Jurnal Mekanikal
June 2012 No 34, 47-56

THE SPRAY COMBUSTION OF PALM OLEIN AND DIESEL FUEL BLENDS

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ABSTRACT

Global interest in renewable source of fuels caused by the escalating price of petroleum fuels and finite source of fossil fuel supply, drive the search for an alternative and sustainable fuels which should be found and developed. Improvement efforts focus on reducing emissions, improving efficiency and lowering costs without sacrificing reliability. Malaysia with abundant of palm oil production, the use of palm oil as blended biofuel could be the potential substitution for fossil diesel. Biofuels have been used in diesel engines, boilers and gas turbines in developed countries without major modification on their system. This paper reports a study on combustion characteristics of blended palm olein in diesel in a water-cooled continuous spray combustion unit. The physical and chemical characteristics of the various blends of biofuels were given and analyzed. The different blending ratios of palm olein of 10%, 20% and 30% in petroleum diesel volumetrically were tested in the combustion unit over a wide range of air fuel ratio from rich to lean. The blended fuels give effect to the combustion efficiencies, flue gas temperatures and emissions. The results were compared to the baseline fuel which is 100% diesel. It was found out that the blended fuel of up to 20% olein gives comparable results as diesel fuel in term of flame length, flame stability and emissions.

Keywords : *Palm oil, spray combustion, fuel blends, emissions, combustion unit.*

1.0 INTRODUCTION

The escalating price of petroleum derived fuels has heavily struck the global economy. Awareness of fossil fuel exhaustion comes earlier than expected has driven the world to search for and develop the alternative and renewable fuel sources. In current extent, vegetable oils have been considered as the feasible partial substitution for petroleum fuel for the near future even though Rudolph Diesel had intended to run his invention with vegetable oil a century ago (Yusof, 2005). Vegetable oils can be used as diesel equivalent biofuel or biodiesel via several methods, including converting the vegetable oils to methyl esters, which could be blended with diesel fuel or burnt directly for energy (Ma and Yusof, 2005, Wikipedia 2006).

European Countries and United States have conducted extensive renewable energy research including research on vegetable oils since the oil crisis of 1973. In fact, the usage of biodiesel has become compulsory in several European Union countries and also in several states in US and Canada. Rapeseed oil and Soyabean oil being abundant in Europe and United States respectively are mostly used as the raw material to produce

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biodiesel in these two regions. Other vegetable oils being used including sunflower oil, corn oil and palm oil. (Ma and Yusof, 2005).

Malaysia as the second main producer of palm oil has great potential to develop biofuels as the substitution or partial substitution of fossil fuel. As the cost and production capacity are the two main factors, which contribute to the selection of oil for biodiesel development, palm oil has obvious advantages over the other vegetable oils. Table 1 shows production and costs information of three most produced oil-yielding crops in the world. Among these crops, palm oil is the most land effective, as it is able to produce 302 tonne/km^2/year of oil and this capacity is 4.5 times of rapeseed oil (67 tonne/km^2/year) and surprisingly 8.4 times of soyabean oil (36 tonne/km^2/year). Besides, palm oil is also the most produced oils in 2009 and more importantly it is the lowest price vegetable oil traded in world market.

Table 1: Annual Production of Major Vegetable Oils

Vegetable Oil	**Annual Production/Cultivated Area[a],2009(tonne/km^2/year)**	**Annual Production, 2009[b] (tonne)**	**Price, 2009[b] (USD/tonne)**
Soybean Oil	36	35,805,000	849
Rapeseed Oil	67	21,343,000	859
Palm Oil	302	45,064,000	683

Source: A Food and Agriculture Organization of the United Nations Statistics (FAOSTAT), 2012 b Malaysian Palm Oil Board (MPOB), 2012

Palm olein (PO) is the refined, bleached, and deodorized form of crude palm oil where the average trading price for the past 10 years is about 7% higher than crude palm oil. Although it can be directly burns for energy, it requires the special design combustion apparatus or major modifications of existing combustion facilities due to its high density and viscosity. However, palm olein can be blended with petroleum diesel in various ratios to produce the simplest kind of biofuels. The blended fuel is able to be burnt in industrial burners, boilers and gas turbines without major modification of the system.

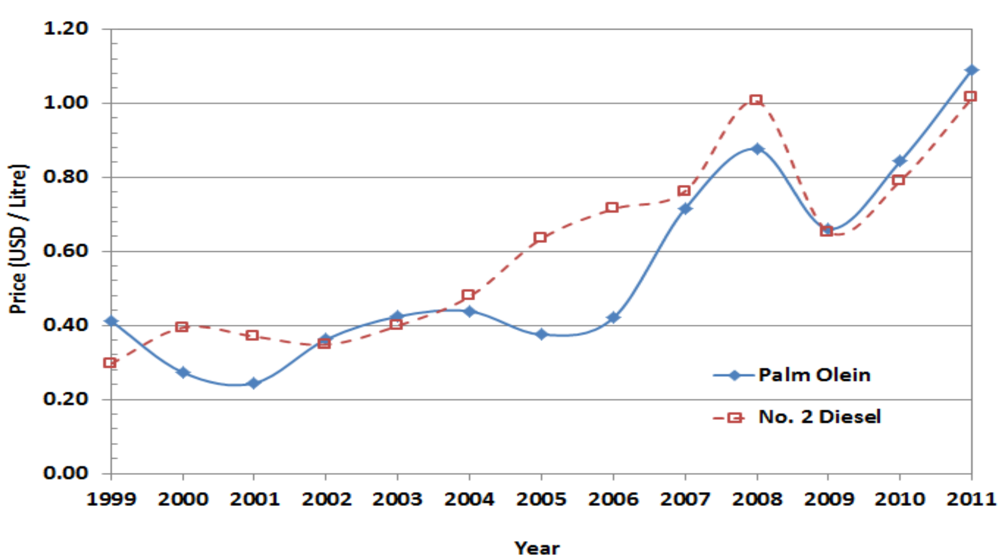

Figure 1: Palm Olein Prices and Diesel Prices (Source: Energy Information Administration 2006, Malaysia Palm Oil Board 2005)

Previously, the major drawback of developing biofuels using palm olein was because of its price was much higher than petroleum diesel as shown in Figure 1. However, if the petroleum diesel price is increased drastically and at the same time, the palm olein price decreased and remained stable, it draws more interests from the government and private companies to refocus into the developments of biofuels. As the future projection indicates that if the petroleum price continue to increase and surpassed the price of palm olein, then the development of biofuels as the diesel substitution becomes vital to the national economy.

Although there are some studies on the combustion and emissions of various blends of biodiesel in water cooled combustion chamber, Tashtoush et. al. (2003), Ng and Gan (2010), limited study were done on neat palm olein. This study is intended to evaluate the combustion performance of blended fuels of diesel with various ratios of palm olein and hence finding the optimum fuel ratio. The combustion experiments of various blended fuels were carried out with a range of air fuel ratio from slightly rich to very lean combustion. Assessment of combustion efficiencies is based on the flue gas temperatures and emissions level, therefore both parameters were measured and recorded.

2.0 METHODOLOGY

2.1 Materials

10%, 20% and 30% of the palm olein were blended with petroleum diesel volumetrically. Each batch of blended fuels was mechanically stirred for 2 hours to ensure the homogeneity was achieved. Samples of the petroleum diesel as well as its blended fuels were lab-tested and the fuels properties are shown in Table 2. The stoichiometric air fuel ratio of diesel fuel and its blended fuels were then calculated from the components in the elemental analysis so that the experimental setting of air fuel ratio during the combustion tests can be decided.

Table 2 : Properties of Diesel, Palm Olein and the Blended Fuels.

		Diesel	90% Diesel 10% PO	80% Diesel 20% PO	70% Diesel 30% PO	Palm Olein
Specify Gravity		0.837	0.844	0.851	0.858	0.907
Elemental Analysis	C	84.76	83.98	83.20	83.26	75.87
	H	14.96	14.83	14.70	14.52	13.31
	N	0.01	0.01	0.01	0.01	0.01
	S	0.27	0.24	0.20	0.19	0.07
	O	0.00	0.94	1.89	3.02	10.74
Stoichiometric Air Fuel Ratio		14.90	14.72	14.55	14.33	12.85
Calorific Value (kJ/kg)		45500	44850	44200	43600	39400

2.2 Continuous Spray Combustion Unit

The combustion test firings of blended fuels have been carried out in a P.A. Hilton Continuous Combustion Unit located in Combustion Laboratory, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia as shown in Figure 2. The water-cooled combustion unit has independent flowrate control of air, fuel and water supplies. Thus, it can be operated over a wide range of desired air fuel ratio and heat transfer rate. A medium pressure air blower is installed to the system, which supply up to a maximum of 160 kg/h of air flow to the system. The air flow rate can be adjusted by a control valve with the flow reading given by an orifice meter.

A gravitational fuel supply is used in this system where the fuel tank is placed 2.5 meters above the burner to create sufficient pressure for the gravitational fuel feeding to the nozzle. The fuel flow rate is controlled by a rotameter pre-calibrated for kerosene. The actual fuel flow rate of each batch of blended fuels was recalibrated to the existing scale prior to the combustion test firing. It was found that, the more viscous fuel moves slower in the rotameter at the same float setting compared to the less viscous one. The maximum fuel flow rate of 100% Diesel fuel in this rotameter is 8.5 kg/h while the maximum fuel flow rate of the 70% Diesel-30% Palm Olein fuel is 5.0 kg/h.

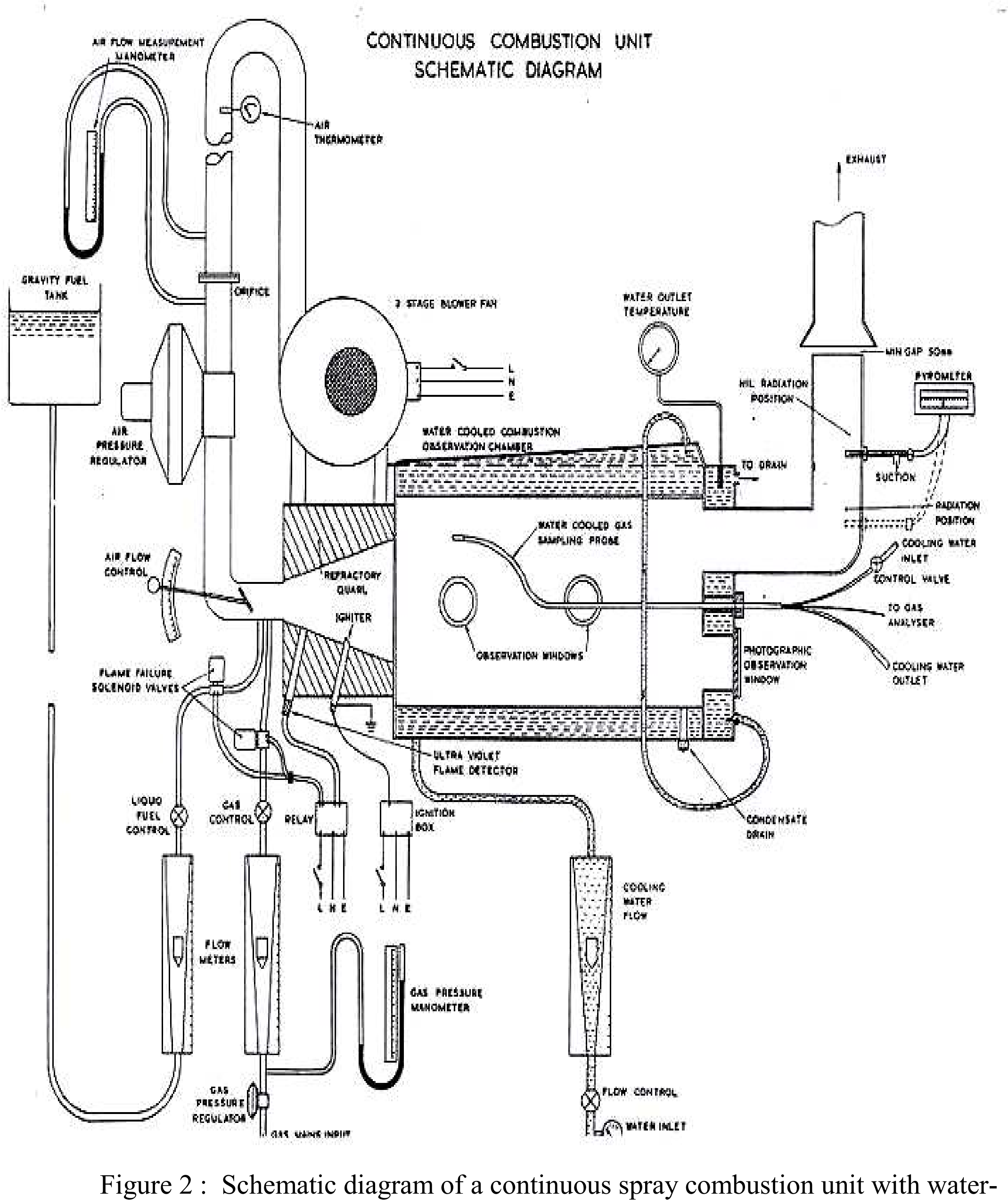

Figure 2 : Schematic diagram of a continuous spray combustion unit with water-cooled furnace (Hilton and Hewett, 1980).

The combustion chamber is a steel horizontal cylinder with a stainless steel water jacket where the water flows in the same direction with the exhaust gas flow. Flowrate of the cooling water is measured by a rotameter fixed before the cooling water enters to the water jacket from the bottom of the combustion unit end with the maximum flow allowed is 1800 kg/h. With no restriction allowed on the drainage pipe, the cooling water flows out from the water jacket at the exit on the top of the exhaust end. Type-K thermocouples connected with the temperature indicators were installed to the system to measure the temperatures of inlet air, exhaust flue gas, inlet water and outlet water.

2.3 Combustion Tests

In common practice, the combustion process is undesirable to be carried out in very rich and very lean conditions. The very rich combustion means fuel is burnt with insufficient air which will leads to the incomplete combustion and produces very high emissions level. In the other end, the combustion in very lean condition produces very unstable flame and results in bad emissions. In order to compare the combustion performance of various blended fuels, the combustion experiments were carried out with the same fuel input. For all four types of fuel tested, the mass flow rates of fuels were set to 5 kg/h to maintain the equivalent fuel consumptions.

The stoichiometric air fuel ratio for 100% diesel, 90% diesel-10% palm olein, 80% diesel-20% palm olein, and 70% diesel-30% palm olein are 14.90, 14.72, 14.55 and 14.33 respectively. The combustion experiments were conducted with the initial air inputs of 70 kg/h to create slightly rich conditions where the air fuel ratio is 14. Air inputs were then increased with the interval of 5 kg/h until the lean limit of the combustion for each batch of blended fuels. The lean limit can be observed in the experiments when large amount of white fumes produced at the exhaust stack, flue gas temperatures dropped significantly and unstable flames occurred. For 100% diesel and 90% diesel-10% palm olein, the combustion were able to be carried out up to maximum air input of 125 kg/h (air fuel ratio: 14 to 25); for the 80% diesel-20% palm olein, and 70% diesel-30% palm olein, the combustion tests were stopped at maximum air input of 120 kg/h.

Exhaust gas emissions were sampled and analyzed with Tempest Telegan 100 Combustion Performance Analyzer. Important components of the emitted gases including CO_2, O_2, CO, NO_x and SO_2 were measured for the assessment of combustion performance of various blended fuels under different air-fuel settings.

3.0 RESULTS AND DISCUSSION

Exhaust gas temperature is one of the primary indicators of combustion performance evaluation. Figure 3 shows the temperatures of various blended fuels at different air-fuel ratio. All four kinds of fuels show similar trends where the temperatures are maximum at the slightly rich zone and then gradually decrease when the air fuel ratio increased.

It is notable that when the air provided keeps increasing until the air fuel ratio is close to the very lean zone, the temperatures start to decrease dramatically. The temperature will drop further when it steps into very lean zone and then the flame becomes unstable and large amount of white fume were produced. In the other end of the graph, the combustion test in the rich zone is not available due to the large amount of black smoke produced, and the combustor vibrated vigorously.

Figure 3 also shows that the overall temperatures of blended fuels are higher than diesel fuel. While 90% Diesel-10% Palm Olein and 80% Diesel-20% Palm Olein recorded highest temperature readings, the further increase of palm olein ratio in the fuel will cause a slight drop in the overall temperature as shown in graph for 70% Diesel-30% Palm Olein.

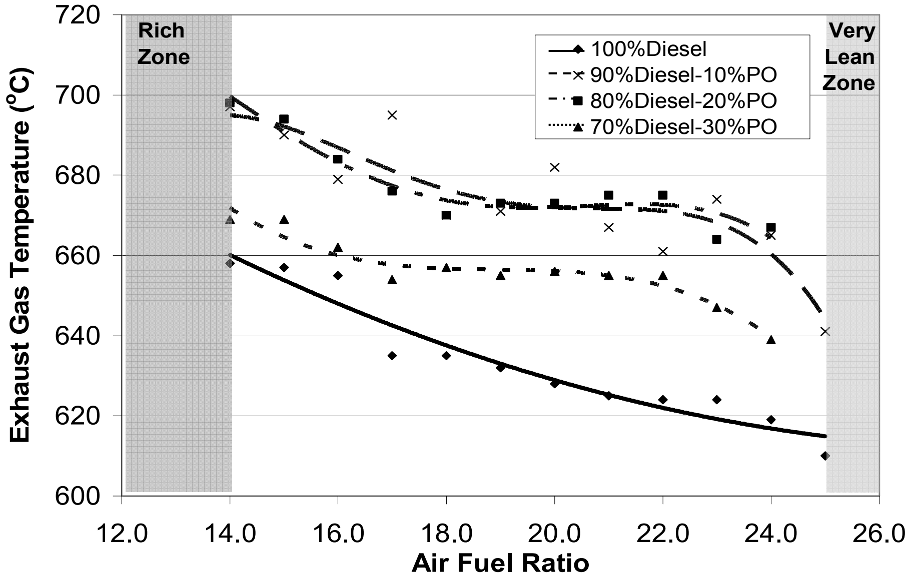

Figure 3: Exhaust Temperatures of the combustions of various blended fuels a 5kg/h

Figure 4 shows the carbon dioxide CO_2 concentration of various fuels in the exhaust gases streams. As CO_2 is known as a major product of complete combustion, the figure shows that the combustion are more complete at slightly rich region where air fuel ratio is 14 or at high equivalent ratio. Combustion test on 100% diesel recorded the lowest overall CO_2 concentration among the fuels tested. With the 10% palm olein in the blended fuel, the overall CO_2 concentration was increased while the blended fuel with 20% palm olein content recorded the highest overall CO_2 concentration. However, with further increases of the palm olein content in the fuel to 30%, the overall CO_2 concentration is dropped to a level close to 100% diesel. Higher CO_2 emission due to higher amount of fuel consumed, thus giving higher exhaust temperature.

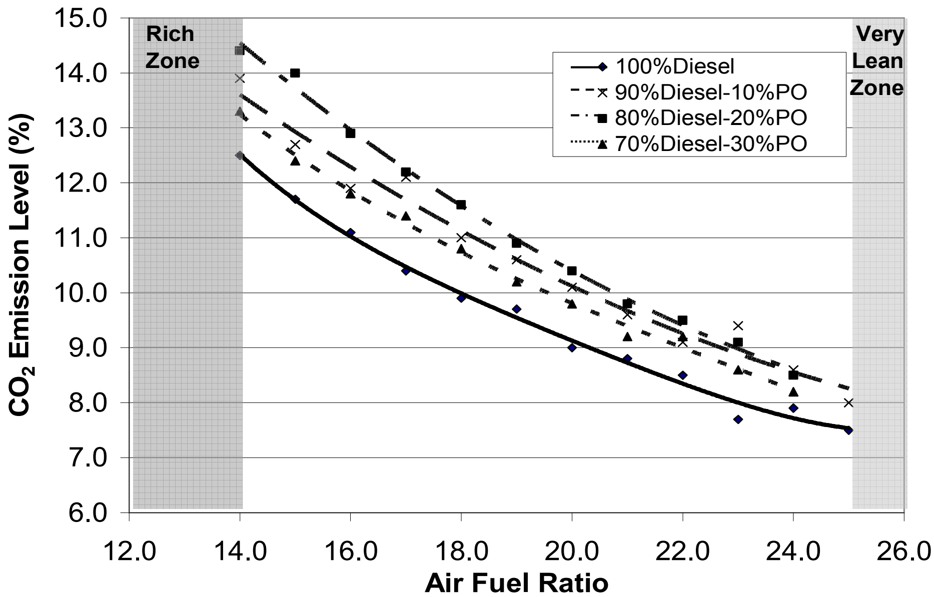

Figure 4: CO_2 emissions of the combustions of various blended fuels at 5kg/h

The emission of carbon monoxide, CO is shown in Figure 5. CO is mainly produced by incomplete combustion. It was found that the CO concentrations at stoichiometric and near lean condition (air fuel ratio 14 to 19) of all tested fuels were low and stable. The concentration of CO increased significantly when the fuels were burnt at very lean condition (air fuel ratio 22 to 25). With much of the excess air provided, the combustion process becomes not viable and not stable. So at very lean condition, the CO level becomes higher and eventually white fumes are produced and the flame will blow off. As compared to the blended fuels, the combustion of 100% diesel appears to produce considerably higher CO concentration in lean condition than the blended fuels.

The results agreed well with Ng and Gan (2010) on their non-pressurised biodiesel fuel burner tested as higher methyl ester in diesel fuel is used, than lower CO emission is obtained. This indicates good combustion characteristic and more complete combustion occurs at lean air-fuel ratio or near stoichiometric conditions. At very lean combustion or above air fuel ratio of 22, the CO emission begins to increase for blended fuels. A 20% palm olein blend in diesel fuel seems to have the lowest CO emission compared with other fuel blends.

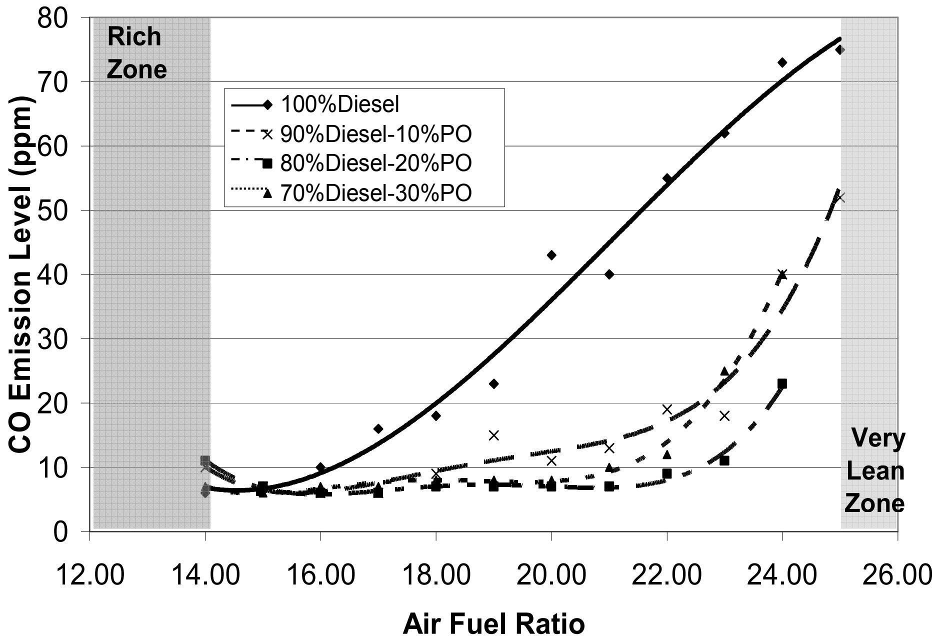

Figure 5 : CO emissions of the combustions of various blended fuels at 5kg/h

With the higher ratios of palm olein in the blended fuels, the Nitrogen Oxides, NO_x emissions become higher as shown in Figure 6. The combustion of 70% diesel-30% palm olein generated the highest NO_x emissions among all tested fuels while the combustion of 100% diesel produced the lowest. The higher exhaust gas temperatures of the blended fuels are the main factor which contributes to the increase of NO_x emissions. The high oxygen content of the biofuels also contributes toward the increase of NO_x emissions. Also, in Ng and Gan (2010) work, higher NO was produced when using higher methyl ester in diesel fuel blends. At lower air-fuel ratio or higher equivalent ratio, the NO_x generated by diesel fuel is much higher than the blended fuels. Also, these are due to the increase in peak temperature of the flame corresponding to the decrease in air-fuel ratio or increase in equivalence ratio, since more fuel was consumed during the combustion process.

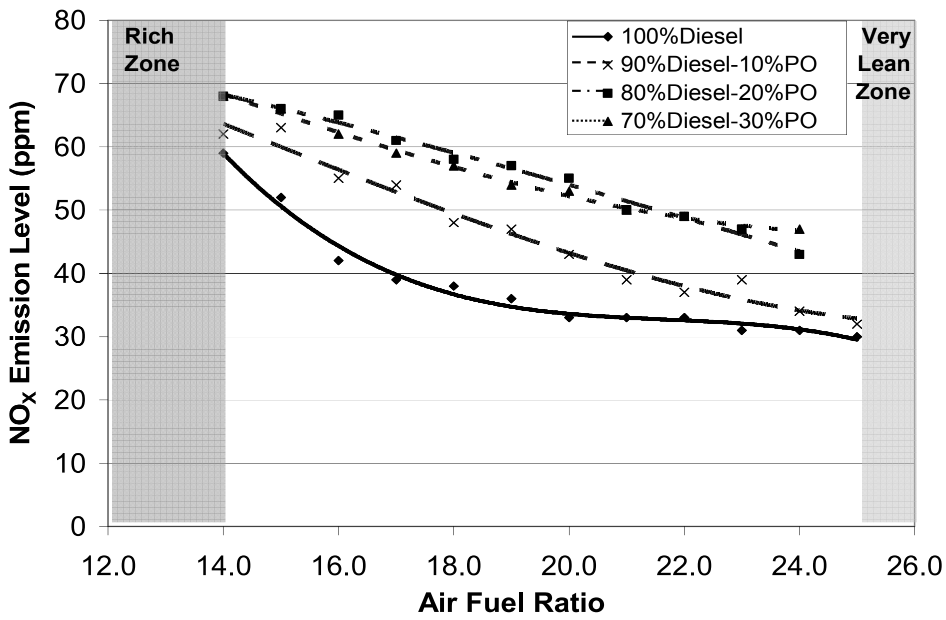

Figure 6 : NO_x emissions of the combustions of various blended fuels at 5kg/h

The sulfur dioxide SO_2 emission of 100% diesel fuel is apparently higher than the blended fuels as shown in Figure 7. With the higher content of palm olein presence in the blended fuels, the more reduction of SO_2 emission can be achieved. The lowest overall SO_2 emissions recorded among four kinds of fuels tested were from the combustion of 70% diesel-30% palm olein. As one of the only two possible methods to reduce the SO_2 emissions is to reduce the sulfur content in the fuel, Turns (2001), i.e. by adding palm olein to petroleum diesel helps in the reduction of SO_2 emissions since the sulfur content of palm olein is much lower than diesel. This result agreed with Tashtoush (2003) in their study, showing higher level of SO_2 emission in diesel fuel as compared with biodiesel fuels.

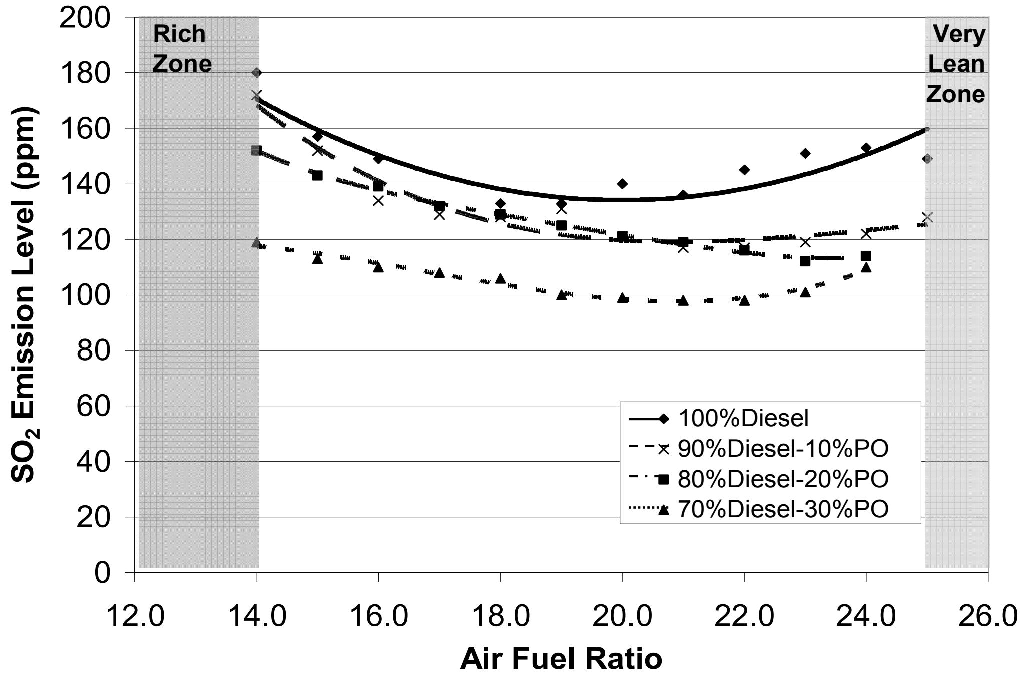

Figure 7: SO_2 emissions of the combustions of various blended fuels at 5kg/h

Combustion efficiencies of various blended fuels are compared in Figure 8. It can be clearly seen that the combustion efficiencies of all tested fuels are highest when the air fuel ratio is close to the stoichiometric value as indicated at air fuel ratio of 14 (AFR=14). The combustion taking place at near-stoichiometric condition will result in more complete combustion where the flue gas temperature is higher, O_2 concentration is lower and CO_2 concentration is higher.

Among the tested fuels, 80% diesel-20% palm olein achieved the highest combustion efficiency for overall air fuel ratio setting. Under the same air-fuel ratio setting, the combustion efficiency was slightly increased by 10% of palm olein blended as compared to 100% diesel. The combustion efficiency reached the highest point with 20% of palm olein blended, however further increase of palm olein content to 30% caused some negative effects and decreased the combustion efficiency.

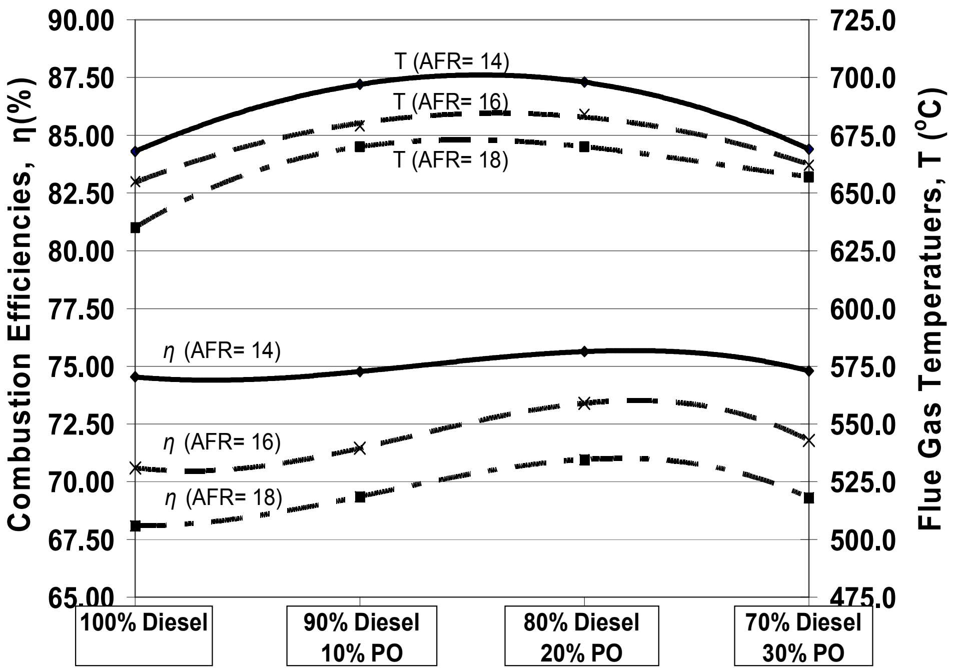

Figure 8: Combustion efficiencies of various blended fuels at different air fuel ratio

4.0 CONCLUSION

The results of the combustion experiments are encouraging with most of the blended fuels giving comparable performance to 100% diesel. 80% diesel-20% palm olein is the most outstanding blended ratio among the three blended ratio tested, where the combustion efficiency recorded is highest. In terms of emissions level, the biodiesel gives reasonable reduction in CO and SO_2, however it produces higher NO_x and CO_2 emissions. Both studies on the combustion and emissions of various blends of biodiesel in water cooled combustion chamber by Tashtoush et. al. (2003) and Ng and Gan (2010), proved the similar trend of emissions. Economically, if the cost of palm olein is less than diesel fuel as from the previous year prices of palm olein and diesel, then with a 20% reduction in diesel, a significant saving on fuel cost could be obtained.

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