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# An Experimental Investigation of a Diesel Engine Using Carbon Nanotubes Blended with Biodiesel

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**Abstract.** The implementation of nano-particles in various application tremendously rise due to its unique characteristics in enhancing the effectiveness of final products. The main purpose of this study is to investigate the effects of adding 50, 100 and 150 ppm carbon nanotubes in biodiesel blend (B10) on the performance, combustion characteristics and emissions of single cylinder diesel engine. The experiment was conducted on Yanmar Model TF120M diesel engine under constant engine speed of 1800 rpm and low, medium and full engine loads. The performances of the engine were analysed in terms of indicated power, fuel consumption, indicate specific fuel consumption and indicated mean effective pressure. While, in-cylinder pressure, in-cylinder temperature and combustion duration were analysed to investigate the combustion behaviour of fuel blends. From the study, addition of carbon nanotubes in biodiesel blends did improved the performances of engine, which reduce the indicated specific fuel consumption especially during low load condition. The peak in-cylinder pressure for CNTs fuel blends were higher than conventional diesel fuels (D100) in all load conditions. However, the in-cylinder pressure for B10C100 was slightly comparable with D100 during 14 Nm load condition.

## 1. Introduction

Biodiesel is considered as a clean renewable energy that come from vegetable oil and animal fats. Biodiesel had become the most promising alternative to diesel fuel due to its almost identical properties with conventional diesel fuel. Lot of research on biodiesel have been conducted for the purpose of exploring the potential of biodiesel to enhance the performance and reduce the exhaust emissions [1–3]. The advantage of biodiesel to be used in diesel engine is it can be used without any special engine modification [4]. However, high proportion of biodiesel still cannot challenge the performance of conventional diesel fuel in certain engine conditions. Therefore, various techniques have been implemented to enhance the performance and combustion characteristics of the engines. Fuel additives is one of the promising strategies that acts as catalyst in improving fuel quality, combustion and reduce pollutant emissions. Numerous additives have been introduced as catalyst to enhance the combustion



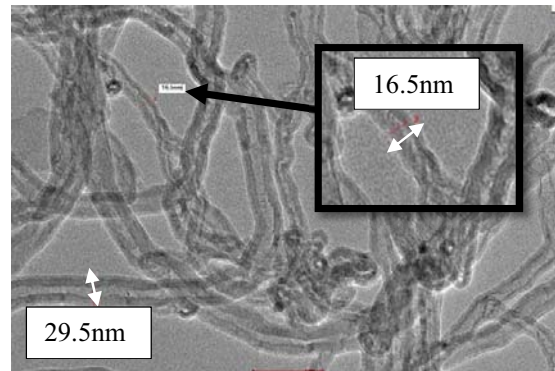
characteristics and reduce exhaust emissions such as alumina ( $\text{Al}_2\text{O}_3$ ), cupric oxide ( $\text{CuO}$ ), cerium oxide ( $\text{CeO}_2$ ), carbon nanotube (CNT) and many others [5–9]. Carbon nanotube (CNT) is one of the mineral additive which used in various engineering fields such as in composite materials as well as in biofuel application. The application of CNT in automotive could act as a potential nano-additive for the fuel to enhance the burning rate of the fuel, improve the cetane number which act as anti-knock and promote clean burning [10–13]. The investigation on CNT is widely explored by previous researchers as an effort of improving engine performance, combustion and reducing undesirable gases [8–17]. Hosseini et al. [16] conducted a study on the effect of adding 30,60 and 90 ppm of CNT in B5 and B10 biodiesel blends on the performance and emissions of diesel engine. The authors had found that the addition of CNT did enhance the engine performance and reduce the exhaust emissions. The large surface area of CNT did enhance the chemical reaction and reduce the ignition delay which improve the degree of fuel-air mixing and leads to better combustion are the main cause of lower CO emission. Studies conducted by El-Seesy et al., [17] indicated that the recommended amount of MWCNTs in B20 was 40 ppm which shown significant enhancement in engine performance and emissions. Ghafoori et al. [10], added 2.5, 5, 7.5, 10, 15, 20, 30 ppm of CNT in B20 biodiesel blends and tested on six cylinders, four strokes diesel engine under different engine speed condition. The authors had concluded that the addition of CNT in biodiesel blend did enhance the performance of diesel engine in terms of power, torque and brake specific fuel consumption (BSFC) up to 17%, 18% and 38.5%, respectively. Furthermore, the UHC and CO emission is decrease after the addition of CNT in biodiesel blends with percentage decrease of 22% and 18% lesser than pure biodiesel. Similar to Hosseini et al. [16], the authors also reported that the improvement of fuel properties and engine performance after addition of nano-additives are due to their enhanced surface area/volume ratio, quick evaporation and shorter ignition delay characteristics. According to the literature review, it is obvious that a limited scientific information on the effects of high MWCNTs content of 50, 100 and 150 ppm. The experiment was conducted on single cylinder CI engine under various engine loads and constant engine speed of 1800 rpm. On these runs of those working conditions, no engine modification is needed to use biodiesel-diesel with addition of MWCNTs.

## 2. Experimental apparatus and procedure

Pure diesel was obtained from local fuel station in Pahang, Malaysia. Biodiesel was obtained from Malaysia Palm Oil Berhad, located in Pahang. Carbon nanotubes (CNT) with 90-95% purity was delivered by local supplier. The blend fuels were prepared by mixing together diesel, biodiesel and CNT at different composition as shown in **Table 1** using ultrasonicator. **Figure 1** indicates the TEM images of CNTs added to the biodiesel-diesel blended fuels.

**Table 1.** Blend configurations and testing conditions.

No.	Blend	Diesel (Vol%)	Biodiesel (Vol%)	MWCNT (ppm)	Engine Speed (RPM)	Load (Nm)
1	D100	100	0	-	1800	7
2	B10C50	90	10	50		14
3	B10C100	90	10	100		21
4	B10C150	90	10	150		28



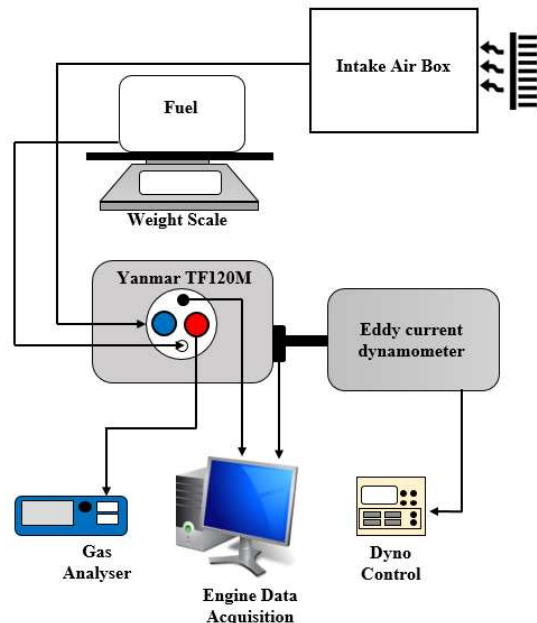
**Figure 1.** TEM images of CNTs in biodiesel-diesel blended fuels

### 2.1 Engine Setup

Experiment were conducted using single cylinder four stroke Yanmar Model TF120M Direct Injection Diesel Engine. **Table 2** shows the general specification of engine use in this test. The schematic layout of the engine setup is illustrated in **Figure 2**. The engine is coupled with eddy current dynamometer capable to deliver power of 15 kW (model Focus Applied Technologies BD-15KW). The in-cylinder pressure was measured using Oprand pressure sensor which linked with crank encoder. Dewesoft Data Acquisition was used to analyse the combustion characteristics of diesel engine. In this test, all thirteen fuel samples were tested under constant engine speed and throttle position. **Table 1** shows the test list and condition that involved in the test.

**Table 2.** Engine specifications.

Model	Yanmar Model TF120M
Type	Horizontal single-cylinder 4-stroke diesel engine
Bore (mm)	92
Stroke (mm)	96
Displace volume (cm <sup>3</sup> )	638
Compression ratio	17.7:1
Continuous rating output	10.5 HP @ 2400 rpm
Maximum rating output	12.0 HP @ 2400 rpm
Fuel injection type	Direct Injection
Injection timing	17° BTDC
Max power	7.7 kW @ 2400 rpm
Max torque	161 Nm @ 4500 rpm
Cooling system	Water-radiation
Fuel tank capacity	11L



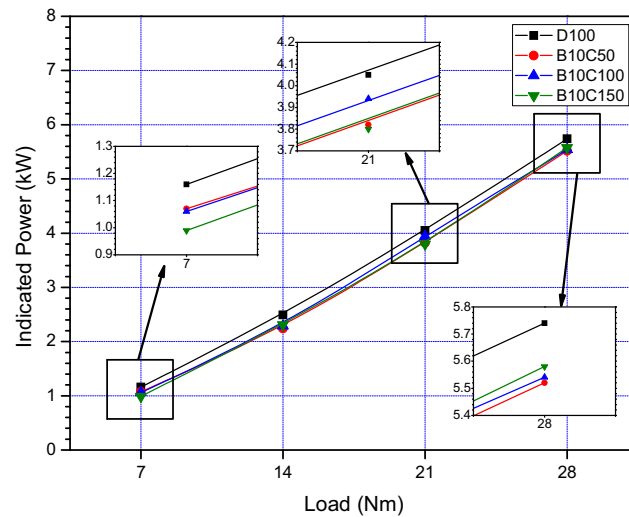
**Figure 2.** Schematic diagram of engine setup.

### 3. Result and Discussion

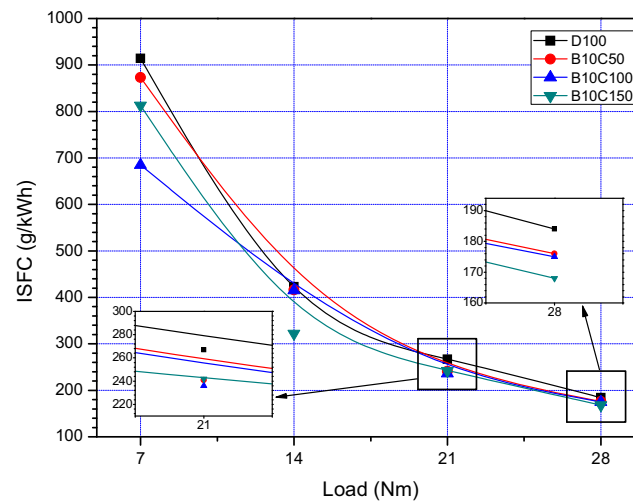
#### 3.1 Performances of CNT-Biodiesel blends

The indicated power of diesel engine with CNT-biodiesel blends under constant engine speed of 1800 rpm and varies engine load of 7, 14, 21, 28 Nm is shown in **Figure 3**. As observed in **Figure 3**, at all engine loads, the indicated power for B10C50, B10C100 and B10C150 were lesser than baseline diesel fuel (D100). The lower engine power for biodiesel blends than baseline diesel is attributed to lower heating value of biodiesel than pure diesel [16]. Rizwanul Fattah et al. [18] studied the performance and emission characteristics of a diesel engine using palm oil based biodiesel blends. They reported that, the brake power for B20 and B100 were 1.02% lower than B0 due to its lower energy content, lower calorific value and higher viscosity. In addition, study done by Buyukkaya [19] indicate that the addition of 5% biodiesel in diesel fuel did not affect the engine power. The engine power was seen to be affected for B20, B70 and B100. They also explained this power reduction with lower heating value of the biodiesel.

**Figure 4** shows the indicated specific fuel consumption (ISFC) for all fuel blends under different engine loads of 7, 14, 21 and 28 Nm. The ISFC for all blends were decreasing as the engine load increased that is closely related to the indicated power of the engine. From the figure, ISFC for all biodiesel-CNT blends were lower than baseline diesel. Under low load of 7 Nm, the addition of CNTs in biodiesel blends did affects the ISFC of the engine. However, the optimum content of CNTs for lowest ISFC was 100 ppm with value of 685 g/kWh that is 25% lower than D100. Furthermore, during high load of 28 Nm, less ISFC were recorded on B10C150 with 79% lower than D100. The presence of biodiesel and CNTs in the fuel blends helps in improving fuel economy which provide oxygen for combustion and accelerate the combustion. Studies done by Arul Mozhi Selvan et al. [6] indicates that at full load, the specific fuel consumption for diesel-biodiesel-ethanol with addition of 50 and 100 ppm of CNT + CERIA were comparable and lower than 25 ppm CNT + CERIA content. Similar to present study, the ISFC for 50 and 100 ppm CNTs blends were slightly comparable.



**Figure 3.** Indicated power under various engine loads

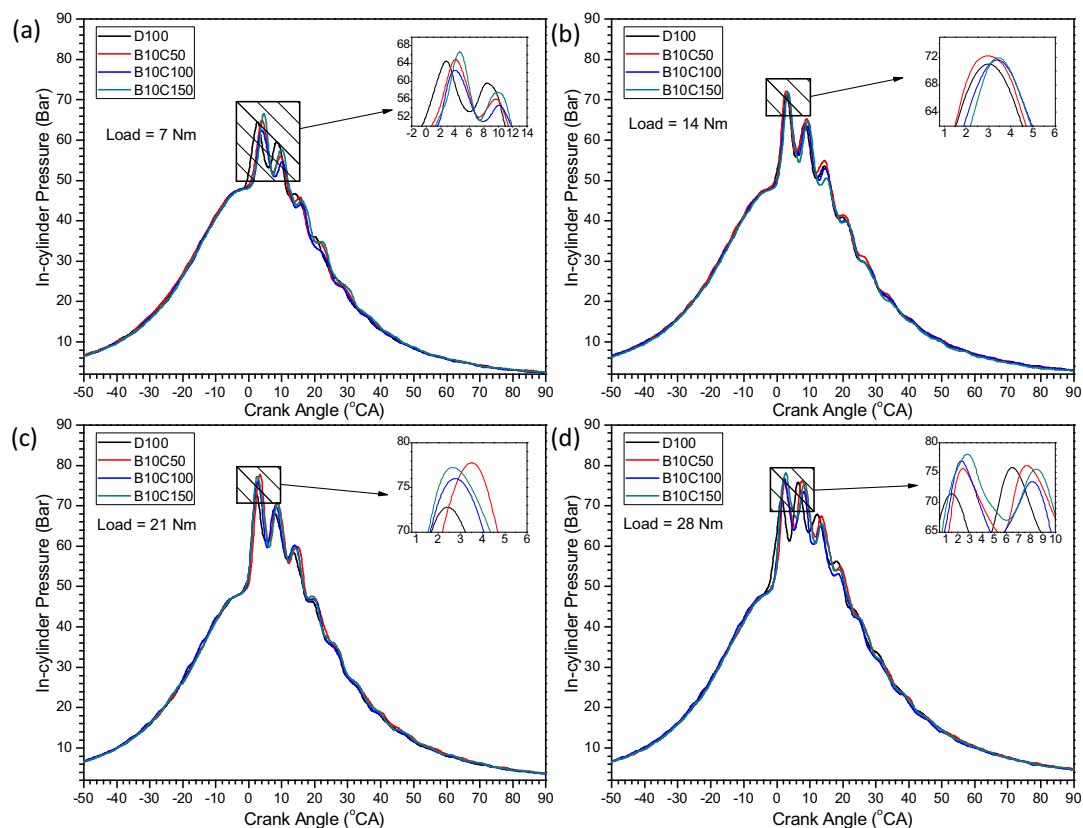


**Figure 4.** Indicated specific fuel consumption under various engine loads

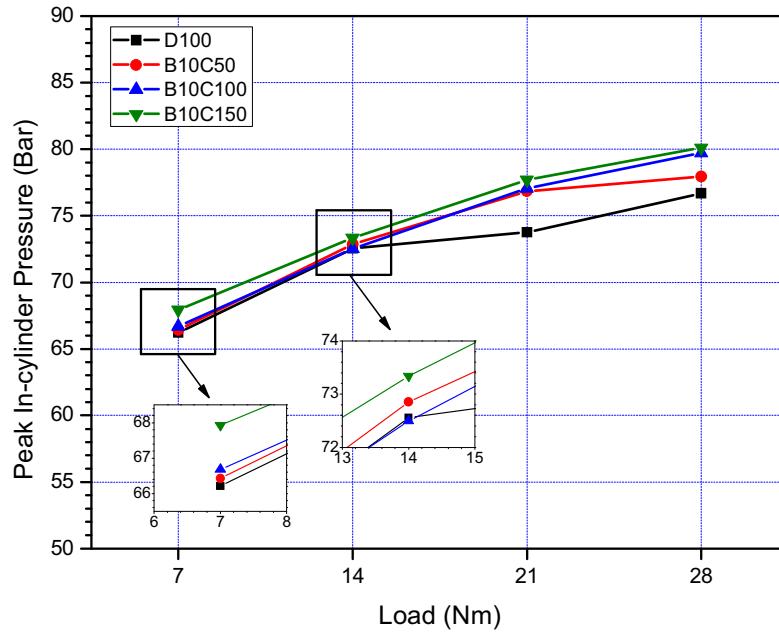
### 3.2 Combustion characteristics of CNT-Biodiesel blends

This research work covers the combustion characteristics based on in-cylinder pressure and the crank angle data. **Figure 5-7** show the combustion characteristic of diesel engine in terms of in-cylinder pressure, peak in-cylinder pressure and combustion duration, respectively. **Figure 5a, 5b, 5c** and **5d** show the in-cylinder pressure curve at maximum pressure cycle from 300 consecutive cycles for D100, B10C50, B10C100 and B10C150 at different engine loads of 7, 14, 21, 28 Nm, respectively. **Figure 5a** shows the effect of different CNT content on the in-cylinder pressure of all fuel blends at low engine load of 7 Nm. As observed in **Figure 5a**, B10C50, B10C100 and B10C150 shows similar pressure rise behaviour that is slight increase in pressure after reaching maximum pressure in crank angle range of 3 °CA to 5 °CA. The D100 reaches maximum pressure earlier than others that occur between 2 °CA to 3

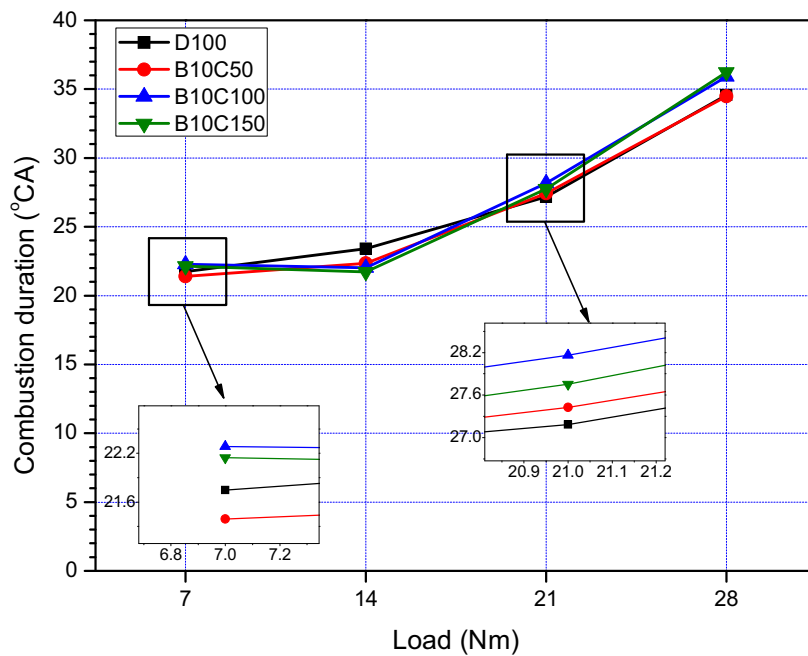
$^{\circ}\text{CA}$ . Therefore, the addition of 10% biodiesel and CNT did affect the behaviour of pressure rise of D100. **Figure 5b** shows the effect of CNT addition in B10 blends under 14 Nm engine load. The pressure rise behaviour for sample B10C50 and D100 was identical. It can be seen in **Figure 5b** that the peak in-cylinder pressure for D100 and B10C50 occurs at crank angle of  $2.5^{\circ}\text{CA}$  to  $3.5^{\circ}\text{CA}$ . While maximum pressure for B10C100 and B10C150 occur at crank angle of  $3^{\circ}\text{CA}$  to  $4^{\circ}\text{CA}$ . The peak pressure for B10C50, B10C100 and B10C150 was higher than D100 due to the shorter ignition delay resulting in higher peak in-cylinder pressure (**Figure 6**). The effect of different CNTs content on B10 blended fuels under 21 Nm engine load shows that pressure rise behaviour for D100, B10C100 and B10C150 was comparable. Sample D100, B10C100 and B10C150 reach peak in-cylinder pressure at crank angle range of  $2^{\circ}\text{CA}$  to  $3^{\circ}\text{CA}$ . While sample B10C50 reach peak in-cylinder pressure at  $3^{\circ}\text{CA}$  to  $4^{\circ}\text{CA}$ . Therefore, the ignition delay for sample B30C50 was longer than other samples. **Figure 6** indicates the peak in-cylinder pressure for all blended fuels. It can be seen from **Figure 6** that the addition of CNT in B10 did increase the in-cylinder pressure compared to non-CNT diesel fuel (D100). During low engine load (7 Nm), B10C150 blend shows the highest In-cylinder pressure at 3% higher than D100. However, under 14 Nm engine load, the in-cylinder pressure for B10C100 was slightly comparable with D100 and lower than other blends. The in-cylinder pressure for D100 under engine load of 21 Nm was 4.2% lesser than B10C50. Najafi [20], studied the effect of 40, 80 and 120 ppm of CNTs in biodiesel on the combustion characteristics, performance and emissions of diesel engine. The author had found that the addition of CNT in biodiesel did increase the peak in-cylinder pressure. In addition, increasing amount of CNTs content did increase the peak in-cylinder pressure of biodiesel when compared to pure diesel and pure biodiesel.



**Figure 5.** In-cylinder pressure behaviour under various engine loads



**Figure 6.** Peak In-cylinder pressure behaviour under various engine loads



**Figure 7.** Combustion duration under various engine loads



#### 4. Conclusion

The performances and combustion characteristics of single cylinder diesel engine using biodiesel-diesel blended with various CNTs content under constant engine speed and varies engine loads were investigated. Based on the experimental investigation, the following conclusions are drawn:

- 1) Increasing amount of CNTs in B10 fuel blends did improved the ISFC of engine. Especially during low engine load condition and the optimum content of CNTs for lowest ISFC was 100 ppm with value of 685 g/kWh that is 25% lower than D100. The presence of biodiesel and CNTs in the fuel blends helps in improving fuel economy which provide oxygen for combustion and accelerate the combustion.
- 2) During low engine load (7 Nm), B10C150 blend shows the highest In-cylinder pressure at 3% higher than D100. However, under 14 Nm engine load, the in-cylinder pressure for B10C100 was slightly comparable with D100 and lower than other blends. The in-cylinder pressure for D100 under engine load of 21 Nm was 4.2% lesser than B10C50.

From the result, it was clearly proved that the addition of CNTs in biodiesel-diesel blends did improved the engine performances and combustion characteristics. The engine run smoothly without any modification along the experiment.

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