International Journal of Engineering & Technology, 7 (3.17) (2018) 250-253

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Opportunity for Optimising a Common Rail Engine Using Palm Oil Biodiesel

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Abstract

emission while producing significantly low black smoke. This is due to the inherent chemical and physical properties of biodiesel which results in un-optimised engine operating parameters. This paper presents the investigation on the potential of optimizing common rail diesel engine for palm oil biodiesel. Low to medium speed and the load was chosen for this optimization due to the significant changes in performance and emission when operating with palm oil biodiesel. Fuel injection and rail pressure sweep were conducted at 2000 rpm and 3000 rpm for biodiesel blends of 10%, 20% and 30%. The smoke and NOx emissions, as well as the fuel consumption, were recorded. The results were compared to nominal fuel injection parameter settings with the aim to improve the fuel economy while keeping the smoke and NOx emissions to within original diesel values. The results indicated that the Brake Specific Fuel Consumption(BSFC) remains relatively constant at a fixed end of injection (EOI) regardless of the rail pressure. NOx and smoke emissions varied significantly with both EOI and rail pressure. It was also shown that the optimum parameter settings for biodiesel were at lower rail pressure and at nominal end of injection, where the emissions were kept to original diesel values and the fuel consumption was reduced.

Keywords: *Common rail, Fuel consumption, NOx emission, Optimization, Palm biodiesel.*

1. Introduction

As the common rail systems are fully electronically controlled, they are more flexible and allow for independent adjustment of many parameters such as the rail pressure, injection pulse width, injection timing, pilot injection control, boost pressure, exhaust gas recirculation (EGR) rate, etc. Different settings for diesel and biodiesel is possible by having separate maps in the electronic control unit (ECU). Alternatively, piggy-back system could be applied that adjusts the injection parameters by altering the signals to and from the ECU.

For the common rail system, results similar to mechanical systems were reported for fuel injection pressure effects. Increasing the fuel delivery by injection pressure and injection duration both shown to increase NOx emissions [1, 2]. However, the effects of the injection pressure are greater than the effects of injection duration [1]. It was also reported that the fuel consumption was less affected by the changes in the injection parameters within the range studied. Engine power could also improve with increasing pressure due to better atomisation [3]. Increasing the rail pressure had also shown to reduce soot emissions.

Advancing the injection timing resulted in increased NOx emissions [1] and reduces smoke. Early injection resulted in increased peak pressure and move the peak pressure early in the cycle [4]. It was also shown that the brake specific energy consumption was less affected by the change in the injection strategy. Thus it showed the feasibility of using injection strategy optimisation for NOx control without sacrificing efficiency. Work by Baek [5] indicated that it is possible to use injection pressure and injection timing for optimising the emissions for biodiesel. Depending on the operating points, the authors adjusted the air flow rate and the injection parameters to achieve the target emissions. The biodiesel used was the rapeseed and soy blends.

Hwang et. al. [2] studied the effects of injection parameters on combustion of waste cooking oil biodiesel. The authors suggested that the effects of rail pressure are dominant in biodiesel NOx emission, but not for petroleum diesel. On the other hand, the smoke emissions reduce as the rail pressure is increased or injection is advanced. At high rail pressure, however, the injection advance was shown to have fewer effects on the smoke emissions.

Work by Bunce et. al. [6] on soy-based biodiesel, indicated that the optimised settings for the biodiesel were at the lower air-fuel ratio, advanced injection, higher EGR fraction and rail pressure similar to diesel settings. NOx emissions were reduced below the diesel level while the smoke emission reduction was substantial. The authors, however, noted that the fuel consumption penalty was not able to be significantly reduced. Subsequent work by Snyder [7] proposed an optimisation strategy by providing an estimation of the biodiesel blend ratio and model-based injection control. Hu et. al. [8] conducted optimization for waste cooking oil on a heavy duty diesel engine which has a cetane number similar to diesel fuel. Lopez et. al. [9] conducted multiple response optimization for best blend ratio for engine load using olive pomace oil methyl esters. No optimization of engine control parameters was conducted. Other works regarding engine optimization

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with biodiesel deals either with performance prediction or related to the addition of other components such as ethanol or hydrogen [10, 11].

Works by other authors focused on optimising the engine emissions by conducting new engine mapping for biodiesel. Manickam et. al. [12] tested jatropha biodiesel on the modified dataset and managed to obtain similar performance as diesel but at the expense of increased NOx. Senatore et. al. [13] optimised the EGR rate and the injection advance for rapeseed and soy biodiesel. Using Euro5 engines with Closed-Loop Combustion Control (CLCC) system provides automatic fuel injection strategy adjustment based on the combustion signal. Typically, they are based on the estimates of the fuel mass-burn fraction from cylinder pressure trace. Tests on biodiesel showed that the NOx emissions were kept to similar diesel values while smoke could be reduced [14, 15]. However, the result of the fuel consumption remains higher for biodiesel.

Although a number of research had been done on the optimisation of biodiesel combustion on common rail engines, the effects on high cetane biodiesel such as palm oil are inadequate. Optimisation with close loop combustion control system allows for putting the emissions in check, but without optimising the fuel economy. Hence the study described in this thesis deals with the optimisation of palm oil biodiesel with the aim of minimising the fuel consumption while keeping the emissions in check. The simplest optimisation of a common rail engine would be by using the fuel injection parameter adjustments.

2. Methodology

There are several ways to optimise the engine operation when using biodiesel. Adjusting the EGR ratio, injection timing, rail pressure and the number of injections are among the commonly studied approaches. In view of its simplicity, the injection timing and the rail pressure were chosen in this study as the control parameter for optimising biodiesel operation. Besides, earlier results from tests with palm oil biodiesel as described elsewhere [16] indicated that these two parameters are adequate to provide significant effects to the performance and emissions. In addition, these controls can also be implemented by the piggy-back approach. A secondary control system may be applied in the way similar to performance-enhancing piggy-back ECUs for petrol engines. This approach would provide immediate effects to existing fleets of the vehicle through simple modifications.

In this study, a 1.5 litre, 4 cylinders' common rail engine as given in Table 1 was used. Note that the Exhaust Gas Recirculation (EGR) of this engine was disabled, thus helps to keep the air flow to the engine comparable between fuels. This engine was coupled to a 150 kW eddy current engine dynamometer to absorb the power from the engine. The dynamometer controller also recorded data such as the engine speed, torque, power, engine temperatures, throttle pedal position, fuel flow and air flow in real time. The fuel flow was measured by a positive displacement fuel flow meter. Automotive grade hotwire anemometer was used to measure the air flow to the engine.

Table 1: The specifications of the engine used in the study.

Engine Specifications	
Displacement Volume	1461 cm3
Cylinder Bore	76.0 mm
Cylinder stroke	80.5 mm
Compression ratio	18.8:1
Injection type	Delphi Common rail
Max power	48kW@4000rpm
Max torque	160Nm@2000rpm
Catalyst	No
Turbo	Yes

The smoke and NOx emissions were measured by AVL 4000 series analysers. For determining the commanded injection timing, the injector voltage supply was tapped and channelled to an oscilloscope. ECU data with regard to the manifold pressure, load demand, manifold air temperature and fuel rail pressure was recorded by using an On-Board Diagnostic (OBD) connection. The injection parameters were adjusted using a piggy-back control device that allows injection timing and rail pressure modifications.

In this study, the engine was operated with variations of rail pressure and injection timing as a given in Table 2. This medium speed and load condition is representative of highway driving conditions. Biofuel derived from palm oil was used throughout this study. Typical Malaysian diesel fuel was used as the base fuel. Blends of 10%, 20% and 30% biodiesel were evaluated. The properties of the fuels are given in Table 3.

Table 2: The engine operating region and fuel injection settings.

Engine Speed, rpm	Torque, Nm	Rail pressure, bar	Start of fuel injection, °CA ATDC
2000	80	700 - 900	10.4 to 14
3100	70	1100 - 1330	6 to 10
3100	100	1270 - 1470	5 to 9.5

Table 3: The specifications of the test fuels.

	bio-diesel	die-sel	B10	B20	B30
Cetane Number	81.8	61.3	62.4	65.8	69.2
Kinematic Viscosity @40°C, cSt	4.567	3.854	3.885	3.932	3.986
Density @ 15°C, kg/m3	875.5	839.1	842.6	846.1	849.6
Calorific Value, MJ/kg	39.93	45.91			
Distillation, °C IBP	323.3	198.4	198.2	208.9	209.3
5% evaporated	323.8	229.5	235.3	238	244.5
10% evaporated	324	243.8	249.4	254.2	261.5
30% evaporated	324.1	260.2	276.7	283.5	290.3
50% evaporated	326.5	293	297.3	304.7	310.4
90% evaporated	324.8	355.4	345.5	348.4	345.5
FBP	350	378	371.9	370.5	367.7

The medium to low speed and the load was chosen for optimisation due to the large performance and emissions deficit when operating with biodiesel, hence greater opportunity for optimisation effort. The results for the performance tests and the fuel system response is described elsewhere [17]. Results from [18] also indicated that the End of Injection (EOI) and the rail pressure are the most appropriate parameters for the optimization of the palm oil biodiesel.

3. Results and Discussion

Figure 1 shows the maps of smoke emission, NOx emission and the Brake Specific Fuel Consumption (BSFC), plotted against speed and EOI for B30 at speed and torque of 3100rpm and 70Nm. The map shows the BSFC lines are relatively vertical, which means that it was dependent on the end of the injection while the rail pressure has little effect. On the other hand, the NOx and smoke emissions exhibit a strong relationship with both rail pressure and EOI.

Hence, keeping EOI would result in relatively consistent BSFC. In order to reduce NOx emissions, rail pressure may be lowered. By doing so, this would increase the smoke emissions at the same time. However, this increase is acceptable for higher biodiesel content in the fuel, because the smoke emission is inherently lower than diesel by a comfortable margin. Nonetheless, care must be taken such that the rail pressure is not too low as this will result in the smoke emissions beyond diesel values.

At this operating point, the base diesel emissions and BSFC figures are as given in Table 4 below. The lines representing the base diesel values are shown as dashed bold lines in Figure 1. By superimposing the maps, the region that indicates the injection parameters where BSFC, smoke and NOx emissions are within base diesel values can be determined. This is shown in Figure 2. The shaded region indicates where BSFC or fuel economy can be improved while keeping the emissions within base diesel values. It is interesting to note that the optimised region lies in the vicinity of lower than nominal rail pressure and the EOI similar to the nominal value. The base diesel nominal rail pressure is 1230bar and EOI of -20°CA, while the optimised injection parameter for B30 is at the region closed to 1100bar and -20°CA.

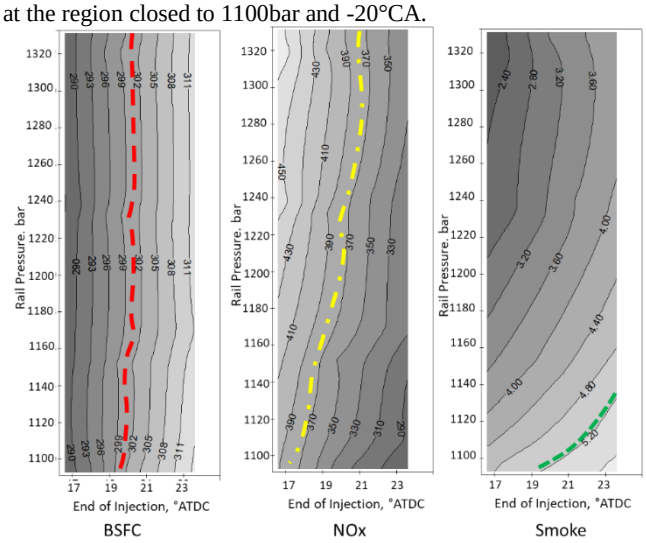


Fig. 1: The map of NOx, smoke and BSFC at 3100 rpm and 70 Nm with respect to EOI and rail pressure.

Table 4: The base diesel performance and emissions

	Parameter	Value
	NOx emission	417ppm
	Smoke emission	4.4%
2000 rpm 80Nm	BSFC	262g/kWhr
	Injection pressure	800bar
	EOI	-21degCA
	NOx emission	374ppm
	Smoke emission	4.8%
3100 rpm 70Nm	BSFC	300g/kWhr
	Injection pressure	1230bar
	EOI	-20°CA
	NOx emission	627ppm
	Smoke emission	8.4%
3100rpm 100Nm	BSFC	266g/kWhr
	Injection pressure	1370bar
	EOI	-22°CA

Graphs in Figure 3 and Figure 4 show the optimised regions for B20 and B10 at the same speed and load settings. For B20, the optimised injection parameter also lies at the EOI similar to diesel nominal setting and at slightly lower rail pressure (-20°CA EOI and 1220bar). Note also that the optimised region for B20 is smaller than for B30. It is also evident that for B10, there are no injection parameter settings that could bring the BSFC to diesel levels. At this blend ratio, the smoke emission is similar to diesel values, resulting in no overlapping region where the emissions are within diesel values. For best compromise of BSFC and emissions, the nominal diesel setting was found to be the optimised setting for B10. Thus it follows that for small biodiesel content, the optimised region is reduced and the injection setting moves towards a nominal diesel setting.

The smoke emissions reduction is more pronounced at higher biodiesel contents, thus allowing for the larger opportunity for optimisation. At lower biodiesel content, the injection parameter region

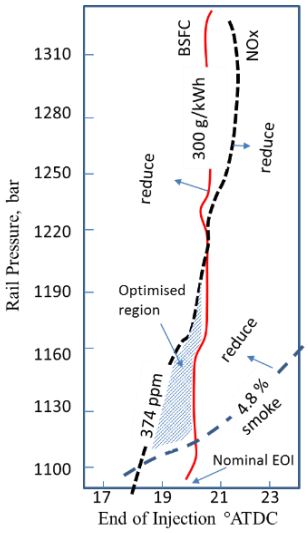


Fig. 2: BSFC, smoke and NOx optimization for B30 at 3100rpm and 70Nm

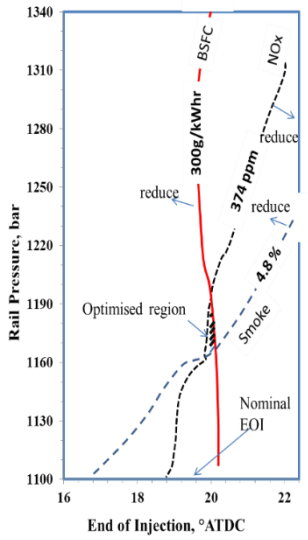


Fig. 3: BSFC, smoke and NOx optimization for B20 at 3100rpm and70Nm

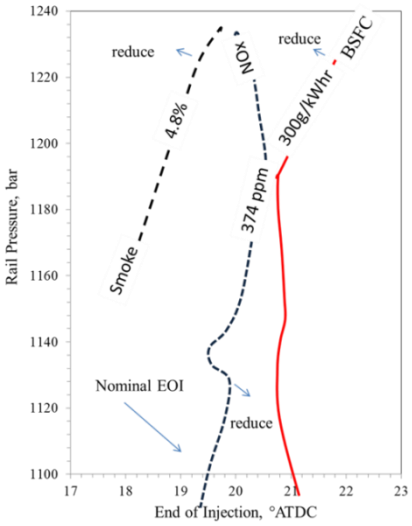


Fig. 4: BFC, smoke and NOx optimization for B10 at 3100rpm 70Nm.

with the optimised operation is reduced. More importantly, this study has shown that the EOI and the rail pressure are adequate to control parameters for optimising biodiesel operation. The general trend for optimised injection timing was found to be at the region

closed to nominal diesel EOI for all fuels tested, regardless of the biodiesel content. On the other hand, the optimised rail pressure seems to depend on the biodiesel blend ratio. As the biodiesel content is increased to 20% and 30%, the optimised rail pressure is found to be at lower pressure.

Table 5 summarises the region of optimised injection parameters for different biodiesel blend ratios at different speeds and loads. Here, the same trend is also observed for other tested speed and load regions. In general, for optimised operation on biofuels, the EOI should be set close to diesel nominal setting. On the other hand, the rail pressure is set to lower pressure as the biodiesel content is increased. At 10% biodiesel, the optimised operation was at the nominal setting as in diesel. Note that this conclusion is valid for biodiesel content up to 30%.

Table 5: The optimised operating region and fuel injection parameters for biodiesel

Speed and load	Fuel	Optimised Rail pressure	Optimised End of Injection
2000rpm 80Nm	B10	Not tested	
	B20	Lower than nominal	Close to nominal
	B30	Lower than nominal	Close to nominal
3100rpm 70Nm	B10	Close to nominal	Close to nominal
	B20	Lower than nominal	Close to nominal
	B30	Lower than nominal	Close to nominal
3100rpm 100Nm	B10	Not tested	
	B20	Lower than nominal*	Close to nominal*
	B30	Lower than nominal*	Close to nominal*

4. Conclusion

Palm oil biodiesel was tested on a passenger car common rail diesel engine and the effect of fuel injection parameters was studied to determine the potential for optimisation. At medium speed and load condition, it was shown that the BSFC was highly dependent on the EOI timing while the rail pressure had little effects. On the other hand, the smoke and NOx emissions had a strong relationship with both parameters. Plotting the map of injection parameters and superimposing for smoke, NOx and BSFC reveal that the optimised region lies at nominal EOI which was at -20°ATDC. On the other hand, the optimised rail pressure lies at a lower pressure than the diesel nominal setting. As the biodiesel content is reduced to 20%, the region where the emissions and BSFC lower than diesel becomes smaller and at 10% biodiesel, the optimised operation on biodiesel would not be able to reduce BSFC to diesel values. In summary, this study had shown that operating palm oil biodiesel in common rail engine could be optimised to obtain improved BSFC while keeping the emissions similar to diesel values. This is more apparent at higher biodiesel content of 20% and 30%.

Acknowledgements

The authors would like to thank the Ministry of Higher Education Malaysia, and Research Management Centre, UTM for providing the financial assistance under project Vote No. 4L653. The authors are also indebted to the University of Malaya for the engine testing facility accorded for the study. The authors wish to thank the Ministry of Higher Education, Malaysia for their financial support under grant LRGS/TD/2016/USM-UKM/P1/01.

References

[1] P. Ye, A. L. Boehman., "Investigation of the Impact of Engine Injection Strategy on the Biodiesel NOx Effect with a Common-Rail Turbocharged Direct Injection Diesel Engine," Energy Fuels 24, 4215–4225 (2010)

[2] J. Hwang, Y.J. Donghui Qi, C. Bae., "Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel," Renewable Energy 63, 9-17 (2014)

[3] M. Ghosal, D. Das, S. Pradhan, N. Sahoo, "Performance Study of Diesel Engine by using Mahua Methyl Ester (biodiesel) and its Blends with Diesel Fuel," Agricultural Engineering International: the CIGR Ejournal 10 (2008)

[4] A. Gunabalan, P. Tamilporai, R. Ramaprabhu, "Effects of Injection Timing and EGR in DI Diesel Engine Performance and Emission - using CFD," Journal of Applied Sciences, 10(22), 2823 - 2830 (2010)

[5] K.H. Baek., "An Experimental Study of EMS Control Parameter Optimization for the Use of Biodiesel Blend Fuel," SAE 2010-01-2272 (2010)

[6] M. Bunce, D. Snyder, G. Adi, C. Hall, J. Koehler, B. Davila, S. Kumar, P. Garimella, D. Stanton, G. Shaver., "Optimization of soy-biodiesel combustion in a modern diesel engine," Fuel 90, 2560–2570 (2011)

[7] D. B. Snyder., "Soy-Based Biodiesel Blend Estimation and Accommodation in a Modern Diesel Engine," PhD Dissertation, Purdue University (2010)

[8] Q. Hu, D. Lou, P.Tan, Z. Hu et al., "Study on Fuel Injection Parameters Optimization for Common Rail Diesel Engine Fueled with B20 Biodiesel," SAE Technical Paper 2014-01-2655 (2014)

[9] I. Lopez, S. Pinzi, D. Leiva-Candia, M.P. Dorado., "Multiple Response Optimization to Reduce Exhaust Emissions and Fuel Consumption of a Diesel Engine Fueled with Olive Pomace Oil Methyl ester/diesel Fuel Blends," Energy 117, 398-404 (2016)

[10] S. Javed, Y.V.V. Satyanaratna Murthy, R. Ull Baig, D. Prasada Rao, "Development of ANN Model for Prediction of Performance and Emission Characteristics of Hydrogen Duel Fueled Diesel Engine with Jatropha Methyl Ester Biodiesel Blends," Journal of Natural Gas Science and Engineering 26, 549-557 (2015)

[11] C. Beatrice, P. Napolitano, C. Guido., "Injection Parameter Optimization by DoE of a Light-Duty Diesel Engine Fed by Bioethanol/RME/diesel blend," Applied Energy 113, 373-384 (2014)

[12] M. Manickam, M. Kadambamattam, M. Abraham., "Combustion Characteristics and Optimization of neat Biodiesel on High Speed Common Rail Diesel Engine Powered SUV," SAE 2009-01-2786 (2009)

[13] A. Senatore, M. Cardone, D. Buono, V. Rocco, L. Alloca, S. Vitolo., "Performances and Emissions Optimization of a CR Diesel Engine Fuelled with Biodiesel," SAE Technical Paper Series 2006-01-0235 (2006)

[14] F. Millo, D. Vezza, T. Vlachos., "Effects of Rapeseed and Jatropha Methyl Ester on Performance and Emissions of a Euro 5 Small Displacement Automotive Diesel Engine," SAE 2011-24-0109 (2011)

[15] C. Guido, C. Beatrice, S.D. Iorio, P. Napolitano, G.D. Blasio., Vassallo, A., Ciaravino, C., "Assessment of Closed-Loop Combustion Control Capability for Biodiesel Blending Detection and Combustion Impact Mitigation for a Euro5 Automotive Diesel Engine," SAE 2011-01-1193 (2011)

[16] M.A. Abdullah, F.N. Ani, M. Hassan., "Performance and Emissions of a Common Rail Passenger Car Engine Fuelled with Palm Oil Biodiesel," Applied Mechanics and Materials 564, 66-71 (2014)

[17] M.A. Abdullah, F.N.Ani, M. Hassan., "Fuel System Response of a Common Rail Passenger Car Engine Fuelled with Palm Oil Biodiesel," Applied Mechanics and Materials 699, 528-533 (2015)

[18] M.A. Abdullah, F.N. Ani, M. Hassan., "The Effects of Injection Parameters on the Performance of Common Rail Light Duty Engine Fulled with Palm Oil Biodiesel," Applied Mechanics and Materials 465-466, 322-326 (2014).