MODELLING OF ENGINE PERFORMANCE, COMBUSTION CHARACTERISTICS AND EXHAUST GAS EMISSION FUELED WITH BIODIESEL B20

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A tractor Diesel engine was tested on a chassis dynamometer with Biodiesel B20 mixed with pure Diesel, to find out its combustion characteristics, performance, and exhaust gas emissions. In the present work, an engine combustion model has been developed using AVL Boost software, which can predict the combustion characteristics, engine performance and exhaust gas emission for Biodiesel produced from Rapeseed. This model involves simulation of effective torque, effective power, brake specific fuel consumption, cylinder temperature and cylinder pressure development in a combustion chamber, NOx and CO emissions at full load and engine speed (1000, 1200, 1600, 1800, 2200 rpm respectively). Model validation is done by comparing the predicted parameters with the experimental results and is found in close approximation.

Keywords: Biodiesel, Diesel Engine, Emissions, Efficiency

1. Introduction

Some of the most significant current discussions worldwide are climate change, the increased price of petroleum products, the fact that reserves of petroleum-derived fuels are diminishing, coupled with increasing demand every day. Recently, researchers have attempted to discover alternative energy sources that are accessible, technically viable, economically feasible, and environmentally acceptable. Biodiesel fuels produced from different vegetable oils is considered one of the best alternative sources of Diesel fuel because of its potential to reduce dependency on petroleum fuel, its capacity to decrease environmental pollutant output, and applications in compression ignition engines without further modifications [1]. Previous studies have primarily concentrated on the properties of Biodiesel and their effect on combustion behavior and emission characteristics. The properties of Biodiesel fuel mainly depend on the fatty acid composition of the oil and the production technique [2]. Biodiesel is non-toxic, biodegradable, its

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physical and chemical properties are very close to Diesel fuel, it contains almost no sulfur, has a higher cetane number than Diesel fuel, has no aromatics, contains10–12% oxygen by weight and is one of the alternative renewable fuels for compression ignition engines [3, 4, 5].

One of the main concerns regarding Biodiesel is its viscosity. Biodiesel fuel has a higher viscosity than Diesel fuel and this influences flow, the start of injection. Poor atomization and carbon deposits have effects on engine parts, such as increased wear on the pump and the injector elements due to higher mechanical effort [6, 7].

Internal combustion engine simulation has been extensively used to improve engine performance, combustion characteristic, and exhaust gas emissions. Diesel engines have been widely used in marine transportation, power generation, and heavy-duty vehicles and are now increasingly being used in light duty vehicles, especially in European countries, due to fuel economy and low pollutant emissions. An alternative simulation of engine performance and combustion characteristics with the help of a mathematical model and powerful digital computers lowers cost and time [8]. However, internal combustion engine numerical simulation can be used to understand combustion characteristics, engine performance, and emission behavior, were these simulations can reduce the number of experiments.

Potdukhe and Deshmukh [9] developed a zero-dimensional single zone combustion model to predict engine performance, the rate of heat release and pressure for a single cylinder Diesel engine fuelled with Biodiesel (10% & 20%) at constant speed Diesel by using the MATLAB software. The results of the models are well in agreement with the experimental result. Engine performance improved with low percentage of Biodiesel mix with Diesel; this is indicated by the higher maximum combustion temperature and pressure.

Another study by Jagadish et al. [10] developed a zero-dimensional model to investigate the combustion performance of a one cylinder direct injection compression ignition engine fueled by Biodiesel (palm stearin methyl ester) with options such as supercharging and exhaust gas recirculation. Simulation results were validated with the experimental results, and it was observed that the present model is successful in predicting engine performance with Biodiesel. They reported that engine performance is improved with a low quantity blend of Biodiesel to Diesel, this being indicated by higher maximum combustion temperatures and pressures when compared with unmixed Diesel. The aim of this study is to determine the accuracy of the model simulating the Diesel engine performance and exhaust gas emissions by using AVL code v2013.2 BOOST simulation tools, fueled with Biodiesel B20 at full load and at different engine speeds.

2. Experimental Infrastructure

The compression ignition engine considered is the most efficient of all types of internal combustion engines, with lower specific fuel consumption and higher thermal efficiency due to the high compression ratio used. The engine that was used in this study for modeling is a four cylinder, natural aspirated, direct injection tractor Diesel engine , liquid-cooled, the maximum power was 50kW at 2400 rpm, maximum torque was 228 Nm at 1400 rpm ,Bore x stroke(102 x 115 mm) , compression ratio equal to 17.5 . The engine was coupled to a eddy-current dynamometer equipped with a load controller. Complete measurement equipment was installed on the Diesel engine in order to measure the performance, exhaust gas emissions and combustion pressure data as shown in Fig. 1 [11].

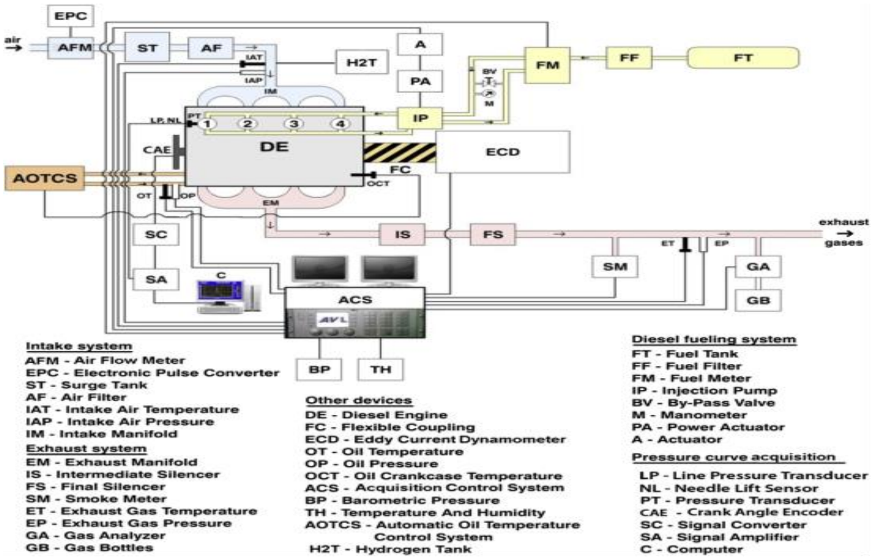

Fig. 1. The schematic of the test bed

The test bed operating on multiple fuels has been adapted for the purpose of the present work, allowing the engine to be alternatively fueled with tested fuels, Diesel and Biodiesel B20. The performances and the emissions of the operated engine were tested at (1000 rpm,1200 rpm, 1600 rpm, 1800 rpm and 2200 rpm) engine speed, full load and the injection timing was measured experimentally for all engine speeds, depending on the injector needle lift.

3. Simulation Procedures

Using the AVL BOOST software, an engine combustion model was developed that could predict the combustion characteristics, engine performance and emissions of the compression ignition engine. AVL BOOST is considered powerful software used to simulate internal combustion engines, this software providing multi-purpose thermo-fluid dynamics with a particular focus on handling fluid flow applications. BOOST provides accurate gas properties for the standard fuels: Gasoline, Diesel, Methane, Methanol, Ethanol, Hydrogen, and Butane, while the gas properties for the Biodiesel B20 blend were calculated and implemented in the program by the author. The Woschni 1990 heat transfer model and AVL-MCC combustion model were chosen for the present model.

The engine calibration parameters were described by using code v2013.2 (AVL BOOST Theory and AVL BOOST Users Guide) [16] . All engine components such as: the intake and exhaust manifolds, the system boundaries, the cylinders' geometry, the air filter, the catalyst…etc. were linked together by pipes as shown Fig. 2. and implemented in the Boost interface based on the real values taken from the test engine.

Petroleum Diesel, 20% Biodiesel blend was tested in the four cylinder Diesel engine at full load and different engine speeds. For fuel consumption, the injection timing has been set at a crank angle (CA) and the rate of fuel injection for every engine speed and both test fuels were experimentally measured and implemented in the program.

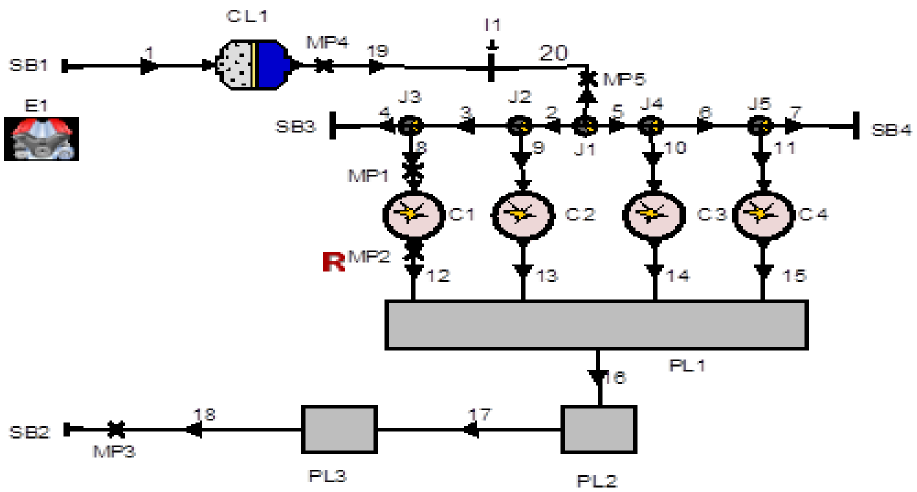

Fig. 2 .Schematic of the engine symbolic model (AVL BOOST Theory and AVL BOOST Users Guide)

Several combustion parameters were changed in the model for the specified test fuel and engine speeds to fit the cylinder pressure, engine performance and exhaust gas emissions. The final parameter values, which make the simulation result capture a good agreement with the experimental result, are listed in Table 2.

Table 2

Calibration parameter values

Parameter	Diesel(D) ,Biodiesel (B20) at full load									
	1000 rpm		1200 rpm		1600 rpm		1800 rpm		2200 rpm	
	D	B20	D	B20	D	B20	D	B20	D	B20
Number of injector holes (-)	5									
Hole diameter (mm)	0.24									
Discharge coefficient(DisC) (-)	0.7									
Rail pressure (RaiP) (bar)	350									
Injection delay calibration factor(IgnDel) (-)	0.45	0.71	0.45	0.30	0.72	0.30	0.72	0.30	0.72	0.30
Combustion parameter (ComPar)(-)	1.75	1.55	1.5	1.18	1.5	1.23	1.3	1.20	1.15	1.34
Turbulence parameter (TurPar)(-)	1									
Dissipation parameter (DisPar)(-)	1.2	1	1.2	1.2	1	1	1	1.2	1	1.2
Premixed combustion parameter (PremixPar)(-)	0.7	0.9	0.5	0.9	0.10	0.15	0.1	0.15	0.21	0.16
NOx kinetic multiplier (NO KM)(-)	1.93	1.93	1.8	1.7	1.69	1.68	1.62	1.595	1.62	1.58
NOx post processing multiplier (NO PM)(-)	0.24	0.24	0.22	0.19	0.19	0.17	0.165	0.156	0.165	0.149
CO kinetic multiplier (COKM)(-)	0.012	0.01	0.016	0.01	0.027	0.019	0.029	0.021	0.29	0.02
EGR parameter (EGRPar)(-)	1									
Evaporation Parameter (EvaPar)(-)	0.70353									

4. Results and discussion

Biodiesel has similar chemical properties to Diesel fuel, therefore; the engine performance when fueled with the Biodiesel B20 blend is expected to be similar to that of Diesel. Biodiesel has both heavier and lighter molecules: the heavier molecules are difficult to burn and led to the formation of deposits on the injector tip, piston head, and cylinder, while the lighter molecules along with fuel-borne oxygen will assist combustion [12, 13]. In this part of the study, the results from the simulation study are first compared to the experimental result to examine the usefulness of the model; second, we present the effect of Biodiesel blend B20 on engine performance and exhaust emissions.

5. Cylinder pressure

Figs. (3-7) present the variations of cylinder pressure with respect to the crank angle, experimental and simulation for Diesel and Biodiesel B20 at an engine speed of 1000 rpm ,1200 rpm ,1600 rpm , 1800 rpm ,2000 rpm and 2200 rpm, respectively, at full load operation. The pressure traces for all engine speeds for the experiment and simulations appear to fit properly.

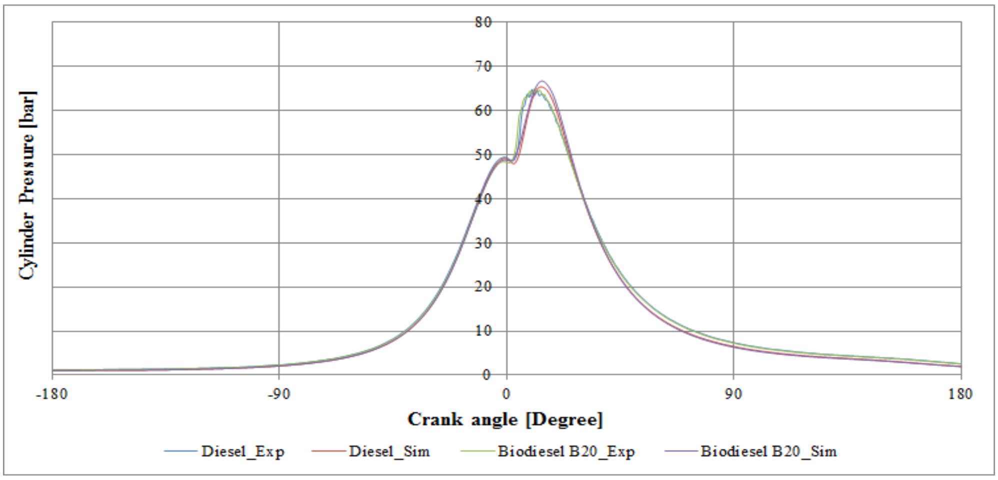

Fig 3 Comparison between experimental and simulation pressure traces for full load, 2200 rpm speed.

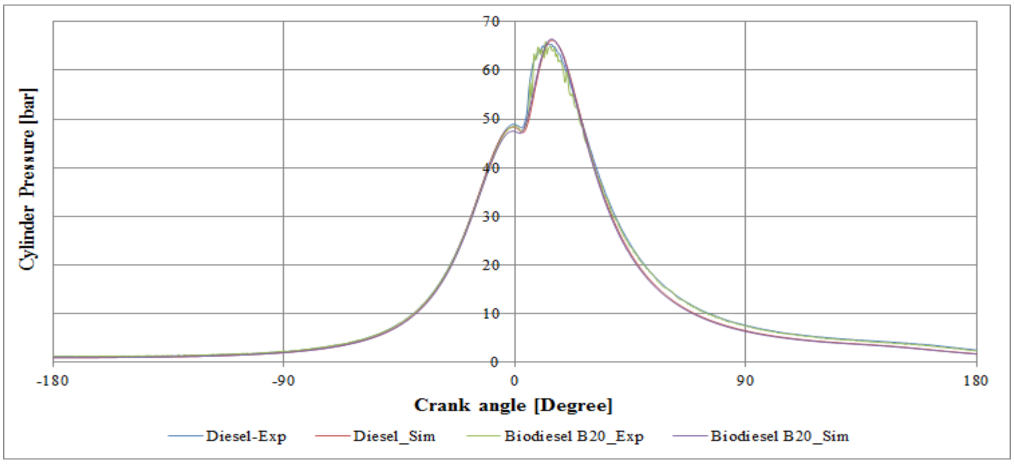

Fig. 4. Comparison between experimental and simulation pressure traces for full load, 1800 rpm speed.

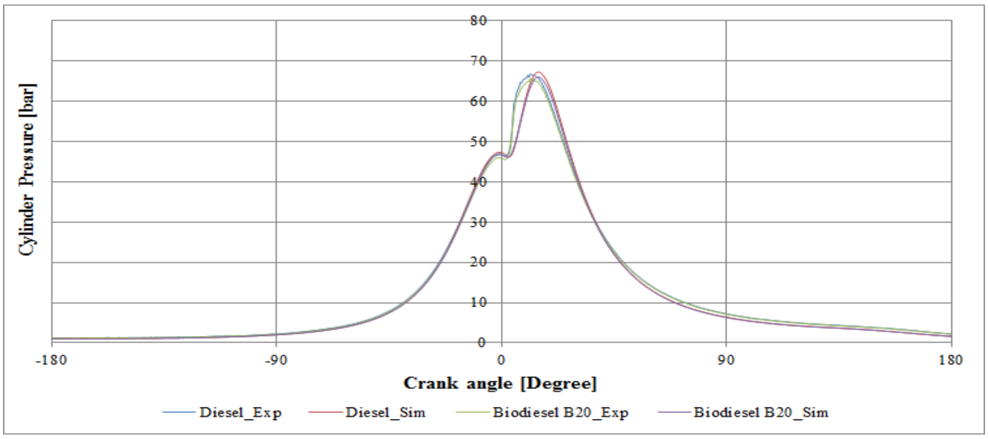

Fig. 5. Comparison between experimental and simulation pressure traces for full load, 1600 rpm speed.

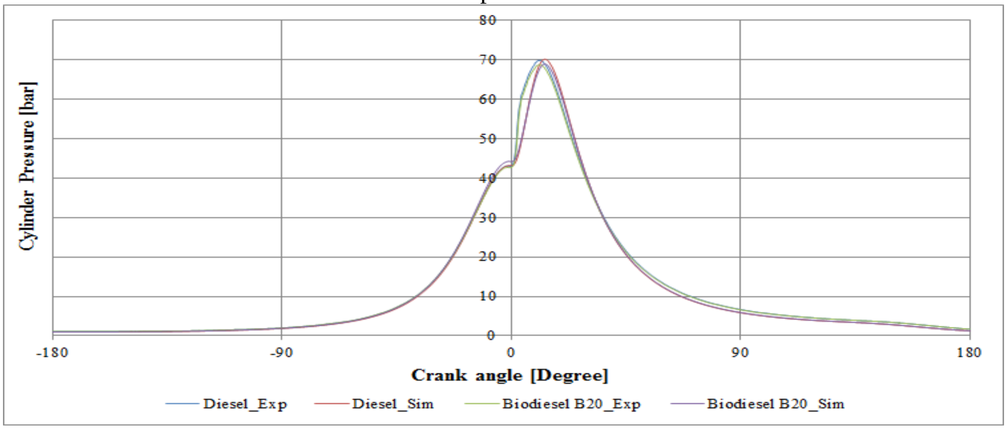

Fig.6.Comparison between experimental and simulation pressure traces for full load, 1200 rpm speed.

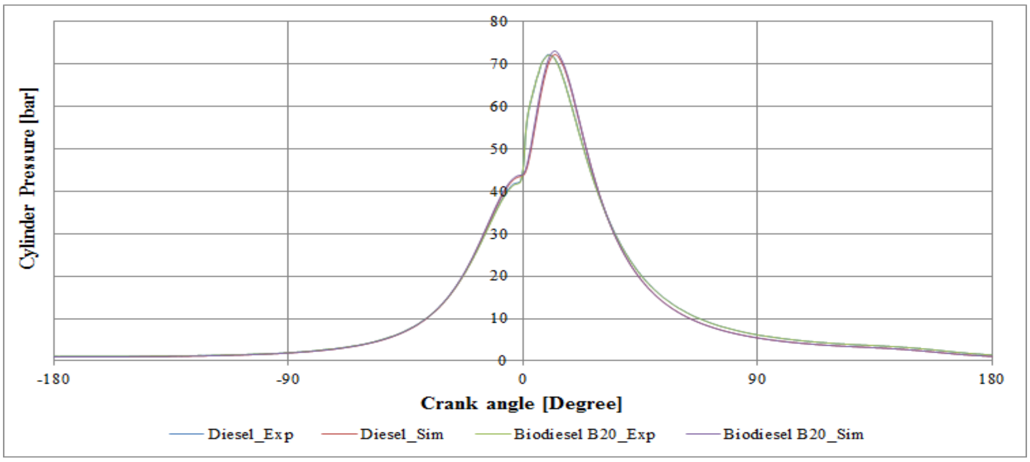

Fig. 7. Comparison between experimental and simulation pressure traces for full load, 1000 rpm speed.

The other results related to the engine performance and exhaust emission such as: effective power, effective torque, BSFC, brake thermal efficiency, NOx and CO emissions for Diesel and Biodiesel B20 fuel simulation results were compared to the experimental results and the relative errors between them are listed in Table 3. The max relative error between the numerical and experimental data related to effective power was 1.79% at 1000 rpm, whereas the max relative error registered for effective torque was 1.65% at 1800 rpm, for BSFC it was 1.89% at 1000 rpm for Diesel fuel. The minimum relative deviation between numerical and experimental data related to effective power was 0.254% record at 1000 rpm the minimum relative error registered for effective torque was 0.265% at 1000 rpm, for BSFC was 0.5% at 1200 rpm for B20 fuel.

Table 3

Comparison between simulation and experimental results

	T_e [N m]		P_e [kW]		BSFC [g/kWh]		BTE [%]		NO_x [ppm]		CO [ppm]	
1000 rpm												
	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp
Diesel	213.41	217.3	22.35	22.7	236.72	232.323	36.39	36.41	1280.41	1290	787	793
St. dev	1.79%		1.54%		-1.89%		0.054%		0.74%		0.76%	
B20	215.65	216.2	22.58	22.64	236.72	239.99	36.32	37.07	1324	1312	679	658
St. dev	0.254%		0.265%		1.36%		2.02%		-0.92%		-3.19%	
1200 rpm												
	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp
Diesel	226.04	227.2	28.41	28.56	234.11	232.843	36.79	35.77	1066.48	1061	756	753
St. dev	0.51%		0.525%		-0.544%		-2.85%		-0.61%		-0.4	
B20	221.25	220.5	27.8	27.7	242.43	243.652	35.953	36.99	1090	1084	748	751
St. dev	-0.34%		-0.36%		0.5%		2.8%		-0.55%		0.4%	
1600 rpm												
	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp
Diesel	219.85	217.7	36.84	36.48	237.27	239.583	36.3	35.38	903.41	925	491	483
St. dev	-0.98%		-0.98%		0.96%		-2.6%		2.33%		-1.66%	
B20	218.85	215.8	36.67	36.16	242.98	246.405	35.88	35.95	950	941	332	326
St. dev	-1.41%		-1.41%		1.39%		0.2%		-0.95%		-1.84%	

1800 rpm												
	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp
Diesel	216.35	212.8	40.78	40.12	239.94	244.018	35.91	34.8	709.67	754	329	340
St. dev	-1.67%		-1.65%		1.67%		-3.19%		5.87%		3.24%	
B20	213.31	210.1	40.18	39.6	244.32	250.505	35.32	35.29	820	840	293	280
St. dev	-1.527%		-1.46%		2.47%		-0.091%		2.38%		-4.64	
2200 rpm												
	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp	Num	Exp
Diesel	198.06	199.2	45.63	45.89	250.47	249.074	34.38	33.98	714.73	709	568	572
St. dev	0.58%		0.57%		-0.56%		-1.18%		-0.81%		0.70%	
B20	197.84	196.3	45.53	45.22	254.3	256.524	34.28	34.58	745	773	360	345
St. dev	-0.78%		-0.796%		0.867%		0.87%		3.62%		-4.35%	

5.2 Effective power

The variation of the effective power experimental and numerical data against engine speed for Diesel and Biodiesel B20 fuels at full load is given in Fig. 8. Biodiesel B20 produced a maximum effective power of 45.63 KW at 2200 rpm, which is 0.56 % lower than that produced by Diesel fuel, which produced a maximum effective power of 45.89 KW at 2200 rpm. In general, the profile shows that at lower engine speeds, Biodiesel B20 produced the same effective power as Diesel, and then decreased when the engine speed increased. This behavior is explained due to the higher viscosity coupled with the lower volatility of Biodiesel B20 and as a result, the B20 blend evaporates slower [13, 15] than Diesel. A good agreement has been obtained when comparing the simulation results against the experimental result.

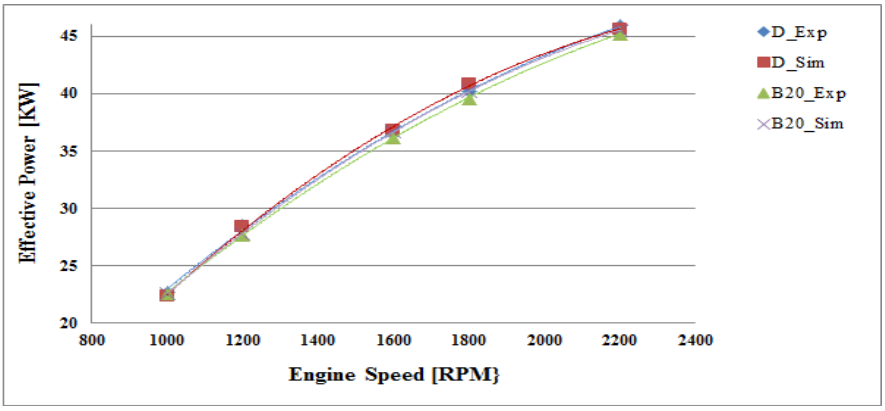

Fig.8. Experimental and numerical results at full load.

5.3 Effective torque

Fig. 9 shows the variation of effective torque with an engine speed of Diesel and Biodiesel B20 fuels at full load. Maximum torque for Diesel and Biodiesel fuels was exhibited at 1200 rpm. However, Biodiesel B20 produced a maximum torque of 226.04 N.m at 1200 rpm which is 0.51 % lower than that produced by Diesel, which produced a maximum torque of 227.2 N.m at 1220 rpm. In general, the profile shows that the torque has same trends at all engine speeds. This model predicted the effective torque in a closer approximation to that of the experimental results.

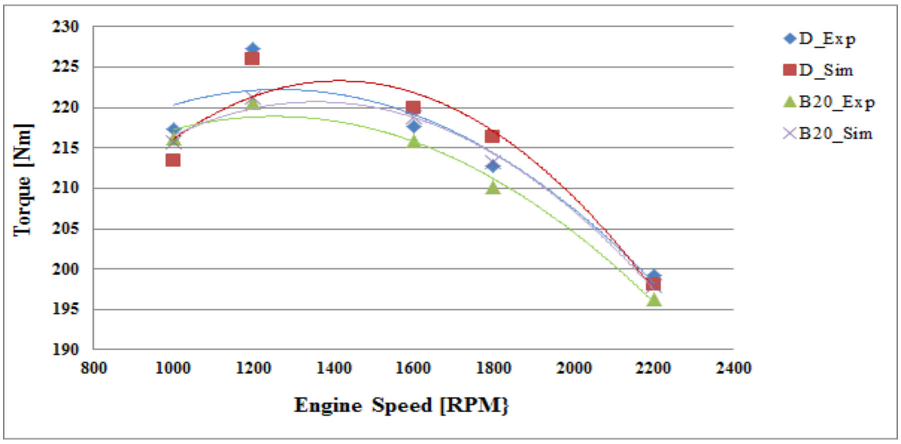

Fig. 9. Experimental and numerical results at full load.

5.4 Brake specific fuel consumption

Fig. 10 plots break specific fuel consumption (BSFC) predictions for different engine speeds and full load for Diesel and Biodiesel B20. Brake specific fuel consumption was higher with Biodiesel B20 at all engine speeds; this may be due to the fact that Biodiesel has a lower heating value and higher density than Diesel fuel, and this lead to more fuel being consumed to produce the same engine power. Simulation results were compared against the experimental result. In general, a good agreement has been obtained.

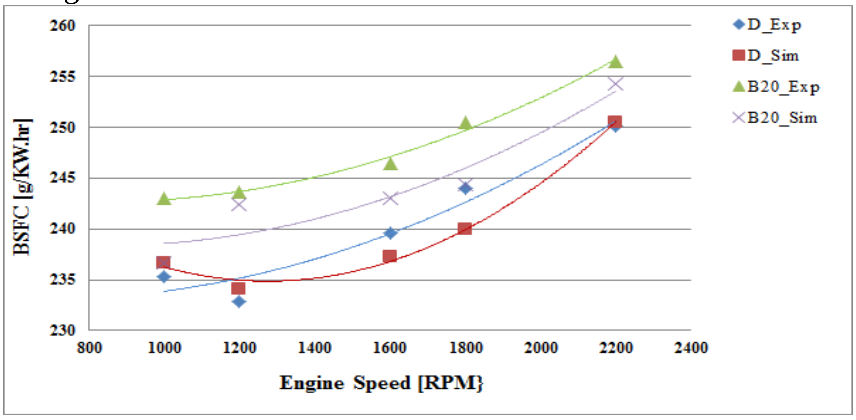

Fig. 10. Experimental and numerical results at full load.

5.5 Brake thermal efficiency

The comparison of brake thermal efficiency with respect to the engine speed at full load for test fuels is shown in Figure 11. The efficiency for Biodiesel B20 was slightly higher than for Diesel at all engine speeds. At 2200 rpm, the thermal efficiency improvement was around 1.017 % due to the presence of oxygen molecules in Biodiesel, which enhances combustion. A similar efficiency improvement, of 0.8 %, was achieved by [12] when running on B20 in a Diesel engine driven a metro bus. The same trend is observed for the experimental and simulation data for all engine speeds at full load, for both test fuels. This model predicted the brake thermal efficiency in closer approximation to that of the experimental results.

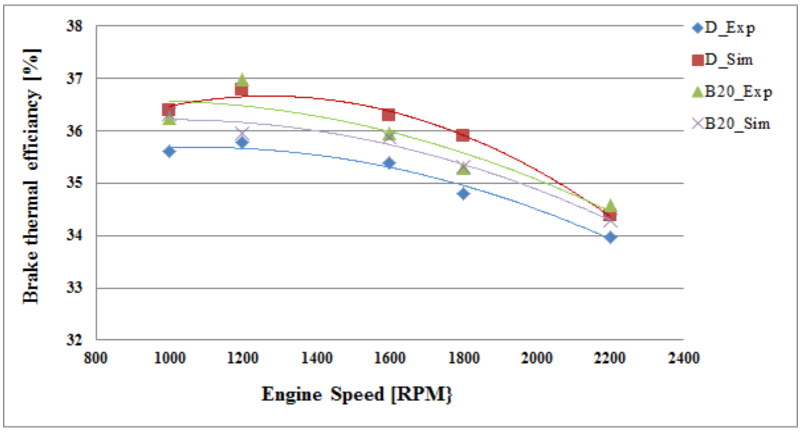

Fig. 11.Experimental and numerical results at full load.

5.6 Nitrogen oxides emissions NOx

Fig. (12) compares the nitrogen oxide emissions (NOx) with and without Biodiesel B20 at 1000 rpm, 1200 rpm, 1600 rpm, 1800 rpm and 2200 rpm respectively, and at full load. The nitrogen oxide emissions formation is affected by the local gas temperature, oxygen concentration and residence time [14]. Biodiesel has a 12% higher oxygen content than Diesel, which can improve the combustion process, enabling a more local gas temperature, contributing to a slight increase in NOx emissions. Comparing the simulation results against the experimental results, they are found in closer approximation for both test fuels.

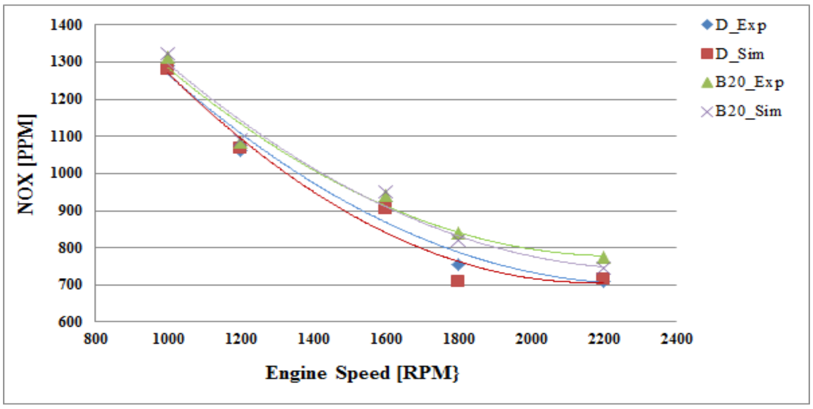

Fig. 12. Experimental and numerical results at full load.

5.7 Carbon monoxide emission (CO)

The effect of Biodiesel blend (20%) on carbon monoxide emissions was experimentally and numerically investigated at 1000 rpm, 1200 rpm, 1600 rpm, 1800 rpm and 2200 rpm respectively, as shown in Fig. 13. Generally, Biodiesel B20 produced lower carbon monoxide than Diesel fuel at all engine speeds. At the low engine speed of 1800 rpm, substantial reductions of the carbon monoxide emissions are observed, and these emissions increase with rising engine speed. This may due to the fact that Biodiesel has a 12% higher oxygen content than Diesel, which can improve the combustion process, enabling a complete combustion and reducing the carbon monoxide emissions. However, comparing the simulation results with the experimental results, they are found in closer approximation for both test fuels and hence the developed simulation model has been proven to be reliable and adequate for the proposed objectives.

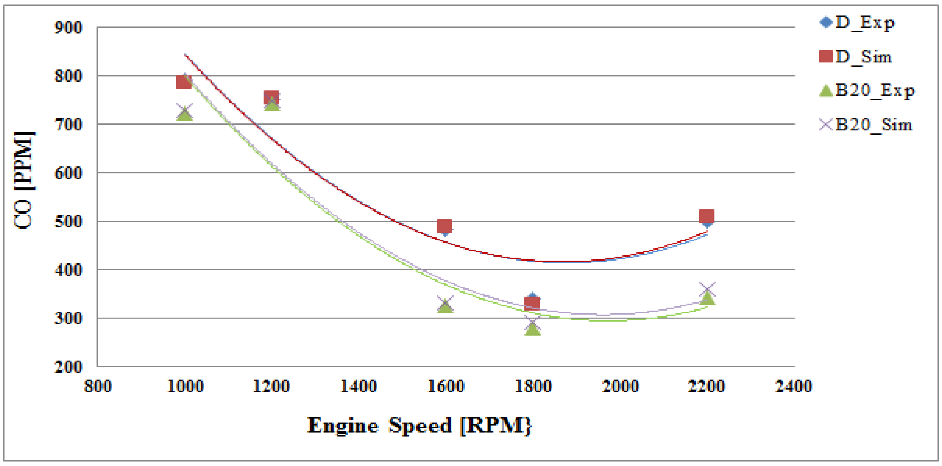

Fig. 13. Experimental and numerical results at full load

6. Conclusion

The influence of Biodiesel B20 fuel and Diesel fuel on the combustion, performance, and emission characteristics were studied numerically and experimentally for a heavy-duty, four cylinders, four strokes, natural aspirated and direct injection Diesel engine. All measurements and simulations were made on full load and different engine speeds. The simulation used to predict the combustion characteristics, engine performance, and exhaust gas emission was created by using the development tool called AVL Boost. The simulation results were validated against the experimental results. Based on the obtained results, the following conclusions can be made:

- This model predicted the engine performance, combustion characteristics and exhaust gas emission in closer approximation to that of the experimental results.
- Lower effective power and effective torque recorded with Biodiesel B20 fuel compared to Diesel.
- The BSFC found to be higher for Biodiesel B20 at all engine speeds when compared to that of Diesel.
- A slight increase in NOx emission was observed when using Biodiesel B20 fuel at all engine speeds, while noting that carbon monoxide was lower.

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