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Comprehensive Analysis of Engine Power, Combustion Parameters, and Emissions of a B30 Biodiesel-Powered IC Engine

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ABSTRACT

Using the AVL BOOST 2016 Simulations, the effects of biodiesel B30 (30% biodiesel + 70% diesel volume) on diesel engine performance, combustion, and emissions were studied. Simulated cases for diesel fuels and B30 biodiesel were compared to experimental results at full load at 1250, 1500, and 1750 rpm. Biodiesel B30 reduces power and effective torque, according the findings of various fuel parameters. Biodiesel B30 includes more oxygen, which aids in proper oxidation in the combustion chamber and reduces carbon monoxide levels. Once compared to diesel, biodiesel raised brake-specific fuel usage by 5%. When comparing Pure Diesel to B30, NO_x emissions increased marginally, reaching 2.57 percent.

1. Introduction

Over the past two decades, global energy demand (depending on conventional fuels) and its applications in daily life have increased as the number of transport and industrial vehicles. The depletion of oil reserves and rising prices push researchers and engine manufacturers in the world work seriously for alternative fuels. This alternative fuel should be technically feasible, economically viable and environmentally acceptable. There are various types of alternative fuels that have been used either pure or as mixtures with fossil fuels in combustion engines, including ethanol, methanol, hydrogen natural gas biodiesel etc.

Biodiesel is a fuel that is biodegradable, non-toxic, fragrant, and renewable [1-3] produced from either vegetable or animal fat. Biodiesel might be used in engines directly directly or after a chemical process, called transesterification converts it to methyl or ethyl esters. Biodiesel has a higher cetane count and 10-12% more oxygen than diesel, which contributes to improved combustion [4]. In fact, that is the Biodiesel has higher flash point so that it safer to handle and store more than the conventional fuel [5].

According to numerous studies [6-8], biodiesel has a high viscosity and a low heating value. These are the major disadvantage. It's had an influence on spray configuration and engine power, as well as an indirect impact on exhaust emissions. The increased viscosity of biodiesel influenced fuel flow

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(especially in a cold climate), atomization quality, spray cone angle, and droplet size diameter, and resulted in extended tip penetration of sprayed fuel. However, in the event of problems caused by the viscosity of biodiesel [9, 10], preheating of biodiesel up to 100 °C or mixing with ethanol could be the main solution.

Gvidonas and Slavinskas [11] used rapeseed oil (2.5, 5, 7.5 and 10 percent volume) in a diesel engine at a variety of speeds and loads. The results revealed that the BSFC brake specific fuel consumption was higher than when using diesel fuel under all operating conditions. The lower heating value of Biodiesel and its combinations is responsible for the increase in BSFC. The research study by Kleinova *et al.,* [12] also noted that BSFC increased by 21.69% with the addition of rapeseed oil.

Golimowski *et al.,* [13] demonstrated the effect of biodiesel on the performance of a John Deere tractor 6830 at tractor engine speed from 1300 to 2200 rpm in increments of 200 rpm. They realized that the BSFC increased by 14% when using rapeseed biodiesel, while torque and power decreased. Recent studies [14, 15] have confirmed that the use of rapeseed biodiesel and its mixtures reduces power and torque. This performance attributed to the lower heating value of biodiesel compared to diesel.

Currently, in most countries, the most common mixture on the market is B5 (5 percent biodiesel mixed with 95 percent diesel fuel per volume). It couldn't be used without changes in compression-ignition engines to the engine hardware, but it has no effect on the final fuel price. The B20 was expected to be use in the near future by the United State, the European Union and East Asia in the soon future. Biodiesel can give a good balance between costs, environmental benefits, start-up in cold conditions and compatibility of the materials [16]. Numerous Researchers have tried different types of software in order to develop specific models to predict performance of the engine, the properties of combustion, and emissions of exhaust when using diesel fuels under different operating conditions.

The ability to observe on a computer screen the changes in temperature, pressure, and volume that occur throughout engine cycles is among the most well-known components of engine modelling that are useful, and these modelling studies save money and time. Although many studies have produced specific models for diesel engines to analysed performance of the engine and emissions of the exhaust, few have focused on biodiesel as a fuel in compression-ignition engines; therefore, needed more researches on modelling of biodiesel-fuelled diesel engines.

Gogoi and Baruah [15] created a theoretical model to analyse a cycle simulation and studied engine performance of an engine that runs on compression ignition utilize diesel, biodiesel, as well as its mixes in a closed system with a single zone at various compression rates, engine speed, and full load operating conditions. The rate of heat output or heat transfer was determined using a single function of the Wiebe and Woschni sub models. Predict the transfer of heat. At higher compression rates, the outcomes of the simulation indicated that there is an increase in effective power, maximum torque, and thermal efficiency of the brakes [17, 18, 20].

Aldhaidhawi *et al.,* [16] created a single-zone closed system model to analyse combustion processes and asses the pressure inside the cylinder, the rate of heat release, temperature of the cylinder, and emissions of the engine compression ignition single cylinder powered by palm oil methyl ester Biodiesel (7 and 10 percent by volume). Authors showed that if the engine works with different compression ratios, biodiesel could be a superior a substitute for diesel.

The aim of this work to propose precise model for predicting performance of the engine, features of combustion, and emissions of the exhaust for a four-cylinder compression ignition engine on rapeseed biodiesel B30 (30% rapeseed oil + 70% diesel volume) fully loaded engine and speeds of 1250, 1500, and 1750 rpm.

2. Methodology

2.1 Experimental Structure

A four-cylinder engine, naturally aspirated A four-stroke diesel engine with direct injection was developed along with several measuring devices to determine parameters, exhaust emissions combustion characteristics as shown in the Figure 1. The specifications of engine perfumed in the present study are as the follows: compression ratio equal to 18: 1, cylinder bore: 100 mm, cylinder stroke 110 mm, the rate of the maximum power at output is 50 kW. With 2500 rpm, and the maximum torque value is 230 Nm at 1500 rpm. An AVL QL21D pressure transducer - sensitivity of 2.5 pC/bar was utilized to measure pressure in cylinders. In the current study, the test bench was modified to accommodate the operation of a variety of fuels. The engine has been tested with pure diesel and biodiesel B30 fuel (the tested Biodiesel fuel was produced from rapeseed and bought it from the local market). Under three engine speeds (1250 rpm, 1500 rpm, and 1750 rpm) at fully loaded, the performance of the engine, combustion parameters, and the emissions of the exhaust were monitored and recorded. All test fuel properties were tested in the laboratories of Babil Oil Company, located in Babil city, Iraq. These fuel properties included density, viscosity, flash point; pour point and cloud point with the test method are listed in table 1.

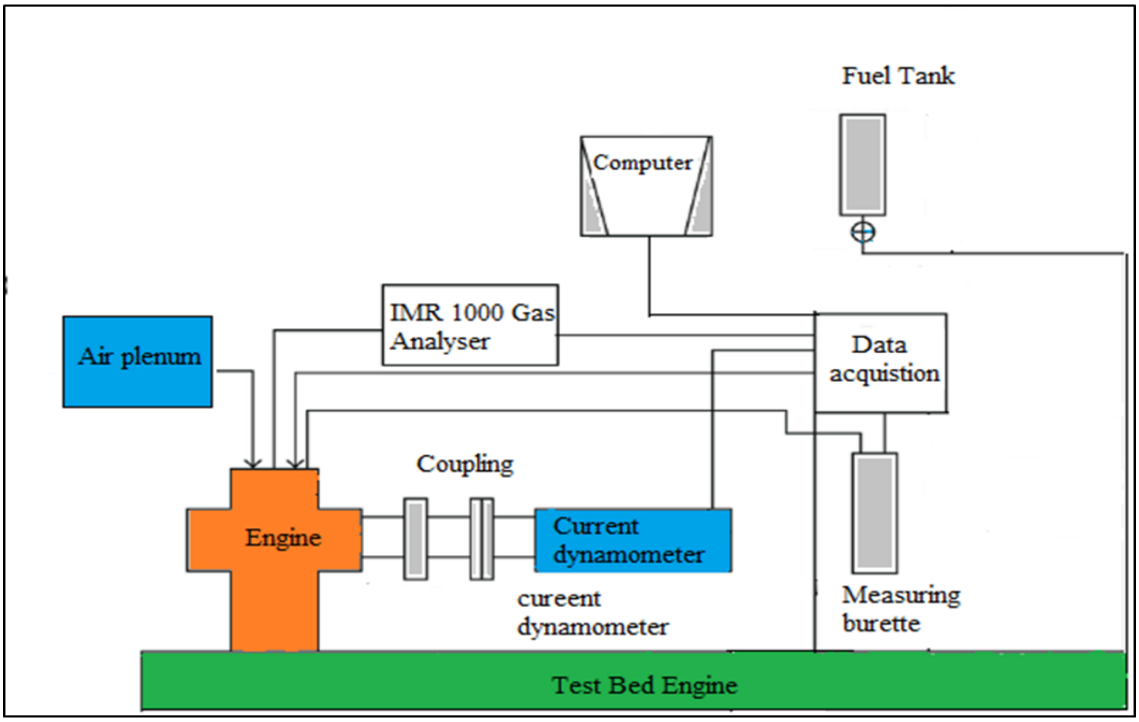


Fig. 1. On the test-bed, the engine is linked to an eddy current dynamometer

Table 1
The test fuel properties

Properties	Diesel	B30	Biodiesel	Test method
Density (g/cm^3) @ 20 °C	0.825	0.86	0.88	SR EN ASO 3675
Viscosity (cSt)@ 20 °C	2.50	5	8.1	SR EN ASO 3104
Flash point (°C)	57.5	83	187	SR 5489
Cetane Number	51.13	54	-	EN ISO 516598
Cold filter plugging point (°C)	-25	-17	-	SR EN 116 2016
Cloud point (°C)	-14	-11	-4	SR EN 23015
Pour point (°C)	0	-8	-17	SR 13552
Lower Heating Value (MJ/kg)	42	40	37	ASTM D 240

2.2 Simulation Procedures

In this study, the AVL BOOT 2016 software has performed to predict combustion engine characteristics, engine power, and emissions. AVL BOOST is a appropriate tool that simulates four- and two-stroke internal combustion engines that run on diesel or gasoline. The Woshni 1990 heat transfer model and the AVL-MCC combustion model were used for this model. The fuel properties of the Biodiesel B30 blend were calculated and are included in the program by t he authors, whereas this software provides the gas properties for popular fuels such as gasoline, diesel, methane, methanol, ethanol, hydrogen, and butane. The pipes connected all parts of the engine, as an example exhaust and intake collectors, system limits, geometry of the cylinder, size of the air filter, and catalyst, as shown in Figure 2.

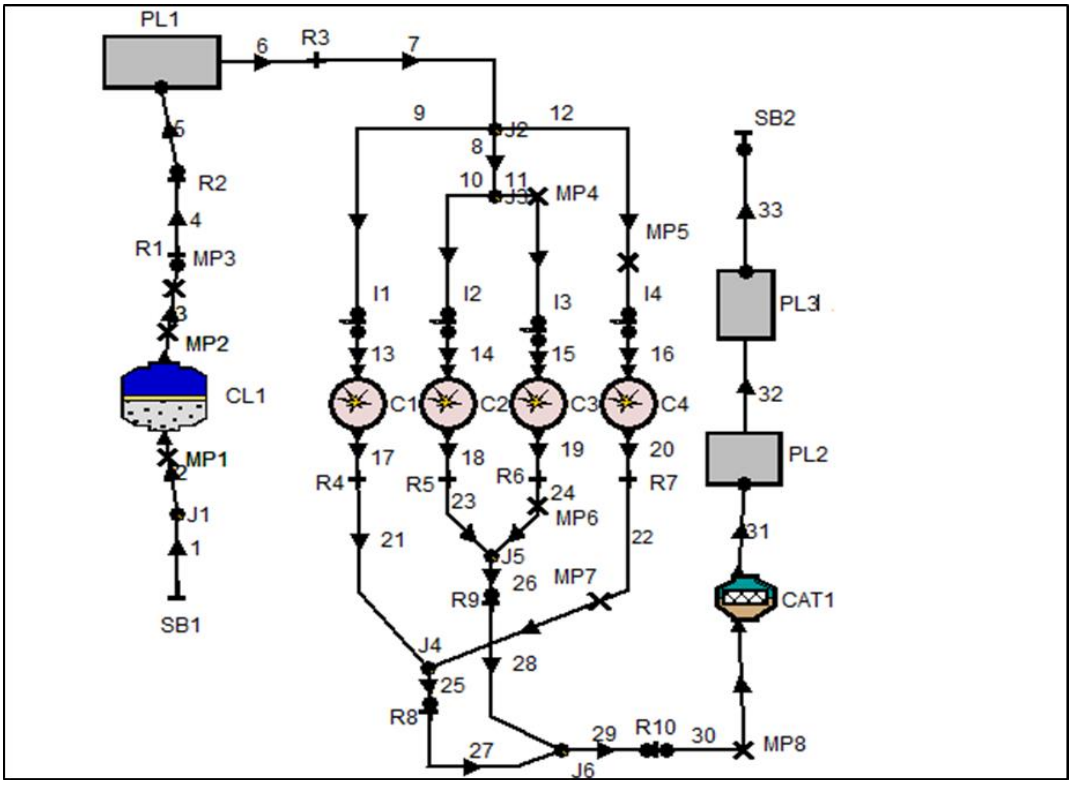


Fig. 2. The engine's symbolic model is depicted in this diagram (AVL BOOST Theory and AVL BOOST Users Guide)

2.3 Mathematical Model

The energy balance equation for the open system is [19]:

$$\frac{d(m_c.u)}{d\theta} = -p\frac{dv}{d\theta} + \frac{dQ_F}{d\theta} - \sum\frac{dQ_w}{d\theta} - h_{BB}.\frac{dm_{BB}}{d\theta} + \sum\frac{dm_i}{d\theta}h_i - \sum\frac{dme}{d\theta}.h - q_{ev}.f.\frac{dm_{ev}}{dt} \tag{1}$$

Where: the $\frac{d(m_c.u)}{d\theta}$: is the value of alteration internal energy in the cylinder, the $-p\frac{dv}{d\theta}$: is the value of piston work, $\frac{dQ_F}{d\theta}$: is the value of fuel input heat, $\sum\frac{dQ_w}{d\theta}$: is the value of wall losses,

$h_{BB}.\frac{dm_{BB}}{d\theta}$: is the value of the enthalpy flow , dm_e : is the value of the mass element flow out cylinder, dm_i : is the value of the mass element flow into cylinder, f : is the value of the fraction of evaporation heat and m_{ev} : is the value of the evaporation heat.

2.3.1 Instantaneous cylinder volume

To calculate the engine cylinder volume (instantaneous volume) at a particular crank angle, use the following equation [19]:

$$S = (r+l).\cos\psi - r.\cos(\psi+\alpha) - l.\sqrt{1-\left(\frac{r}{l}.\sin(\psi+\alpha)-\frac{e}{l}\right)^2} \quad (2)$$

$$\psi = \arcsin\left(\frac{e}{r+1}\right) \quad (3)$$

Where: S: is the value of the piston distance from TDC, and r: is the value of the crank radius, l: is the value of the con road length, Ψ: is the value of the crank angle (among the vertical crank position and the piston TDC), e: is the value of the piston pin offset and a: is the value of the crank angle relation to TDC.

2.3.2 Rate of heat release

Since the combustion process in a diesel engine is complicated [17], it is represented using the Mixed Control Combustion (MCC) model shown in the following equations [19]:

$$\frac{dQtotal}{d\theta} = C_{comb}.f_1(m_F, Q_{MCC}).f_2(k,V) \quad (4)$$

With

$$f_1(m_F, Q) = \left(m_F - \frac{Q_{MCC}}{LCV}\right).(w_{oxygen,available})^{C_{EGR}} \quad (5)$$

$$f_2(k,V) = C_{Rate}.\frac{\sqrt{k}}{\sqrt[3]{V}} \quad (6)$$

Where Q_{MCC} is cumulative heat release [kJ], C_{Comb} : it is the value of combustion constant [kJ/kg/deg CA]. C_{Rate}: the value of the mixing rate constant [s], K: the value of the local density of turbulent kinetic energy [m^2/s^2], mF: the value of the vaporized fuel mass (actual) [kg], LCV: lower heat value [kJ/kg], V: cylinder volume [m^3]. A: is crank angle [deg CA] , W:Oxygen available.

2.3.3 Ignition delay

The delay of the ignition is the amount of time that passes among the beginning of the injection of fuel and the beginning combustion. The Andree and Pachernegg equation [19] is used to calculate the ignition delay:

$$\frac{dI_{id}}{d\theta} = \frac{T_{UB} - T_{ref}}{Q_{ref}} \tag{7}$$

Where: dI: is the amount of the ignition delay, T ref: is the mount of the reference temperature = 505.0 [K], T_{UB}: is the amount of the unburned zone temperature [K], Q $_{ref:}$ is the amount of the reference activation energy.

2.3.4 Heat transfer

As indicated in equation [19], the Woschni equation was performed to calculate the coefficient of the heat transfer among gases produced in combustion chamber by chemical reactions as well as the wall of cylinder:

$$\alpha w = 130 D^{-0.2}.p_c^{0.8}.T_c^{-0.53}.\left\{c_1.c_m.\left[1 + 2\left(\frac{V_{TDC}}{V}\right)^2 IMP^{-0.2}\right]\right\}^{0.8} \tag{8}$$

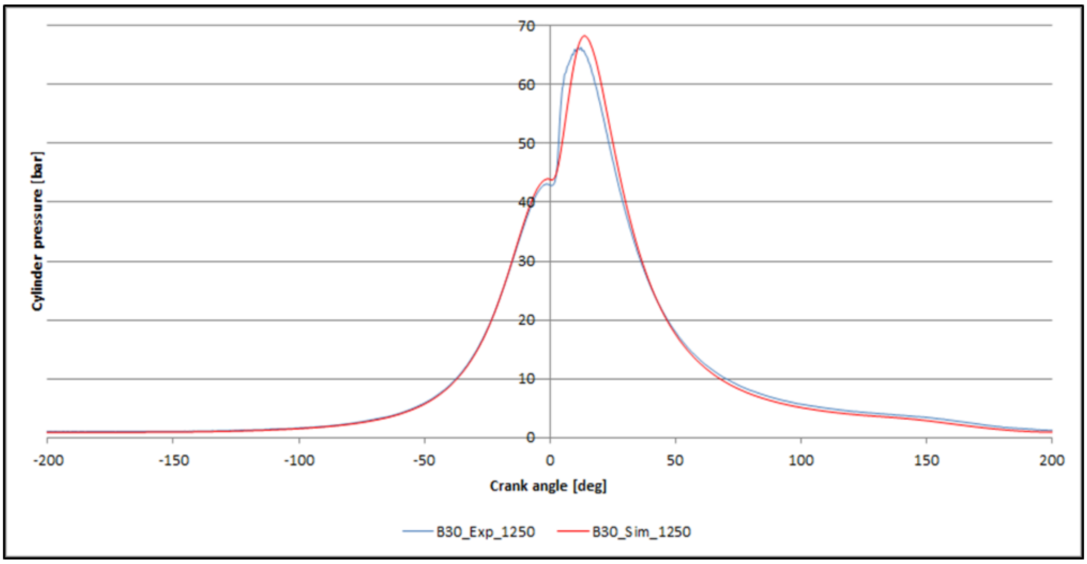
V $_{TDC}$: is the volume in the cylinder, V: is the actual cylinder volume, IMEP: is the indicated mean effective pressure, cm: is the mean piston speed, C_1= 2.28 + 0.308 *(c u / Cm), Cu: is the circumferential velocity.

3. Results and Discussions

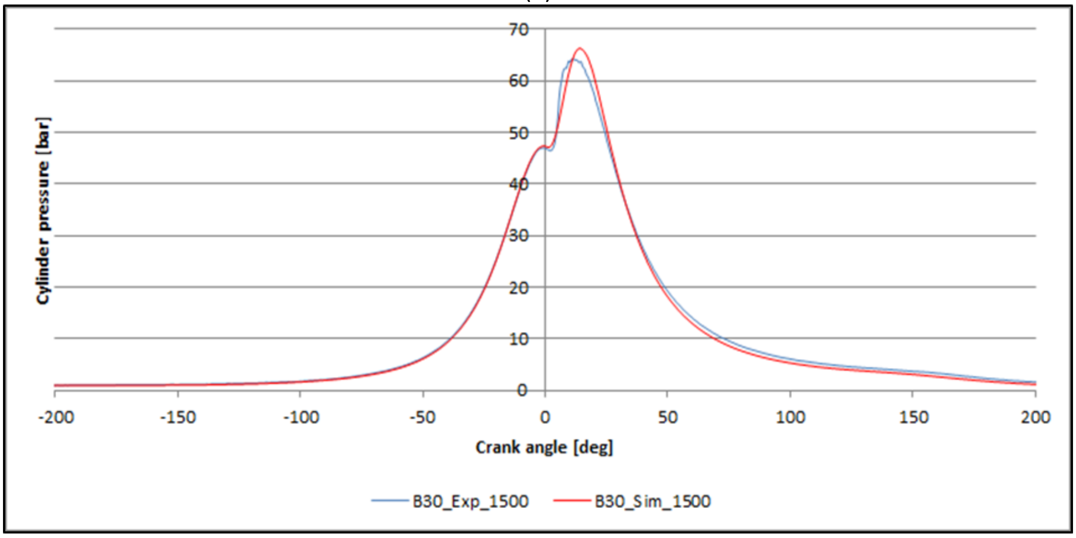
In order to evaluate the influence of biodiesel on the performance of the engine, characteristics of the combustion, and emissions of the exhaust, an AVL BOOT simulation model was constructed. All data was collected at various engine speeds (12500, 1500, and 1750 rpm), full load, and with both diesel and biodiesel B30 fuel

3.1 Trace of Cylinder Pressure

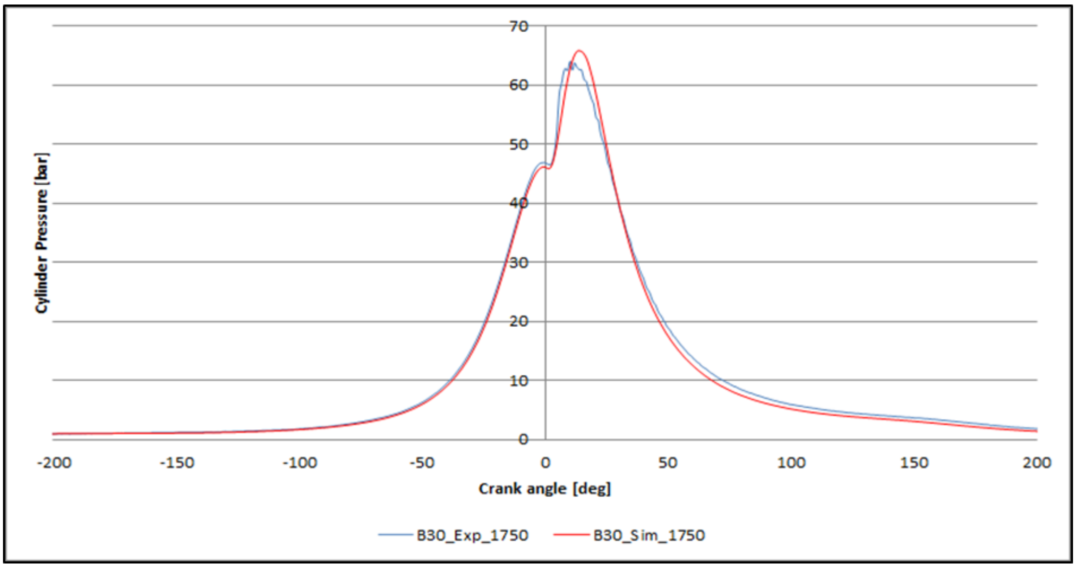
Figure 3 illustrates the experimental and Changes in cylinder pressure as a function of crank speed angle in the case of diesel and biodiesel B30 at engine speeds of 1250 rpm, 1500 rpm, and 1750 rpm under full load operation. The pressure traces of the cylinders, both experimental and simulation, agreed well under general operating conditions, as demonstrated in these figures.



(a)



(b)



(c)

Fig. 3. Pressure traces (experimental and simulation) under full load condition at engine speeds (a)1250 rpm, (b) 1500 rpm, (c) 1750 rpm

3.2 Brake Power

At full engine load, Figure 4 demonstrates the variance in effective power (experimental and simulation power) vs. engine speed for diesel and biodiesel B30 fuels. In comparison to diesel fuel, the Biodiesel B30 provided less effective power under normal operating circumstances. This behaviour is explained that Biodiesel has a lower calorific value than conventional diesel, a higher viscosity, and a lower volatility than diesel, so the B30 blend evaporates slower [15, 16].

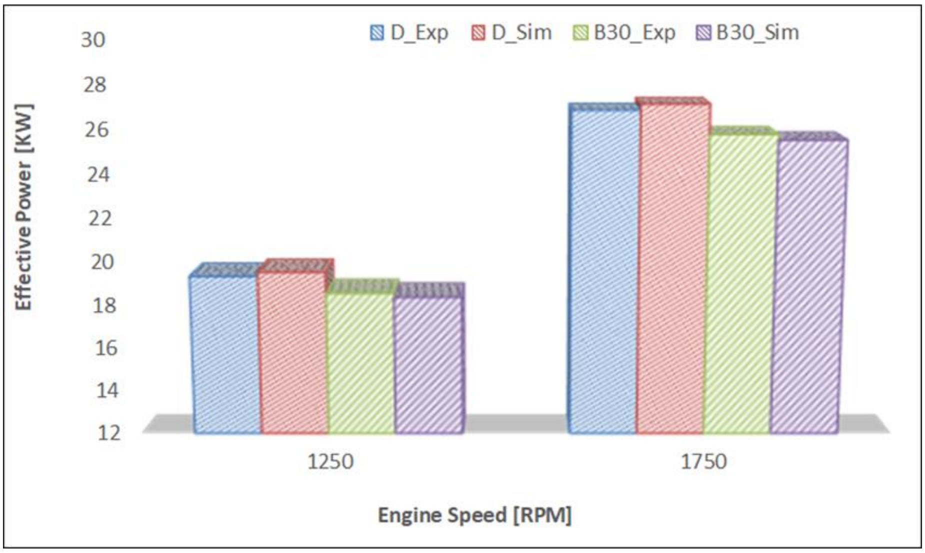


Fig. 4. Effective power vs. engine speed at full load condition

3.3 Brake Torque

Figure 5 shows the variation in effective torque (experimental and simulation) for a biodiesel fuels B30 and diesel as a function of engine speed under full load conditions. The maximum torque of biodiesel B30 was 128.4 Nm at 1250 rpm, which was 3% less than the maximum torque of pure diesel, which was 132 Nm at 1250 rpm

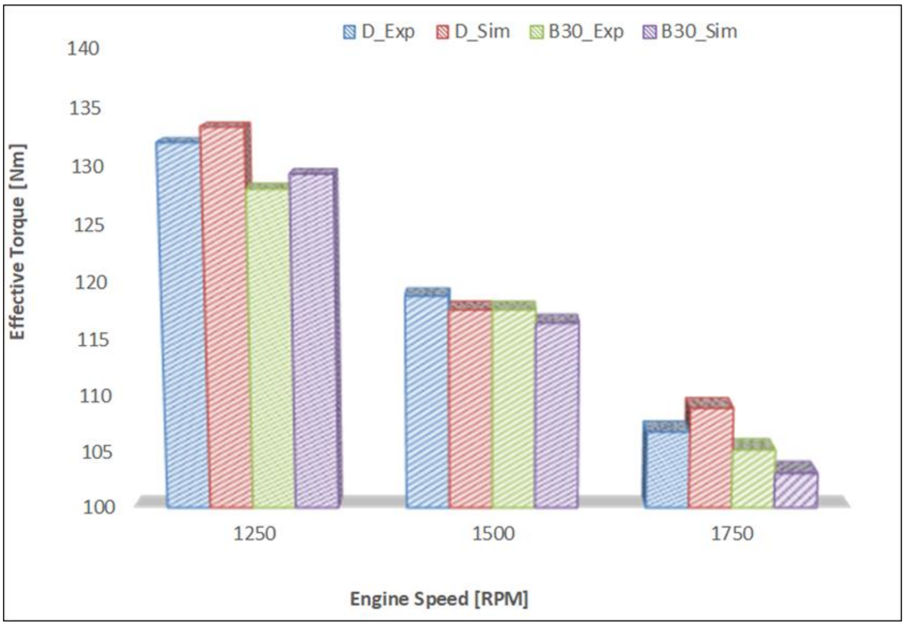


Fig. 5. Effective torque vs. engine speed at full load condition

3.4 Brake Specific Fuel Consumption

Figure 6 indicated the difference in the value of the brake specific fuel consumption (BSFC) experimental and simulation models as a function of engine speed under typical operating conditions. The BSFC is higher while using B30 at all engine speeds than when using diesel fuel. Biodiesel has a higher density and a lesser heating value than diesel fuel. Previous research [11, 14, 16] reported higher BSFC when Biodiesel and its mixes were utilized, and this conclusion is consistent with those findings.

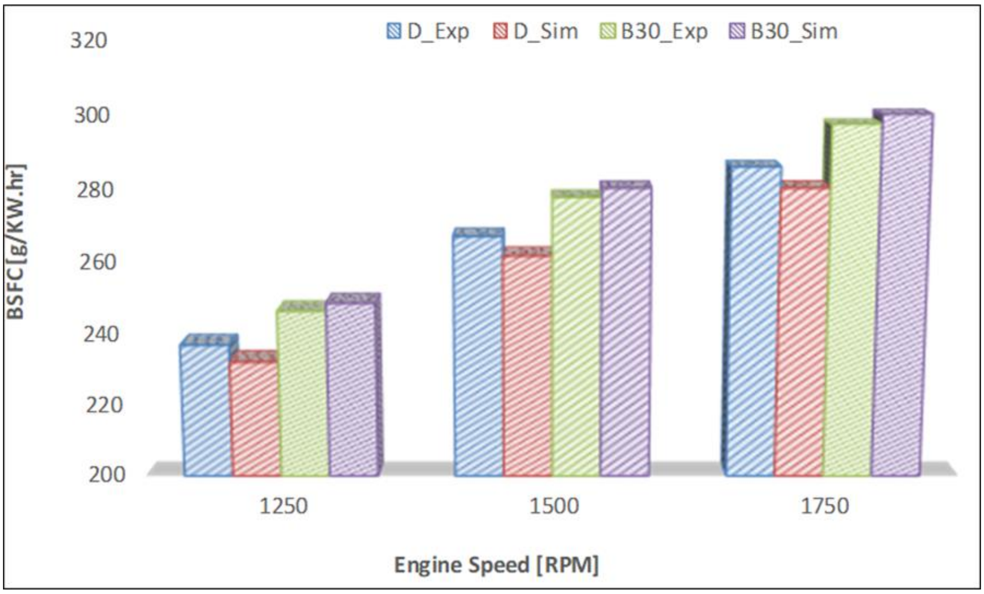


Fig. 6. Effective torque vs. engine speed at full load condition

3.5 Brake Thermal Efficiency

Conditions, with the engine fuelled by pure diesel and biodiesel B30, which was numerically, obtained using AVL BOOST simulation and experimentally presented in Fig 7. The results obtained from the experimental and simulation indicate that the brake thermal efficiency of diesel and biodiesel B30 fuel was higher at low engine speeds and lower at high engine speeds than for diesel fuel. The explanation of this behaviour may be due to higher volumetric efficiency at low engine speeds with the natural aspirated engine. Biodiesel B30 produced lower brake thermal efficiency than that of diesel fuel due to the fact that the biodiesel has lower calorific value than that of diesel which mean consume more fuel to produce same effective power. The finding is consistent with findings of past studies by Arifin *et al.,* [17].

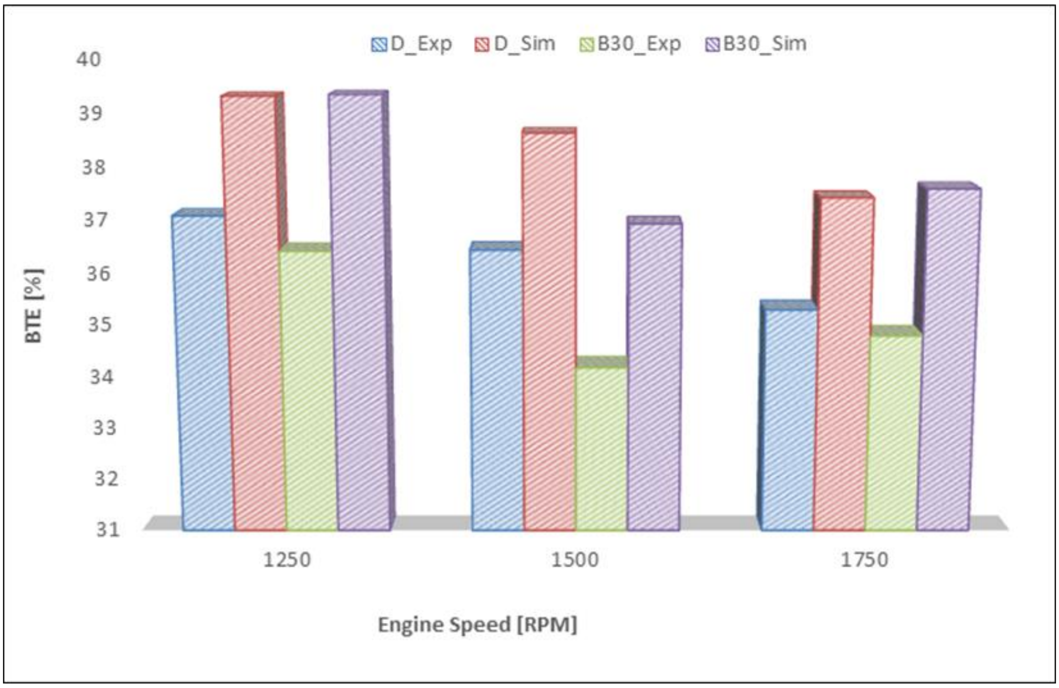


Fig. 7. Brake thermal efficiency vs. Engine speed at full load

3.6 Emissions of the No_x

NO_x emissions are influenced by cylinder temperature, oxygen availability (O_2) and dwell time. Figure 8 shows the variation in the full load NO_x values when fuelled by Diesel and B30. Biodiesel B30 produced more NO_x emissions than diesel under general operating conditions, probably due to reduced radiative heat transfer as a result of a lower level of soot and a higher level of oxygen from biodiesel, which may be connected with a greater post-call temperature, which could be the main explanation for increased NO_x emissions.

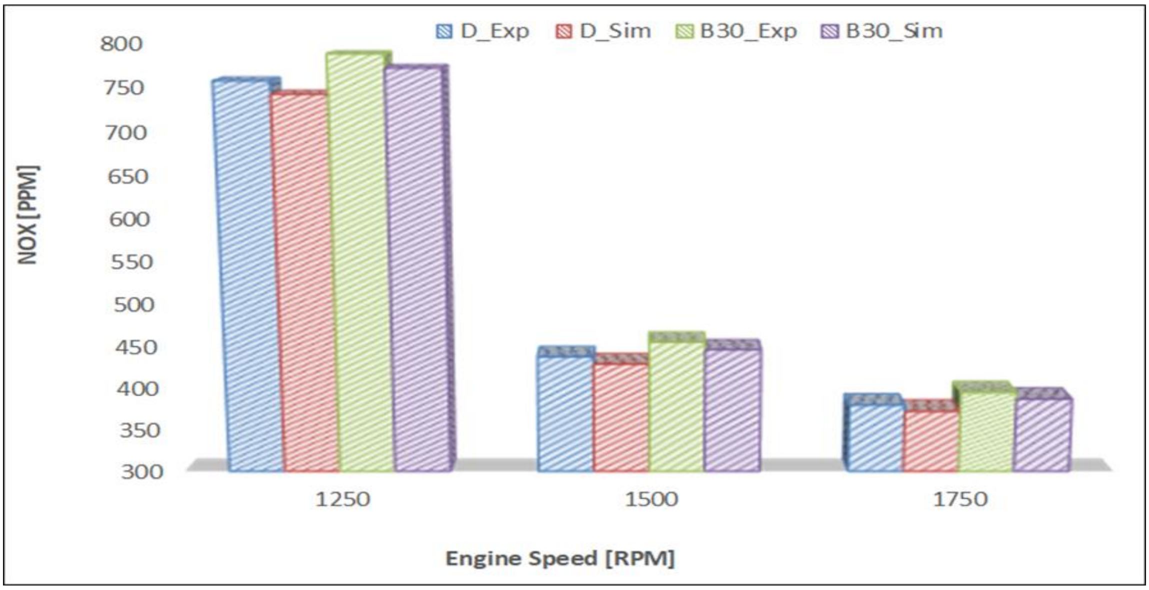


Fig. 8. Nitrogen Oxides (NO_x) vs. engine speed at full load

3.7 The CO Emissions

The influence of biodiesel B30 on carbon monoxide emissions were numerically assessed at various speeds 1250, 1500, and 1750 rpm and compared with the experimental data as shown in Figure 9. The figure clearly indicates that biodiesel B30 produces less carbon monoxide than diesel fuel under all operating circumstances. This is because biodiesel has more oxygen than diesel fuel, which has improved the combustion process, permitting complete combustion and reducing carbon monoxide emissions. Similarly, Mofijur *et al.,* [7] discovered that using Biodiesel and its mixtures reduced CO_2 emissions.

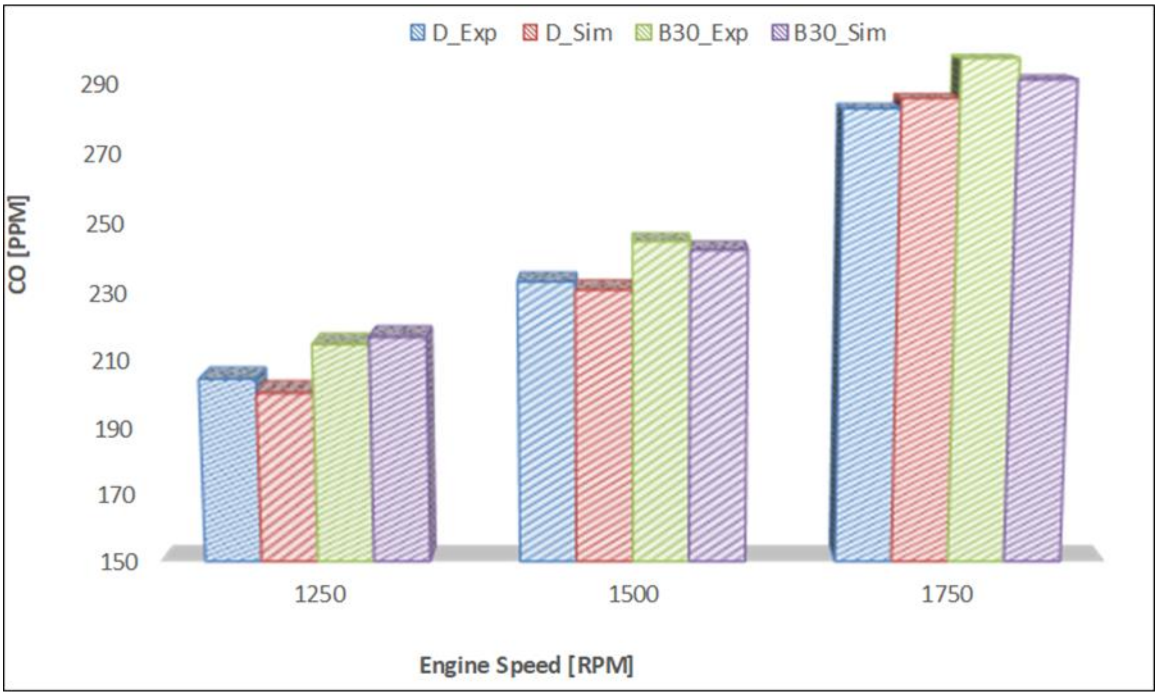


Fig.9. CO (carbon monoxide) vs. engine speed at fully loaded

4. Conclusions

A simulation model was developed with AVL Boost in order to determine the properties of combustion, performance of the engine, and emissions of the exhaust. By comparing the results of the simulation to the outcomes of the experiment, the simulation results showed good agreement with the experimental data. The data was collected using Diesel and Biodiesel B30 at three distinct engine speeds: 1250 rpm, 1500 rpm, and 1750 rpm under full load. The following are the most important findings:

i. The present model accurately predicted performance of engine and emissions of exhaust, and it was determined that the model could also predict cylinder pressure.
ii. Because of its lower heating value, B30 has a lower effective power and torque.
iii. Because biodiesel's has higher heating value and density than diesel, the BSFC for Biodiesel B30 was shown to be higher under overall operating circumstances when compared to diesel fuel.
iv. Using Biodiesel B30 fuel result, NOx emissions increased slightly.
v. When Biodiesel B 30 used, The CO emissions reduced.

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