiesel blends and biodiesel components performed to determine the influence of unsaturated levels and the hydrocarbon chain length on the flame temperature. In Figure 3.9, when compared with unsaturated methyl esters, the resulting saturated methyl esters have higher flame temperatures. The shorter chained methyl esters of fatty acid lead to higher flame temperatures compared to longer chained counterparts and higher propensity to form thermal NO_x. As the degree of insaturation increased, the fuel consumption rate increased. Figure 4.9 shows the thermal images of flames of different fuels.

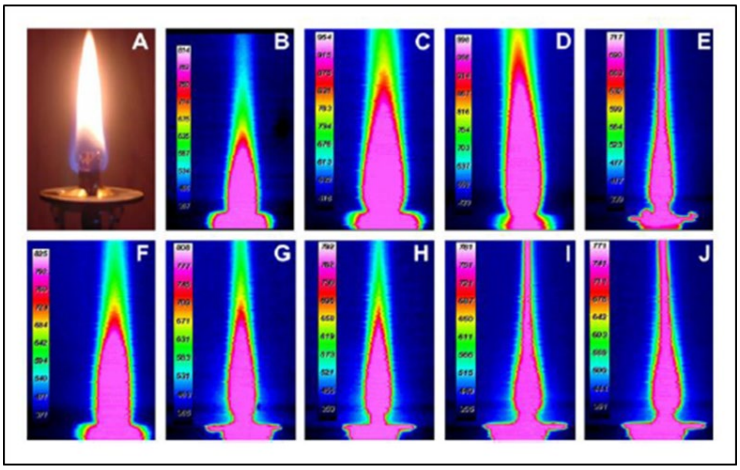

Figure 9: Thermal image of flames: A. Flame arrangement; B. Soybean biodiesel; C. Ethanol; D. Methyl Acetate; E. Diesel; F. Methyl Palmitate; G. Methyl Stearate; H. Methyl Oleate; I. Methyl Linoleate; and J. Methyl Linolinate [7]

4. Emission of Gases

The use of fossil fuels is a major source of air pollution, notably emissions of NO_x, CO, CO_2 and SO_2. The burning of fossil fuels contributes significantly to four pressing environmental issues, namely global warming, acid rain, photochemical smog and depletion of ozone [8]. Arizal *et al.* [6] presents the combustion performance of Jatropha oil-derived biodiesel in an oil burner designed for conventional diesel. Biodiesel used in this study is a blend of diesel with JME and combustion efficiency was calculated and compared with CDF. The performance of Jatropha biodiesel in combustion is based on the amount of gaseous emissions emitted such as NO_x, SO_2 and CO.

The emission characteristics suggest the biodiesel blend's suitability as a substitute diesel fuel. Gaseous emissions, such as NO_x, SO_2, and CO have been measured in this experiment. Profiles of emissions are necessary to ensure that fewer toxic gasses are emitted into the atmosphere, ensuring green technology [6]. Figures 10, 11 and 12 show the emissions of NO_x, SO_2 and CO from Jatropha biodiesel as compared to conventional diesel fuel combustion. From Figure 3.10, NO_x increases by 5 ppm for B5 blend at equivalence ratio, $\phi = 1.0$, while B20 blend increases by 3 ppm. Other blends remain unchanged which is similar to the values of diesel. These rises are very low, so they are reasonable and are not going to affect the environment. Figure 3.11 shows that the emission of SO_2 emitted from the combustor increases by 4 ppm for B20 blend while B5 blend shows a 2 ppm reduction. The emission profiles maintain the same pattern which is the similar trend although magnitude differences are slight. Figure 3.12 shows the emission of CO for all blends is nearly the same at $\phi = 1.0$ and $\phi = 1.34$. While on the contrary, the amount of CO emitted for all blends was less than CDF which showed better and more efficient combustion using Jatropha biodiesel at $\phi = 0.72$.

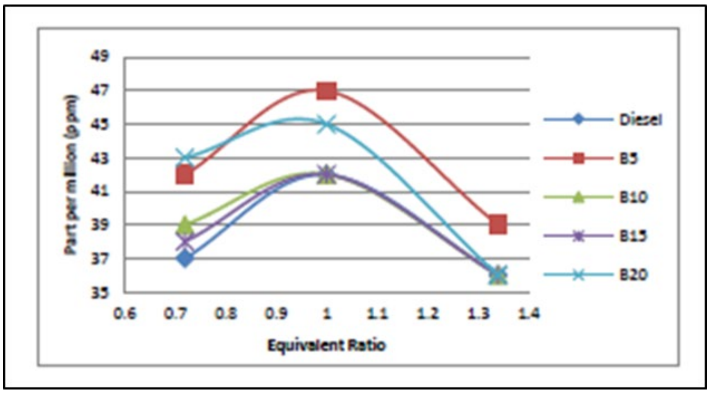

Figure 10: NO_x emissions versus equivalence ratio for each blend [6]

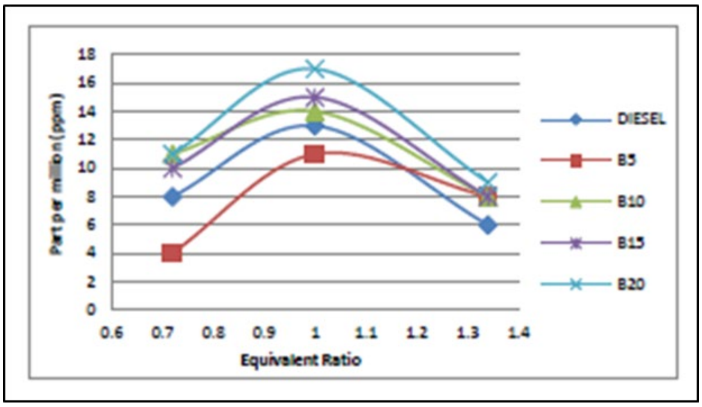

Figure 11: SO_2 emissions versus equivalence ratio for each blend [6]

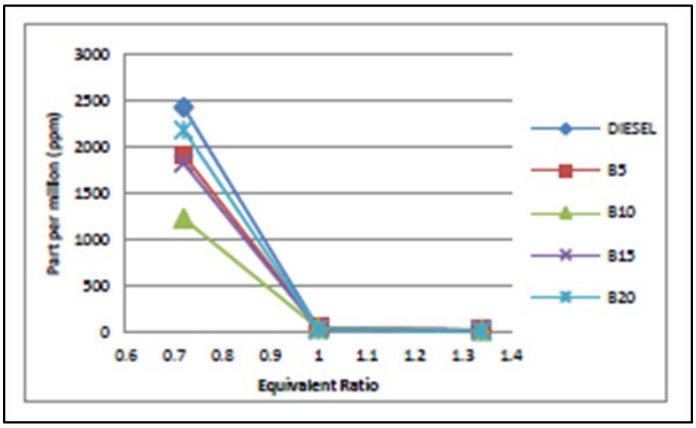

Figure 12: CO emissions versus equivalence ratio for each blend [6]

5. Conclusion

Despite decades of research in burner combustion, there are many challenges in the application especially to meet the combustion efficiency and stringent emission regulations. This paper summarize the combustion characteristics by the previous researchers. Discussions were made on the development of flame during burning process, flame characteristics such as flame length, flame height and flame area in combustion and emission characteristics of NO_x, CO, SO_2 and CO_2. Results are summarized as follows:

1. Flame height of the combustion for pure diesel is higher than other diesel-water mixtures. Apart from that, when larger flame area produced by higher equivalence ratio, as this may be employed as a qualitative measure of the enhancements of fuel-air mixing.
2. SGB has better combustion characteristics than DD and FGB in terms of burning rate and flame length. SGB50 has shown promising results compared to other blends except for flame length. Even though SGB80 shows a comparable performance to SGB50 in terms of emission and combustion efficacy, the flame length of SGB80 is shorter than both DD and SGB50.
3. Emission of NO_x produced from Jatropha biodiesel was shown to be increased by a maximum of 12%, while other emissions remain almost the same. Overall, biodiesel from Jatropha oil has a comparable emissions and temperature profile with diesel fuel. As a result, combustion performance of Jatropha biodiesel in oil burner is acceptable and was shown to be quite promising as replacement of fossil diesel.
4. The emission and performance characteristic of biodiesel burner system clearly indicated that this form of alternative fuel can be an attractive renewable alternative energy source for burner system. Physical and chemical properties of biodiesels can have significant effects on the combustion process, which will impact on the burner performance and emissions.
5. The search for cost-effective feedstock and processes to produce quality biodiesels must not only consider economic factors, but also focus on long term ecological and environmental issues. The possibilities to reduce the problems of higher toxic emission such as NO_x, CO, SO_2 and CO_2 is achievable. Even though it is just a small impact on the reduction of some of the emissions from fossils, this is also important from an environmental point of view.

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