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# PERFORMANCE OF OIL BURNER SYSTEM UTILIZINGVARIOUS PALM BIODIESEL BLENDS

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## ABSTRACT

This paper presents an investigation on the performance of an oil burner system utilizing various palm biodiesel blends. Biofuel used in this study is a blend of diesel and palm olein, called palm biodiesel. The performance of burner system using palm biodiesel is based on its temperature profile and emissions generated such as nitrous oxide ($NO_x$), sulphur dioxide ($SO_2$) and carbon monoxide (CO). In this study, Computational Fluid Dynamic (CFD) is extensively used to simulate the combustion process in the combustion chamber. The results were validated with experimental result. The experimental data was obtained from the burner test rig. The simulation covered three main areas which are cold flow (non reacting flow), evaporation of liquid spray and Eddy Dissipation combustion. The turbulence model used is k-ε model while discrete phase modeled (DPM) was modeled using Lagrangian framework. The CFD results showed reasonable agreement with experimental for flame length while for the temperature profile the simulation results were over predicted.

**Keywords:** Emissions, CFD, biofuel, NOx, temperature profile.

## 1. INTRODUCTION

Biodiesel is a diesel-type fuel made by separating glycerin from animal and vegetable oils to create methyl esters. It is an alternative fuel that can be used in diesel engines and provides power similar to Conventional Diesel Fuel (CDF). Recent environmental and economic concerns (Kyoto Protocol) have prompted resurgence in the use of Biodiesel throughout the world. In 1991, the European Community, (EC) proposed a 90% tax reduction for the use of biofuels including Biodiesel and today, 21 countries worldwide produce Biodiesel (DOE, 2006). By knowing that palm oil is one of the highest yielding crops Malaysia has a genuine and rare opportunity to explore and exploit the biofuels markets globally. On 21st March 2006, Malaysian government successfully released the states National Biofuel Policy which is the first step for the nation towards developing palm oil as a major source of biofuel (Ministry of Plantation, Industries and Commodities, 2006). Parallel to this, the objective of this study is to determine the performance of various blends of biofuel. Blend of Refined, Bleached and Deodorized Palm Oil (RBDPO) and diesel is selected as the biofuel. Several parameters have been studied such as temperature profiles, emissions and flame length. This performance study is limited to RBDPO biofuel blends B2, B5, B10, B15 and B20. However, for experimental test, tests were done up to B15. Due to the implementation of the National Biofuel Policy, Malaysian Palm Oil Board (MPOB) works very closely with Malaysian government to conduct research on palm oil regarding the feasibility and capability of the oil towards biofuel production (Cheng *et al*, 2005; Choo *et al*, 2005). Malaysian national electricity provider, Tenaga Nasional Berhad has been testing the possibility of using palm oil biofuel for power generation. Studies were conducted by MPOB on the usage of RBDPO without any chemical modifications as a substitute to petroleum diesel. RBDPO/ petroleum diesel blends were tested for industrial use and for transportation (Economic Planning Unit, 2006).

The fuel properties of RBDPO/petroleum diesel blends (B2, B5, B100) were tested and evaluated and it was concluded that the resultant fuel blends exhibited advantages and fuel characteristics that are better compared to that of RBDPO and petroleum diesel when used solely as fuel.

## 2. METHODOLOGY

### Fuel Properties

The physical properties of the petroleum diesel, palm olein and biodiesel blends are listed in Table 1.

Table 1: Physical Properties of Petroleum Diesel, Palm Olein and Biodiesel Blends

| Types of Fuel | Density ($kg/m^3$) | Surface Tension (N/m) | Dynamic Viscosity (kg/m-s) |
|---|---|---|---|
| Petroleum diesel | 828.7 | 0.03 | 0.0032 |
| B5 | 832.2 | 0.0305 | 0.0038 |
| B10 | 836.1 | 0.0305 | 0.0042 |
| B15 | 838.9 | 0.0305 | 0.0046 |
| B20 | 842.0 | 0.0305 | 0.0050 |
| Palm olein | 901.2 | 0.0345 | 0.0352 |

For the chemical properties, the default value in FLUENT is used throughout this study. The default values are shown in Table 2 for the mixture and Table 3 for droplet particles.

Table 2: Chemical Properties – Mixture

| Properties | Value |
|---|---|
| Species | $C_{10}H_{22}$, $O_2$, $CO_2$,$H_2O$, $N_2$ |
| Reactions | Eddy Dissipations |
| Mechanism | Reaction Mechanism |
| Density (kg/m$^3$) | Incompressible-ideal-gas |
| $C_p$ (J/kg-K) | Mixing law |
| Thermal Conductivity (w/m-K) | 0.0454 |
| Viscosity (kg/m-s) | 1.72 x 10$^{-5}$ |
| Mass Diffusivity (m$^2$/s) | Constant dilute approximations (2.88 x 10$^{-5}$) |

Table 3: Chemical Properties – Droplet Particles Material

| Properties | Value |
|---|---|
| Density (kg/m$^3$) | (Based on Fuel) |
| $C_p$ (J/kg-K) | 2090 |
| Thermal Conductivity (w/m-K) | 0.149 |
| Dynamic Viscosity (kg/m-s) | (Based on Fuel) |
| Latent Heat | 277000 |
| Vaporization Temperature (K) | 341 |
| Boiling Point (K) | (Based on Fuel) |
| Volatility Component Fraction (%) | 100 |
| Binary Diffusivity (m$^2$/s) | 3.79 x 10$^{-6}$ |
| Saturation Vapor Pressure (Pascal) | 1329 |
| Heat of Pyrolysis (J/kg) | 0 |
| Droplet Surface Tension | (Based on Fuel) |

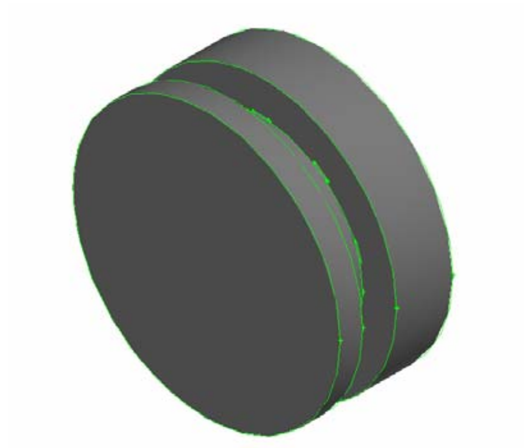
**CFD Input Values**

In this study, the inputs are basically the air flow rate and fuel flow rate, 68.48 g/s and 3.2 g/s, respectively which are the same amount of air and fuel entering the burner during the experimental tests. This is to ensure consistency between numerical and experimental.

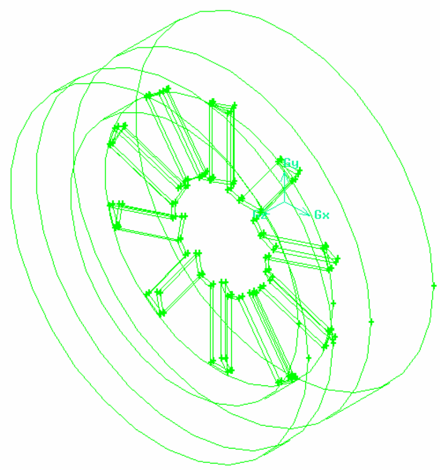
**CFD Setup**

Normally, the CFD starts with grid creation. The grid is drawn using GAMBIT, a mesh creating tool normally associated with FLUENT. Firstly, the retainer is drawn followed by combustion head and finally combustion chamber. After that, the grid is meshed with appropriate size and scheme. The retainer is shown in Figure 1(a) and combustion head in both shaded and wireframe view in Figure 1 (b) and 1 (c) while the mesh is shown in Figure 2.

(a) Retainer



(b) Combustion head : Shaded View



(c) Combustion Head: Wireframe View

Figure 1: (a): Retainer, (b) and (c): Combustion Head in Shaded and Wireframe View

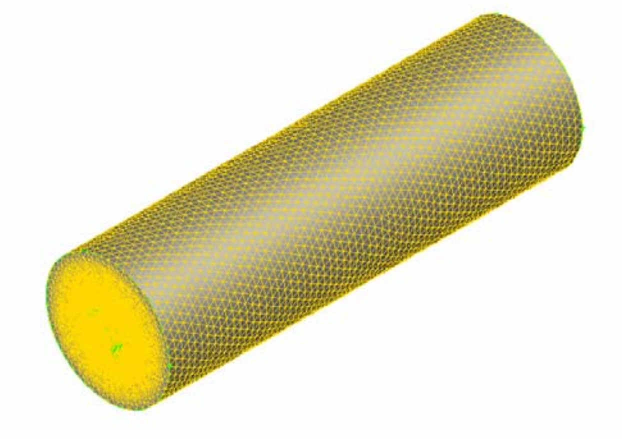


Figure 2: The Meshing Grid

**Experimental Test Set Up**

The experimental test rig set-up for the burner tests is shown in Figure 3. The burner and combustion chamber are placed horizontally on a fixed structure. The air is supplied by a main compressor in the laboratory. For all tests, the exhaust sampling probe is mounted at the end pipe. The gas analyzer used in these tests was the Tocsin IGD gas analyzer that measures several exhaust gases such as $NO_x$, CO, and $SO_2$.

## 3. RESULTS AND DISCUSSION

In order to achieve better mixing between fuel and air in a liquid fuel burner, turbulence flow must be generated to promote mixing. Turbulence energy is created from the pressure energy dissipated of the retainer.

Figure 4 shows the velocity vector. It is clearly shown that there are three main areas of recirculated flow in the combustion chamber. The recirculated flow areas or sometimes called back flow regions are at the central recirculation zones and corner recirculation zones, top and bottom of the combustion chamber. The central recirculation zones or normally called Central Toroidal Recirculation Zones (CTRZ) exist due to the presence of retainer at the combustion head.

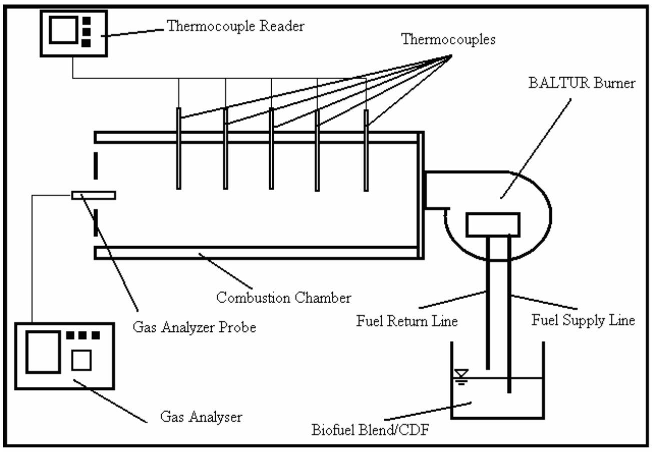



Figure 3: Schematic of Experiment Setup

The retainer creates swirling air and this promotes air and fuel mixing resulting in better mixing. Furthermore, the retainer acts as a flame stabilizer by generating turbulence in the combustion chamber. The formations of the swirling flow at the adjacent to the atomizer give more stable combustion and rapid heat release.

In addition, the presence of the corner recirculation zones at the top and bottom of the combustion chamber could be based on the type of the combustion chamber which is sudden dump expansion.

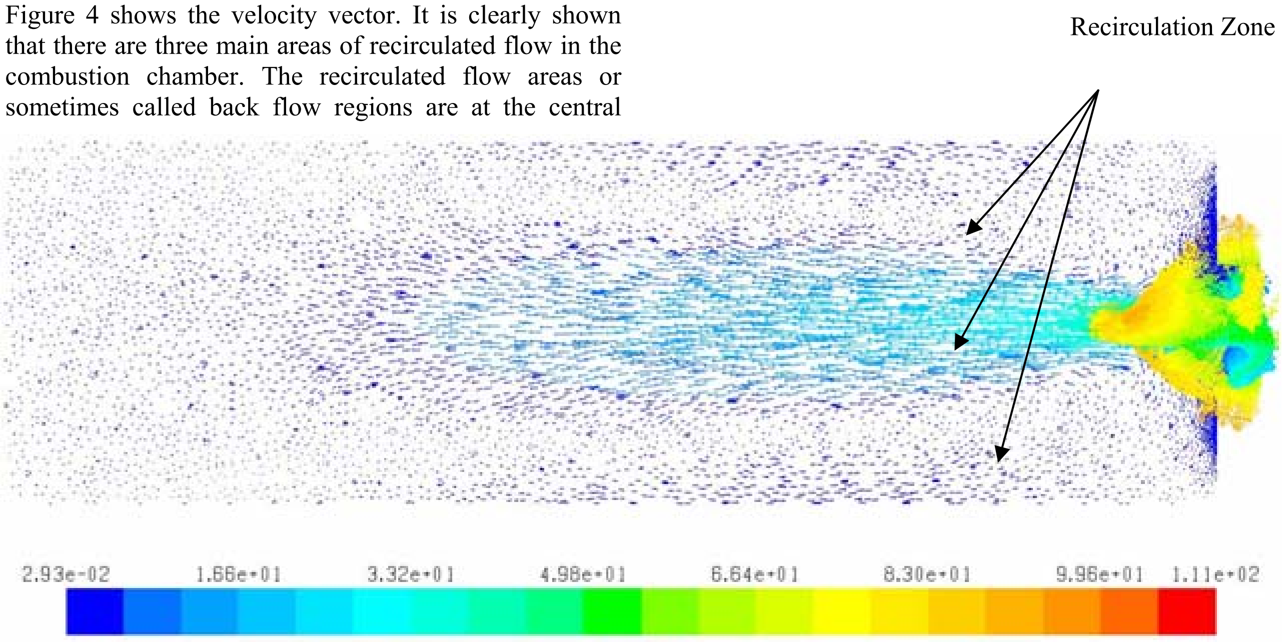



Figure 4: Recirculation Zone

**Spray Analysis**

In this study, the burner used air blast atomizer to spray the fuel. The fuel is formed into a sheet by the nozzle and air is then directed against the sheet to promote atomization. Usually this type of spray produces a very fine atomization and widely used in liquid-fuel combustion such as in gas turbines, oil furnaces, and direct-injection spark-ignited automobile engines. In this analysis, three methods are used to determine the spray characteristics of the burner's atomizer. The methods are CFD, empirical equation and Phase Doppler Anemometer (PDA) while the parameter is Sauter Mean Diameter (SMD). Equation below is one of the empirical equations that correlate the physical properties and Sauter Mean Diameter (SMD) (Lefebvre, 1989)

$$SMD = 2.25\sigma^{0.25}\mu_L{}^{0.25}\rho_A{}^{-0.25}\Delta P_L{}^{-0.5}m^{0.25}$$

The justification of using more than one method to find the droplet SMD is to get proper range of results and observe the pattern of each method.

To ensure accuracy and consistency of the PDA result, the result is taken 100 times at the same position for all samples. Apart from that, the atomizer that is used in this experiment is also the same atomizer that is used in the burner, and also the same pressure (10 bars) is applied for all samples. Then the intersection of all four laser beams is placed about two centimeters below the atomizer. The PDA manages to capture the spray distribution at different positions using mesh generator function.

Figure 5 shows the SMD of different biodiesel blends. It is shown that all three curves follow similar trends where the increasing of palm olein percentage in the blends increases the size of SMD. This is because; the increase of palm olein percentage in the blends increases the viscosity and surface tension of the fuel and thus increasing the SMD. Apart from that, the PDA measurement shows largest value of SMD followed by empirical equation and lastly CFD. There are many possible factors to the discrepancy of the results. For the CFD, the properties of the fuel are insufficient and almost all properties use default values. These values are not necessarily correct in representing the actual fuel properties. This affects the evaporation of the fuel and finally droplets size. Another factor is that for CFD and empirical equation, there is no interruption from the surroundings, unlike PDA where the condition during the experiment will contribute error to the reading such as gust, temperature, pressure and light.

**Combustion Analysis**

Figure 6 shows that when increasing the percentages of RBDPO in the biodiesel blends, the temperature reduces considerably. This is due to the fact that the calorific value of the fuel is decreased when the RBDPO amount is increased.

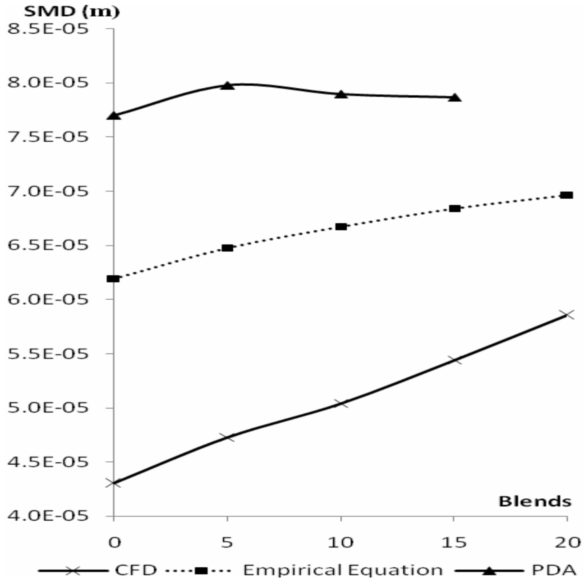



Figure 5: Sauter Mean Diameter (SMD) at Different Biodiesel Blends

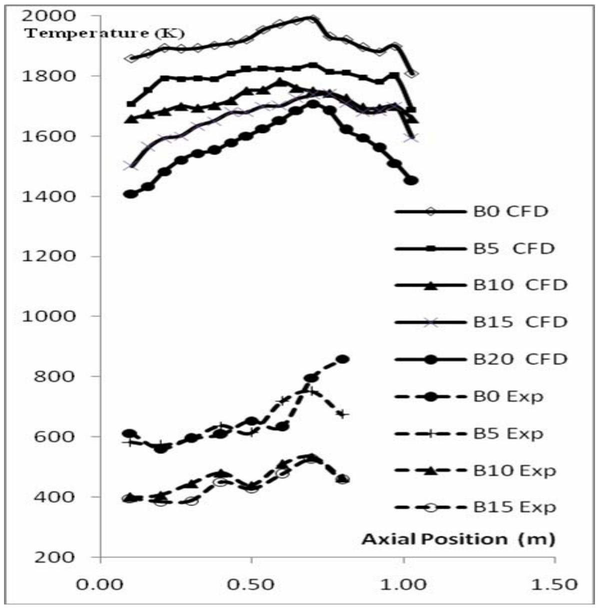



Figure 6: Comparison Between Experimental and CFD Results

If we compare the result from CFD and experimental, it shows that the temperature different between the CFD and experimental result is large. This may be due to the fact that in CFD, the variables specific heat (Cp) is used instead of constant Cp. This makes the simulation more realistic. However, if the Cp is constant (2090 J/kg-K), the temperature of the combustion becomes slightly different as shown in Figure 6. Figure 7 shows that for the constant Cp and experimental, there exists correlation between them. This trigger a doubt because when variables Cp is chosen it should reflect the actual case but the problem between them, their temperature is very low and this cannot be tolerated since the combustion of biodiesel exceed 1000K as proven in literature (Eunice Akyereko, 2006; David Rochaya, 2007) Another reason why the temperature profiles from experimental results show lower values is because the temperatures were measured near the wall of the combustor rather than in the combustion chamber itself near the flame. This is due to the lack of equipments that are available. A better reading could be obtained if other techniques are used such as pyrometer.

**Emission Results**

Figure 8 shows that combustion of CDF emits more NOx compared to biodiesel. The increasing percentages of palm olein contained in the biodiesel will significantly reduce NOx emissions thus reducing the discharge of this dangerous pollutant to our environment. This makes biofuel blends a better choice in terms of NOx emissions.

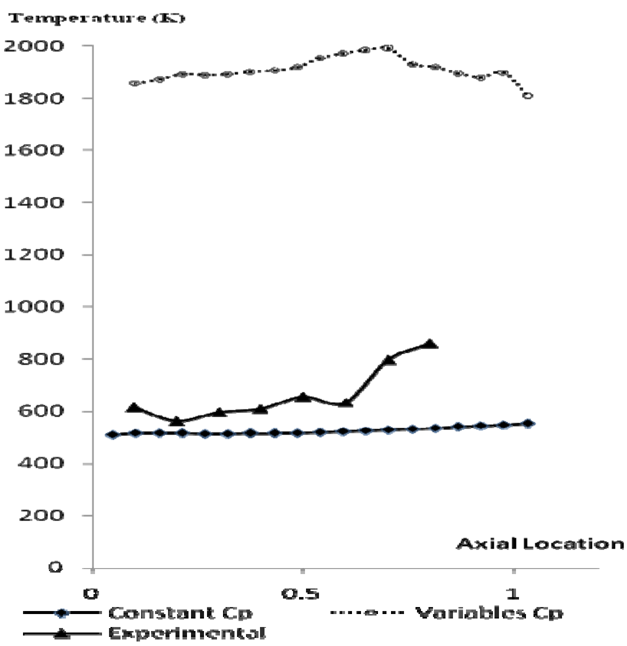



Figure 7: Comparison among Variable Cp, Constant Cp and Experimental for Temperature Profile

The CFD analysis successfully predicted the trend; however, the values are not in good agreement. This may be due to several factors, including the fact that in CFD there are so many assumptions made and that there are several model available that need to be tried. Further study is required to find a better model for reacting flow prediction. Furthermore, it is worth to remind that in the CFD, the calculation of NOx is based on prompt and thermal NOx (FLUENT 6.3, 2006).

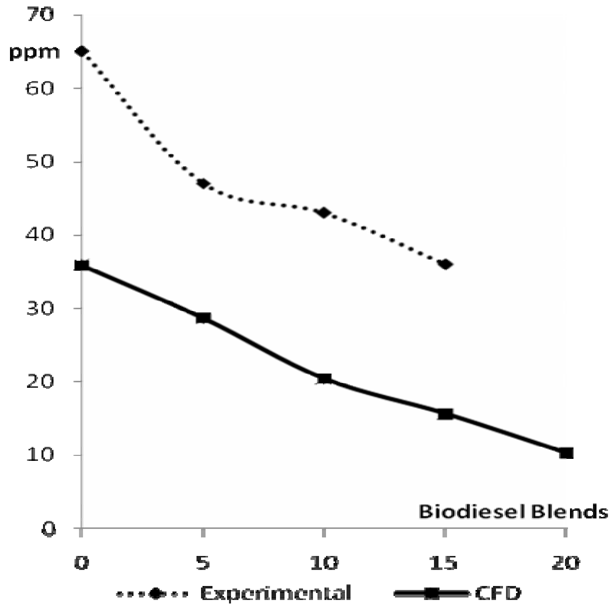



Figure 8: Comparison Between Experimental and CFD on NOx Emissions

## 4. CONCLUSION

The performance of light oil burner, i.e. temperature profile along the combustion chamber and its emissions, was studied for difference biofuel blends. The study was done using Computational Fluid Dynamic (CFD) simulation and verified by experimental results. Both the temperature and emission of biofuel decrease when the percentage of palm olein in the blends is increased. The B5 blend showed the best performance followed by B10, B15 and finally B20. This is true for both numerical and experimental approach, even though there is large discrepancy in term of values between them. The Sauter Mean Diameter (SMD) for biofuel blends also shows the same trend. The B5 blend has the smallest SMD followed by B10, B15 and B20. The trends are similar for all three different methods namely PDA, empirical equation and lastly CFD.

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