Thermodynamic performance investigation of a diesel engine running on biodiesel derived from pangium edule and cocos nucifera

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Abstract. This study investigates the use of biodiesel derived from Pangium Edule Reinw (Pangium biodiesel) and Cocos Nucifera (palm biodiesel) in diesel engines as alternative fuels. A direct injection (DI) diesel engine simulated via a thermodynamic cycle model for investigation. Thermodynamic and performance parameters and compared for diesel, Pangium biodiesel, and palm biodiesel at two different states. The results displayed that Pangium biodiesel shows a relatively higher cylinder temperature and pressure compared to palm biodiesel and diesel fuel at a lower crank angle. It also means that 100 % biodiesel is capable of performing a smaller engine capacity compared to diesel fuel at similar injection conditions. The brake power declines about 8.1% and 8.3% at 3800 rpm, while brake specific fuel consumption increases about 8.7% and 9.4% at 1900 rpm for Pangium biodiesel and palm biodiesel, respectively. The engine performance for Pangium biodiesel and palm biodiesel significantly improve at the same equivalence ratio condition. However, a more amount of fuel is required, which is approximately 20.7% for palm biodiesel and 8.5% for Pangium biodiesel. The brake thermal efficiency for Pangium biodiesel and palm biodiesel is generally better than diesel fuel.

1. Introduction

Many studies have been conducted to improve the performances of biodiesel fuel. The effort to seek viable-sustainable-renewable resource for fuel is still challenging up to this date. The fossil fuel is expected to run out shortly [1], and vegetable oil will once again be one of the leading candidates for replacement of current commercials fuel sources [2] suitable for application in diesel engines with currently available technology. The biodiesel is not a new issue, since its earlier day, it has been a common understanding that the vegetable oil act as a fuel in diesel engines [3,4]. This study investigates the use of biodiesel derived from Pangium Edule Reinw (Pangium biodiesel) and Cocos Nucifera (Palm biodiesel) in diesel engines as alternative fuels. However, there are several issues concerning biofuel practice, i.e., automotive engine compatibility in long-term operation, and relationship to the awareness of food security problem that might arise from biofuel production out of food-grade oil-seeds [5].
The combustion process in diesel engines appears to be one of the most challenging procedures to simulate. This process is determined and accompanied by several other methods and phenomena. There is powerful interaction between the motion of the fuel jets and air flow in the cylinder, heat transfer inside the combustion chamber zones and walls or its surroundings, volume evaporation from the surface of liquid droplets. All this leads to the formation of the active nucleus of the fuel oxidation and its ignition, volumetric, and then the diffusion combustion [6,7]. Since the majority of modern diesel engines have direct injection (DI) fuel systems, these engines are more sensitive to fuel spray quality than indirect injection engines. Therefore, a fuel with properties that are closer to No. 2 diesel fuel is needed [8]. Furthermore, higher fuel temperature contributes to the higher injection pressure, producing shorter ignition delay in the combustion process that improves cylinder pressure as well as resulting higher energy content. In consequence, there are many experimental works have been carried out investigating the influence of fuel temperature variations of a diesel engine regarding engine performance, combustion, and emission characteristics operating with biodiesel [9].

2. Methods
The thermodynamic cycle of a direct injection diesel engine simple to investigated via simulation using the software. Thermodynamic and performance parameters and compared for diesel, biodiesel (Pangium biodiesel and Palm biodiesel) fuels at two different states is conducted in this research. Simulation is conducted using Diesel-RK Software. The Diesel-RK is professional thermodynamic full-cycle engine simulation software. This tool covers a wide range of practice tasks, ranging from general multi-cylinder engine concept analysis, up to the design of engine systems. The kernel of Diesel-RK includes gas-exchange model, heat-exchange in engine elements, turbocharging, exhaust gas recirculation, friction, water condensation, and nearly all aspects for full cycle simulation. Diesel-RK focused on advanced diesel combustion simulation and emission formation prediction [10,11]. Engine parameter used in this simulation generally includes water-cooled four-stroke diesel turbocharged engine with direct injection combustion similar to Mercedes-Benz OM646 engine. Fuel parameter for engine performance analysis in this research is accessible through Table 1. The engine presumed to run by pure biodiesel. The result covers specific fuel consumption (SFC) with variation in speed for a different use, brake mean effective pressure (BMEP), cylinder pressure ($p_c$), cylinder temperature ($T_c$), and heat release rate (HRR).

Table 1. Fuel parameter of Pangium biodiesel and Palm biodiesel used in the simulation.

| Parameter                       | Pangium Biodiesel | Palm Biodiesel |
|--------------------------------|-------------------|----------------|
| Calorific value (MJ/kg)        | 39.91             | 40.18          |
| API gravity (specific gravity: 0.866) | 31.90             | 30.23          |
| Kinematic viscosity at 40 °C (cSt) | 4.90             | 4.70           |
| Cloud point (°C)               | 16.00             | 1.00           |
| Pour point (°C)                | 15.00             | -6.00          |
| Flashpoint (°C)                | 172.5             | 155.50         |
| Fire point (°C)                | 331.00            | 274 + 3        |
| Conradson carbon residue (% w/w) | 0.30             | 0.30           |
| Ash content (% w/w)            | 0.0066            | 0.012          |
| Nitrogen (% w/w)               | 0.00              | 0.00           |
| Carbon (% w/w)                 | 0.1882            | 0.76           |
| Hydrogen (% w/w)               | 0.3439            | 0.11           |
| Oxygen (% w/w)                 | 0.02              | 0.11           |
| Sulfur (% w/w)                 | 0.04              | 0.00           |
| LHV of Fuel [MJ/kg]            | 37.00             | 39.50          |
Table 1. Cont.

|                             | 52.00 | 39.9 – 51.6 |
|-----------------------------|-------|-------------|
| Density at 323°K (kg/m³)   | 879.3 | 886.30      |
| Surface Tension of Fuel at 323 K [N/m] | 0.0301 | 0.028       |
| Fuel temperature [K]       | 293   | 293         |

3. Results and discussion

3.1. The Specific Fuel Consumption (SFC) and Brake Mean Effective Pressure (BMEP)

The lower the SFC, the more efficient the engine is. The result of the simulation shows that both pure biodiesels still cannot surpass the superiority of diesel fuel in term of SFC. At 1900 rpm all fuel sample reach their lowest consumption at 0.225 kg/kWh, 0.243 kg/kWh and 0.268 kg/kWh, while at 3800 RPM increased to 0.235 kg/kWh, 0.263 kg/kWh and 0.292 kg/kWh for Diesel fuel, Pangium and palm biodiesel respectively, as can be seen on figure 1. Therefore, approximately 20.7% more Palm biodiesel and 8.5% more Pangium biodiesel is required to perform the same as diesel fuel. Uniquely, palm biodiesel demonstrates a lower SFC at engine rotation lower than 950 RPM. As for the BMEP, the result of the simulation, as shown in figure 2, depicts that Pangium has a higher value compared to palm biodiesel and diesel fuel, which is, at 12.3 bar, 9.6 bar and 11.2 bar at 1900 RPM and 11.3 bar, 10.4 and 8.7 bar at 3800 RPM, respectively.

![Figure 1](image1.png)  
**Figure 1.** Comparison of Specific Fuel Consumption (kg/kWh) of both biodiesel in the RPM range (e) Pangium (f) palm (g) Diesel fuel.

![Figure 2](image2.png)  
**Figure 2.** Comparison of Brake Mean Effective Pressure (bar) of biodiesel in the RPM range (b) Pangium (c) Palm and (d) diesel fuel.

3.2. Cylinder pressure ($p_c$) and cylinder temperature ($T_c$)

Cylinder Pressure is the pressure in the engine cylinder during the four strokes of engine operation (intake, compression, combustion and expansion, and exhaust). The most significant impact of the pressure on the diesel engine observed during the expansion phase, where the cylinder pressure is pushing on the piston to produce power. The biodiesel and diesel fuel show almost identical trend at each crank angle (CA) degree. At around 500 degrees of CA, as in figure 3, Pangium biodiesel shows a higher pressure compare to diesel fuel and palm biodiesel, they are 6.9 bar, 6.3 bar, and 5.9 bar. At the same time, it performs a higher cylinder temperature compare to other fuel, as seen in figure 4.
Nevertheless, at a higher degree of CA, 700 degrees, the cylinder pressure of Pangium seems to have a slight decrease, 2.2 bar, and palm biodiesel demonstrated a higher pressure, 2.6 bar, until the all fuel pressure become uniform at the highest degree of CA.

3.3. Heat Release Rate (HRR)
Both biodiesels show a higher HRR either at 1900 RPM or 3800 RPM compare to diesel fuel. Pangium and palm biodiesel can reach 122 J/deg about 90 J/deg at 1900 RPM and respectively reduce to 95 J/deg and 76 J/deg at 3800 RPM. Figure 5 and 6 portray the combustion of biodiesel during pre-mixer and diffusion, which appears to increase the heat release rates, but at the same time shortened combustion duration than diesel fuel combustion. The phenomena seem to enhance the engine thermal efficiency over the diesel baseline combustion.
4. Conclusion
The results showed that Pangium biodiesel expressed a higher cylinder temperature and pressure compared to palm biodiesel and diesel fuel at lower CA, while at higher CA, the palm biodiesel reverses the performance. Averagely, the biodiesel still capable of performing a smaller engine capacity compared to diesel fuel at similar injection conditions. The brake power declines about 8.1% and 8.3% at 3800 rpm while brake specific fuel consumption increases about 8.7% and 9.4% at 1900 rpm for Pangium biodiesel and palm biodiesel, respectively. The engine performance for Pangium biodiesel and palm biodiesel significantly improve at the same equivalence ratio condition. However, a more amount of fuel is required, which is approximately 20.7% for palm biodiesel and 8.5% for Pangium biodiesel. The brake thermal efficiency for Pangium biodiesel and palm biodiesel is generally better than diesel fuel.

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