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Calculation of Specific Exhaust Emissions of Compression Ignition Engine Fueled by Palm Biodiesel Blend

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ABSTRACT

Biodiesel is regarded as one of the most beneficial forms of renewable energy, with qualities similar to diesel fuel. Commercially, biodiesel is used in the form of blends – a mixture of diesel and biodiesel, and they have proven to reduce hazardous emissions in the environment. The desire for Euro 5 fuel adoption is essential to meet growing market demands and limited legal emission restrictions. An installation of pricey special equipment is required for measuring the emission based on the European Union legislation. Therefore this paper proposes a calculation method of conversion for percentage volumetric emission into specific emission (g/km).

Keywords:
Palm biodiesel; CI engine; Engine performance; Exhaust emission; Euro 5

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1. Introduction

The rapid growth of the world's population has increased the use of finite fossil resources. In good light, this paradigm fosters the creation and innovation of new renewable fuels, such as biodiesel [1]. Biodiesel has attracted much interest as a future fuel because of its plentiful resources and environmental benefits [2-3]. Biodiesel, which can be made from animal fats or plant oils (palm, corn, rapeseed, and soybean), is comparable to petroleum diesel [4-5]. Biodiesel is frequently employed in car engines in either a pure or blended form, with no engine modifications required [6-7]. One of the benefits of using biodiesel is that they have a minor negative impact on the environment since they emit fewer greenhouse gases. Another advantage is that they allow for greater energy diversification, leading to greater energy independence [8]. Because of the increased use of biofuels, consumers will have less need to rely on imported fossil fuels, which will help slow the depletion of crude oil stocks [9]. Biodiesel fuel has been used extensively for the past few decades on diesel engines. Even though

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100% biodiesel is not implemented for commercial vehicles, from as low as 5% to 30% biodiesel addition to pure diesel, diesel-biodiesel blends are accepted and used globally.

Palm oil is the primary feedstock for biodiesel manufacturing in Malaysia, owing to the country's role as a major agricultural export commodity. As the focus of the study, Malaysia started using palm diesel-biodiesel blend B5 (a mixture of 5% palm methyl ester (PME) and 95% regular petroleum diesel) in 2011. The B5 implementation was successfully rolled out, covering both the northern area and the country's eastern region by the end of 2014. To further boost the consumption of CPO, the B5 was upgraded to B7 (7% PME and 93% regular petroleum diesel in December 2014, while B5 is still in the move for whole peninsular Malaysia and complete rollout in December 2015 nationwide [1]. B10 program (10% PME and 90% regular petroleum diesel) was implemented in December 2018 by phase to boost local biodiesel demand further and increase the sustainability of energy sources [10]. However, the B10 rollout only affects Euro 2M diesel, while B7 is Euro 5. The new mandate would lower national palm oil inventories and increase local biodiesel demand [1]. A new program began in January 2020 to introduce B20 (20% PME and 80% regular petroleum diesel). The program has started in Langkawi, Kedah, for the transportation sector. The program is expected to expand the destination to East Malaysia by phase and lastly to Peninsular Malaysia in mid-2021. However, due to economic recovery and the Covid-19 pandemic, the schedule was delayed until 2022 [11].

The EN 590 European diesel fuel standard specifies that the qualities of diesel fuel, such as cetane number, sulfur level, and FAME biodiesel concentration, are regulated to reduce the environmental impact. In EN 590:2004 regulation, the requirement for sulfur limit in diesel fuel is 10 ppm (Euro 5) and EN 590:2009 revision required 7% of FAME content as regulated by Directive 2009/30/EC [12]. At the same time, the Euro 5 emission standard (January 2011) was further tightened to reduce exhaust emissions from diesel engines [13]. The European Union has created regulations and standards with well-defined limitations for various exhaust gas components throughout the last few decades (CO, CO2, HC, NOx and PM) [14-15]. To compare with the European Union emission standard, the installation of specific equipment is required to perform the exhaust emission measurement. These pricey measuring devices are typically used by type-approval agencies, automobile manufacturers, or significant research and development centers [14]. Therefore, this paper proposes a calculation method from the percentage volume of exhaust emission to specific emission.

2. Methodology

2.1 Engine Test

The test engine is an unmodified common-rail 2.5L direct-injection 4-inline cylinder compression ignition engine, as shown in Table 1. The fuel used in the testing is palm diesel-biodiesel fuel B7 (7% palm biodiesel, 93% diesel). The experiment instrumentation used in this experiment was a chassis dynamometer (Dynapack 4022) for braking load measurement, a gas emission analyzer (SPTC Autocheck 5-channel Gas) for exhaust gas emission measurement, a liquid fuel mass flow meter (Ono Sokki FZ-2100) for biodiesel-diesel fuel mass flow rate measurement, and an OBD-II ECU diagnostic (Bosch KTS-570) for monitoring real-time engine condition.

The experiment was carried out in steady-state conditions at a constant road speed of 90 km/h with several percentages (%) of accelerator pedal positions (APP). The gear ratio was set at 1:1 at the 4th gear, allowing the dynamometer reading to translate directly to the engine torque and power output.

Table 1
Specification of the test vehicle

Item	Specification
Engine Code	2KD-FTV
Number of Cylinder	4 In-line
Valve Mechanism	16 Valve DOHC
Fuel System	Common-rail Direct Injection
Engine Displacement	2494 cc.
Bore	92mm
Stroke	93.8
Compression Ratio	17.4:1
Maximum Torque	120 DIN 80kW/3600 rpm
Maximum Power	325 Nm/2000 rpm
Tank Capacity	80 litre

2.2 Specific Emission Calculation

Emission produced from engine testing was measured using a gas emission analyzer and the result obtained was in concentration, part per million (ppm) or percentage (%). Hence, conversion to mg/m^3 is necessary to calculate specific emissions per distance travel. The general equation (5) is derived from Avogadro's Law, Eq. (1) and Ideal Gas Law Eq. (2) by solving absolute pressure and ideal gas constant to convert PPM to mg/m^3.

$$\frac{V}{n} = k \tag{1}$$

$$PV = \mathrm{nRT} \tag{2}$$

$$k = \frac{V}{n} = \frac{\mathrm{RT}}{\mathrm{P}} \tag{3}$$

$$Gas_{con} = ppmv\,\frac{MW}{RT/P} \tag{4}$$

$$Gas_{con} = ppmv\,\frac{MW}{V_n} \tag{5}$$

where the Volume of the gas (L), *V*, amount of the gas (moles), *n*, Volume of the gas per moles (L/mol), V_n, constant for a given temperature and pressure, *k*, temperature (K), *T*, absolute pressure (P = 101.323 kPa), *P*, ideal gas constant (R = 8.31451 J/mol.K), *R*, milligrams of gaseous emission per cubic meter of ambient air (mg/m^3), Gas_{con}, ppm by Volume, *ppmv*, molecular weight of the gaseous emission (g/mol), *MW*.

The specific emissions were then calculated by multiplying gaseous emissions with exhaust gas flow rate shown in Eq. (6) and divided by vehicles speed as shown in Eq. (7).

$$Q_{exhaust} = VE \times (Vol/Cyl) \times \frac{\mathrm{T}_1}{\mathrm{T}_0} \times RPS \tag{6}$$

where the exhaust gas flow rate (L/s), $Q_{exhaust}$,. Volumetric efficiency, *VE*, Volume per cylinder (L), *Vol/Cyl*, air intake temperature (K), T_0, tailpipe exhaust temperature (K), T_1, Revolution per second, *RPS*.

$$Specific\ Emission = Gas_{con.} \frac{Q_{exhaust}}{v_{vehicles}} \quad (7)$$

where the specific emission per distance travel (mg/km), *Specific Emission*, gaseous emission concentration (mg/m^3), $Gas_{con.}$, Exhaust gas flow rate (m^3/s), $Q_{exhaust}$, vehicle speed (km/s), $v_{vehicle}$.

3. Results

3.1 Calculation samples

The exhaust emission result was obtained from the emission analyzer. The result obtained was CO, HC and NOx in either part per million (ppm) or percentage (%). The result shows that both HC and NOx were presented in ppm while CO is in %, as shown in Table 1. Therefore, a conversion of the data is required for comparing with the specific emission in g/km.

Table 1
Exhaust gaseous emissions result from laboratory testing at 90 km/h and several accelerator positions (APP)

App (%)	CO (%)	HC (ppm)	NOx (ppm)
30	0.01	5.00	235.00
45	0.01	6.00	618.00
60	0.02	7.00	1067.00
75	0.01	6.00	1075.00
90	0.01	6.00	1096.00

Based on Table 1, the exhaust emission results were converted into gaseous emission per cubic of ambient air (Gas_{con}) using Eq. 5. The final calculation for Gas_{con} is presented in Table 2. Note that the molecular weight of the gaseous emission (MW) used in the calculations were 28.01 g/mol, 16.04 g/mol and 46.01g/mol for CO, HC and NOx, respectively.

Table 2
Gaseous emission per meter cubic volume of ambient air

App (%)	CO (mg/m3)	HC (mg/m3)	NOx (mg/m3)
30	112.60	3.22	434.67
45	112.60	3.87	1143.09
60	225.21	4.51	1973.59
75	112.60	3.87	1988.38
90	112.60	3.87	2027.23

Table 3
Specific emission of CO, HC, NO_x and HC + NO_x

App (%)	CO (g/km)	HC (g/km)	NOx (g/km)	HC + NOx (g/km)
30	0.12	0.0034	0.46	0.47
45	0.12	0.0041	1.22	1.22
60	0.12	0.0048	2.10	2.10
75	0.24	0.0041	2.11	2.12
90	0.12	0.0041	2.16	2.16

To finalize the calculation, data for exhaust flowrate, $Q_{exhaust}$ is calculated using Eq. 6. The volumetric efficiency (VE) is at 85% and the Volume per cylinder (L), (*Vol/Cyl*) is 0.625L. The intake temperature and exhaust tailpipe temperature are 313.15 K and 373.15 K, respectively. The engine speed during testing is 42 revolutions per second (RPS). All pre-calculated result is then inserted into Equation 7 for specific emission (g/km). The result for all specific emissions is depicted in Table 3.

4. Conclusions

The methods for calculating the specific emission (g/km) from percentage volume or part per millions (ppm) is able to calculate the emissions of transport using available data. It also helps the researcher without appropriate equipment to measure specific emissions.

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