Experimental Analysis of the Injection Timing Effect on a Diesel Engine Performance Using Environmental Friendly Diesel-Biodiesel Blends

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ABSTRACT: Considering the differences between diesel and biodiesel fuels, engine condition should be modified based on the fuel or fuel blends to achieve optimum performance. In this study, the effect of fuel injection timing on performance of a diesel engine was investigated experimentally using environmental friendly diesel-biodiesel blends. Different experiments were carried out on the test diesel engine at engine speeds of 1200, 1600, 2000 and 2400 rpm. The injection timing was regulated for 10, 15 and 20 degree crank angle BTDC. The experimental results related to engine torque, BSFC, cylinder pressure and exhaust gas temperature for fuel blends of B20, B40, and B100 at different engine speeds and injection timings were recorded and analyzed. The results showed that advancing the fuel injection timing for fuel blends of B20, B40, and B100 increased engine torque approximately 2.1%, 2.9% and 6.3% respectively and decreased maximum brake specific fuel consumption approximately 2.7%, 3.3% and 6.6% respectively.

Keywords: Torque, BSFC, Cylinder Pressure, Injection Timing.

INTRODUCTION

Diesel engines currently find applications in most heavy load mobile and in many stationary power-generation units, because they can achieve greater efficiencies and higher indicated mean effective pressures due to the higher compression ratios where they operate [Narayana and Ramesh, 2006]. Current and future legislations on emissions require engine developers to produce cleaner and more efficient power plant systems. Today due to increase in environmental pollution and decrease in fossil fuels many countries make decision to restrict using of fossil fuels and instead use renewable fuels. Renewable fuels are generally emission produced from biological sources. Carbon dioxide that produces from biofuel engines and vehicles are could be absorbed by biological sources for their growth. So, these fuels have a closed cycle of Carbon dioxide. Biodiesel is a renewable fuel that is used in diesel engines purely or blended with common diesel [Aksoy, 2011; Kegl, 2011; Golovitchev and Yang, 2009; Yuan and Hansen 2009; Sapuan *et al.*, 1996]. There are some differences in properties of diesel and biodiesel fuels that can decrease the engine performance and increase the emissions. For example, high viscosity and surface tension of biodiesel affects the atomization by increasing the mean droplet size which in turn increases the spray tip penetration [Abdul and Van Gerpen, 2001; Çelikten, 2003; Demirbas, 2006; Forson *et al.,* 2004; Raheman and Phadatare, 2004; Ejim *et al.,* 2007; Kegl, 2006; Murillo *et al*., 2007; Ramadhas, 2005; Sapuan *et al.*, 1996]. Therefore, considering the differences between diesel and biodiesel fuels, the optimum parameter of diesel engines may not seem suitable for biodiesel. So, engine conditions should be modified based on the fuel or fuel blends to achieve optimum performance.

In some researches the effect of injection timing on engine performance for biodiesel has been investigated.

Carraretto *et al*. [2004] observed that power and torque were increased up to almost pure diesel levels by reducing injection advance. Banapurmath *et al.* [2009] compared the effect of three injections timings (19, 23 and 27 ◦CA) and the different injection pressure on the torque (BTE) for HOME (Honge oil methyl ester). They found that there was an improvement in the BTE for biodiesel by retarding injection timing, and that the highest BTE occurred at 260 bar. Tsolakisa *et al.* [2007] retarded injection timing by 3 °CA on a DI diesel engine equipped with pump–line–nozzle type fuel injection system, and they observed that the BSFC was increased for both B50 and pure RME (rapeseed methyl ester), although the increase was not significant. Nwafor, *et al.* [2000] have carried out an investigation to study the effect of advanced injection timing on the performance of rapeseed oil in diesel engines. According to the test results, mechanical efficiency was observed to be reduced with advanced injection timing compared to the standard injection timing at 2400 rpm. The engine was running smoothly with advanced timing as compared to the standard timing.

Bari*, et.al* (2004] examined the changes in the behavior of waste cooking oil (WCO) with changes in injection timing of a direct injection (DI) diesel engine, compared with those of diesel fuels. The results revealed that WCO and diesel responded identically to injection timing changes. With injection timing advanced by 4 °CA, the engine produced better efficiency by 1.6 percent for WCO and by 1.1 percent for diesel. For all instances, WCO had shorter ignition delays than diesel, but the ignition delay for WCO was more sensitive to load and injection timing than that for diesel.

In an investigation, the influence of effect of engine operating parameters and fuel injection timing on performance and emission characteristics of Jatropha biodiesel has been investigated experimentally. Advancing the injection timing (5 crank angle degree from factory settings (345 CAD)) caused reduction in BSFC, CO, HC and smoke and increase in BTE, peak cylinder pressure, HRRmax and NO emission with Jatropha biodiesel operation. However, 5 crank angle degree retard in injection timing caused increase in BSFC, CO, HC and smoke and reduction in BTE, peak pressure, HRRmax and NO. The best injection timing for Jatropha biodiesel operation with minimum BSFC, CO, HC and smoke and with maximum BTE, peak pressure, HRRmax is found to be 340 CAD [Ganapathy *et al.*, 2011].

The effect of varying injection timing was evaluated in terms of thermal efficiency, specific fuel consumption, power and mean effective pressure, exhaust temperature, cylinder pressure, rate of pressure rise and the heat release rate. It was found that by retarding the injection, the fuel delivery was also reduced resulting in slightly lower pressure rise with peak shifting towards outward stroke reducing the negative work. Also retarding the injection timing by 3 degrees enhances the thermal efficiency by about 8 percent [Jindal, 2011].

In a research work conducted on a CIDI engine using biodiesel blend as fuel, it is clearly seen that BSEC increased by 3.11% on advancing the injection timing to 30°CA BTDC while reduced by 5% on retarding to 18°CA BTDC from the original injection timing of 24° CA BTDC. It was found that there was 5.07% increase in brake thermal efficiency when injection timing was advanced to 30°CA BTDC but about 3.08% decrease while retarded to 18°CA BTDC [Pandian *et al.,* 2009].

A computational fluid dynamic investigation was carried out by Jayashankara and Ganesan to study the effect of fuel injection timing and intake pressure on the performance of a DI diesel engine with toroidal combustion chamber configuration operating at 1000 rpm speed. They showed that an advanced injection timing resulted in an increase in-cylinder pressure, temperature, heat release rate, cumulative heat release and NOx emissions and retarded injection timing resulted in reverse trend [Jayashankara and Ganesan, 2010].

The influence of injection timing on the performance and emission characteristics for various Karanja biodiesel-diesel blends has been investigated by conducting experiments on a single cylinder diesel engine. The best injection timing for neat Karanja biodiesel based on efficiency and emission levels was 22bTDC for the present engine. [Maheshwari *et al.,* 2011].

Sayin and Canakci [2010] have carried out an experimental investigation on a single cylinder diesel engine to study the influence of injection timing on the engine performance and exhaust emissions using ethanol blended diesel fuel. The original ignition timing gave the best results of BSFC and BTE by about 34% and 32% average value, respectively, compared to the other injection timings.

Shivakumar *et al.* [2011] have investigated the influence of injection timing on the performance and emissions of a diesel engine was studied using biodiesel blended with diesel. The experimental results showed that brake thermal efficiency for the advanced as well as the retarded injection timing was lesser than that for the normal injection timing for all sets of compression ratios. For example when the injection was advanced there was reduction in the thermal efficiency by 1% at full load for B20. On the other hand for retarded injection timings the thermal efficiency at full load for B20 reduced by 2.25%.

In the present research work, the effect of the injection timing on performance of a DI diesel engine using diesel-biodiesel fuel blends is investigated experimentally.

MATERIALS AND METHODS

Set up An overall view of the engine test-rig used in this investigation is shown in Fig. 1. The engine tests were conducted on a four-stroke compression ignition engine. The specification of the engine is given in Table 1. The test engine was coupled to a Schenck W400 electric eddy current dynamometer. In cylinder pressure was measured with a Kistler pressure transducer type 6053BB120. Engine was run at several speeds at full load. Before starting the engine, the injection timing was adjusted at 15 BTDC which is the factory instruction. For adjustment, the gear wheel of the pump was turned against the pump shaft. After that, adjusted gear wheel has been fitted to the engine pump. Engine was tested in speed ranges of 1200–2400 rpm with the interval of 400 rpm. During the experiments, brake torque, in cylinder pressure, exhaust gas temperature and brake specific fuel consumption (BSFC), were recorded by a PC computer. Similarly, these measurements were repeated for different blends of diesel and biodiesel fuels.

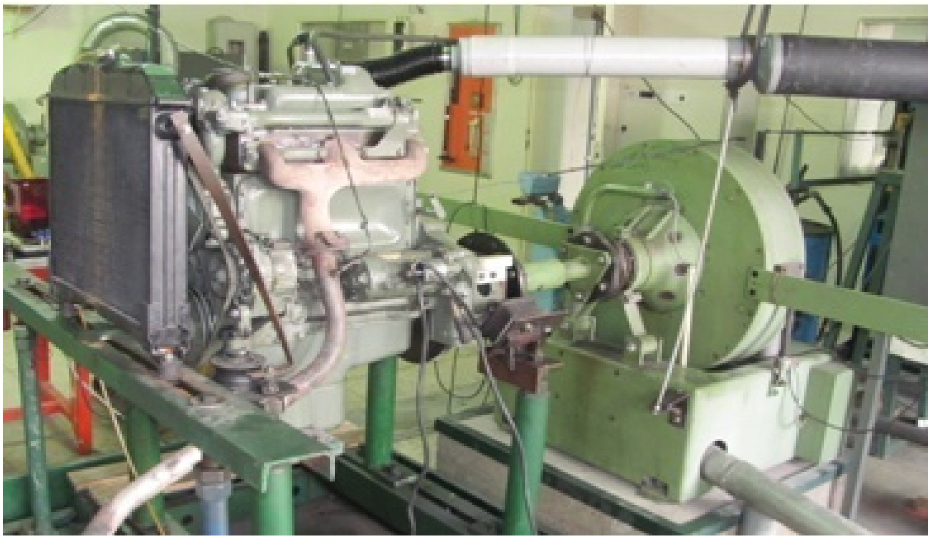

Figure 1. The diesel engine experimental set up

Table 1: Specifications of OM314 diesel engine

No. of cylinders	4
Bore	97mm
Stroke	128mm
Swept volume	3780 cm3
Compression ratio	17:1
Max .power (with gas oil)	85 hp (63 kW)
Max. Torque (with gas oil)	235 Nm
Max. speed	2800 rpm
Injection pressure	200 bar
Fuel Injection Timing	15 BTDC

Biodiesel Fuel The environmental friendly biodiesel fuel produced from waste vegetable cooking oil and its blends with diesel were considered in this study. Some of the important fuel properties of waste vegetable cooking oil biodiesel (B100) and diesel fuel were determined based on the ASTM standards and procedures which are summarized in Table 2. The waste vegetable oil biodiesel was added to diesel fuel in 20 and 40 percent ratios and then it was used as fuel for the diesel engine under test.

Table 2: Important properties of diesel and biodiesel fuels

Property	Method	Units	Diesel	Biodiesel
Flash point, closed cup	D 93	°C	64	182
Pour point	D 97	°C	0	3
Kinematical viscosity, 40 °C	D445	mm^2 /s	4.03	4.15
Sulfated ash	D 874	wt.%		0.00
Total Sulfur	D 5453	wt.%	0.0500	0.0018
Copper strip corrosion	D 130		1a	1a
Cloud point	D 2500	°C	2	0

RESULTS AND DISCUSSION

Effect of fuel injection timing on engine torque To determine the effect of engine fuel injection timing on engine torque for fuel blends of B20, B40 and B100, the engine torque at different engine speeds and fuel injection timings for each fuel blend was measured separately. The results of these experiments are shown in Fig. 2. In this figure, the horizontal axis represents engine speed, vertical axis shows the engine torque and each curve shows the engine torque versus engine speed at certain fuel injection timing. The maximum torque at injection timing of 15 BTDC for fuel B20 was 192.5 Nm and it occurred at 2000 rpm. By advancing the injection timing to 20 BTDC, the maximum value of torque was increased to 196.5 Nm. Maximum torque at 10 BTDC was reduced to 187 Nm. Maximum torque in the case of B40 at 15 BTDC that is the standard injection timing of engine was 192 Nm and occurred at 1600 rpm. With earlier injection timing, the maximum torque was 197.5 Nm and this torque was measured at 1600 rpm. At retarded injection timing the maximum torque was increased to 186 Nm. For pure biodiesel at standard injection timing, the maximum torque was 183.5 Nm and occurred at 1600 rpm. For advanced injection timing, the maximum torque was increased to 197 Nm. With retarding the injection timing, the maximum torque was decreased to 177 Nm. As can be seen in Fig. 2, the variations of engine torque different injection timings have the same trend for all fuels. Generally advancing the injection timing of fuel causes an increase in the average torque and retarding the injection timing of fuel causes the average torque of engine to reduce. With advancing the injection timing, the peak Pressure takes place closer to TDC and therefore produces a higher mean effective pressure to do work and the value of the engine torque increases. On the other hand, later injection causes later combustion, and therefore the pressure rises only when the cylinder volume is expanding rapidly, and the result is a reduced mean effective pressure to do work and the value of the engine torque decreases.

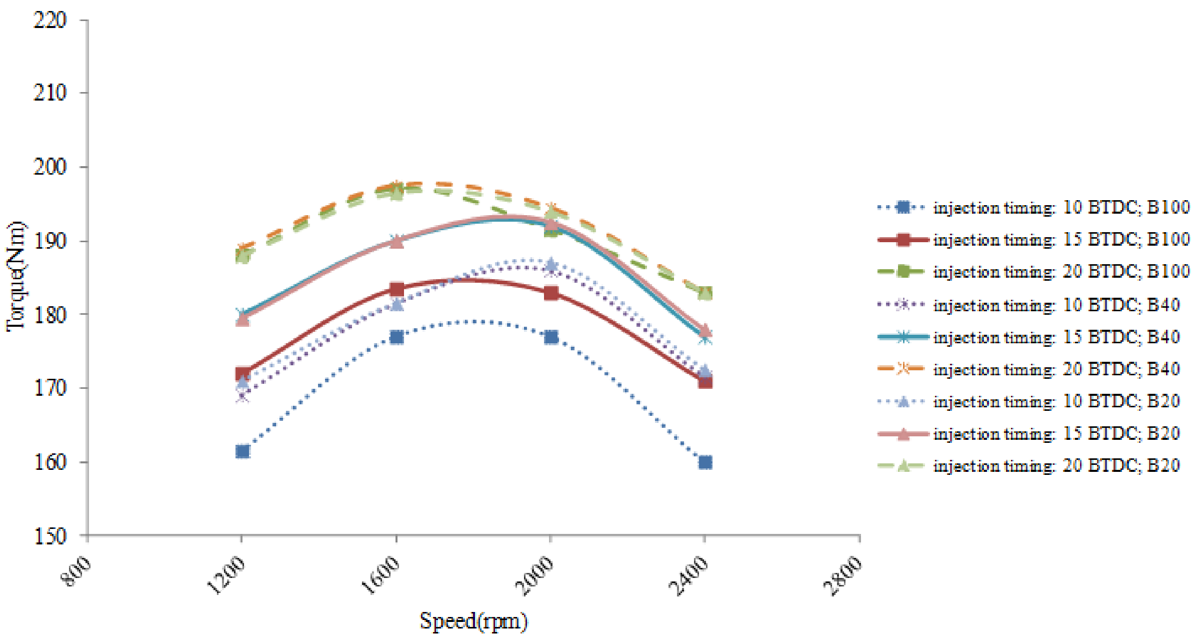

Figure 2. The engine torque versus engine speed

Effect of Fuel Injection Timing on BSFC Brake specific fuel consumption (BSFC) indicates the fuel level required to produce one kW power for one hour when the engine is operating. To determine the effect of fuel injection timing on BSFC, for fuel blends of B20, B40 and B100, the brake specific fuel consumption of engine at various engine speeds and different fuel injection timing for each fuel was measured separately. The results of these experiments are shown in Fig. 3. In this figure, the horizontal axis represents engine speed, the vertical axis shows specific fuel consumption and each graph shows BSFC versus engine speed for certain fuel injection timing. In the case of B20 at the standard injection timing, maximum brake specific fuel consumption was 290 gr/kW.h. By advancing the fuel injection timing into the combustion chamber, this value was reduced to 282 gr/kW.h (2.7% reduction). In the case of B40 at the standard injection timing, maximum brake specific fuel consumption was 297 gr/kW.h. By advancing the injection timing to 20 BTDC it was decreased about 3.3% which is equaled to 287 gr/kW.h. During the application of B100 at 15 BTDC injection timing, maximum brake specific fuel consumption of engine was 330 gr/kW.h. By advancing the fuel injection timing about 5 degree crank angle, BSFC reduced approximately 6.6% and was equal to 309 gr/kW.h. For biodiesel and its blends with diesel fuel, by retarding the fuel injection timing, comparing to the standard injection timing, the brake specific fuel consumption was increased. Advancing the fuel injection timing reduced the specific fuel consumption. This is due to the fact that the soybean oil based waste cooking oil used in this study exhibits shorter ignition delay compared with diesel fuel. So, for biodiesel and its blends with diesel fuel, with retarding the fuel injection timing, as compared with the standard injection timing, the brake specific fuel consumption increased. Nwafer et al. [2000] has carried out a similar research with rapeseed oil that has a longer ignition delay than diesel. Their research showed that with advanced fuel injection timing, BSFC was increased.

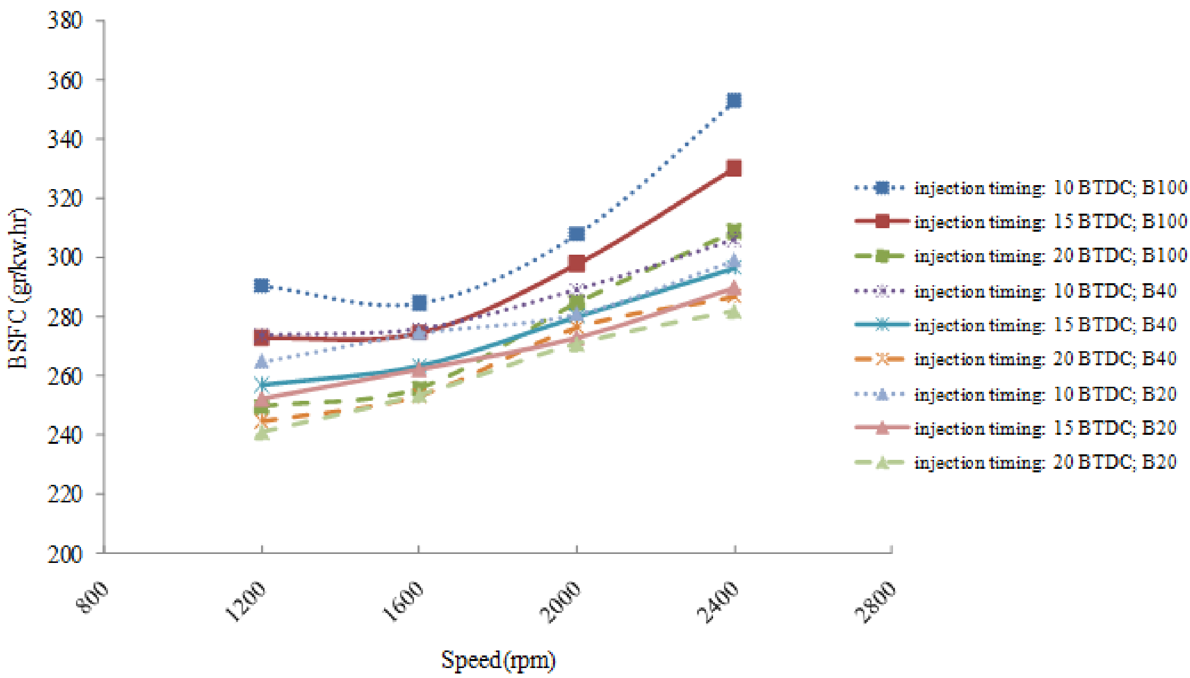

Figure 3. The engine BSFC versus engine speed

Effect of Fuel Injection Timing on Incylinder Pressure Figure 4 shows the in cylinder pressure versus crank angle for different fuels in different fuel injection timings at 1600 rpm speed. As can be seen in Fig. 4, advancing fuel injection timing increases the peak cylinder pressure for B20, B40, and B100. This could be due to the facts that for a diesel engine, fuel injection timing is a major parameter that affects the engine combustion. The state of air into which the injected fuel changes as the injection timing is varied affects the ignition delay. When the fuel injecting occurs before the standard injection timing, the pressure and temperature of the charged air in the cylinder is less than that of the fuel when it was injected at standard injection timing. So, ignition delay of the injected fuel is extended and simultaneously, the penetration of fuel spray is enhanced. Therefore, the reaction between fuel and air is improved which prepares a good mixture for burning. When the combustion starts, the rate of heat release is increased in premixed or rapid combustion phase of the combustion process due to suitability of the mixture of air and fuel. Most of the energy is released at the first phase of combustion and hence the peak pressure of cylinder takes place close to TDC and is increased. Also by advancing the fuel injection timing, the fuel spray can promote the in cylinder turbulence and it helps to mixing. When the injection timing is retarded, the fuel is injected in to the

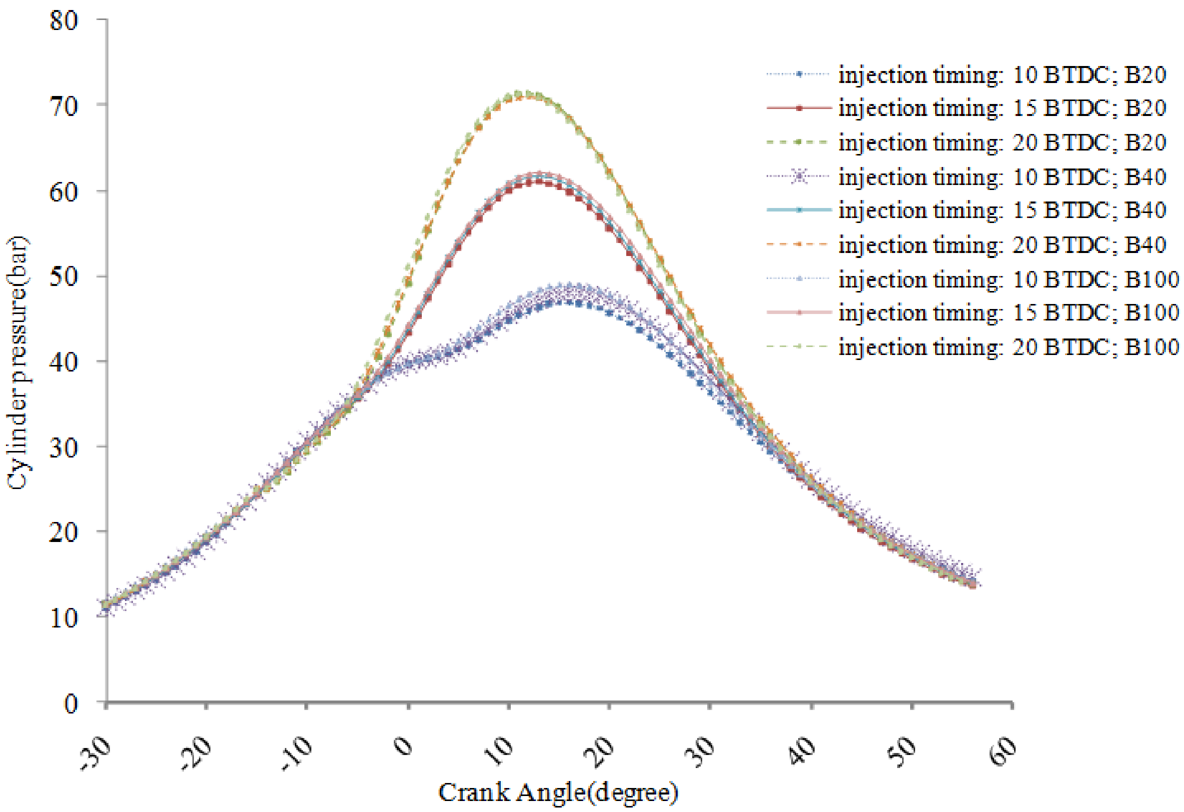

Figure 4. The engine cylinder pressure versus crank angle

charged air that has high temperature and pressure. So, the ignition delay is decreased and the fuel doesn't get enough time to mix well with the air and therefore at the time combustion starts, the rate of heat release is decreased in premixed combustion phase of the combustion process and the peak pressure of cylinder is decreased and is far away from TDC.

Effects of Fuel Injection Timing on Exhaust Gas Temperature Figure 5 compares the exhaust gas temperature of B20, B40, and B100 at different injection timing. The exhaust gas temperature is decreased for all fuels by advancing the injection timing which is an indication of complete combustion. This is due to this fact that with advancing the injection timing, more part of fuel is burnt at the first phase of combustion process that can be observed from the diagrams of in cylinder pressure. It's due to less heat loss as evident from low brake specific fuel consumption. The exhaust gas temperature is found to be more by retarded fuel injection timing for 10 BTDC, which is an indication of incomplete combustion.

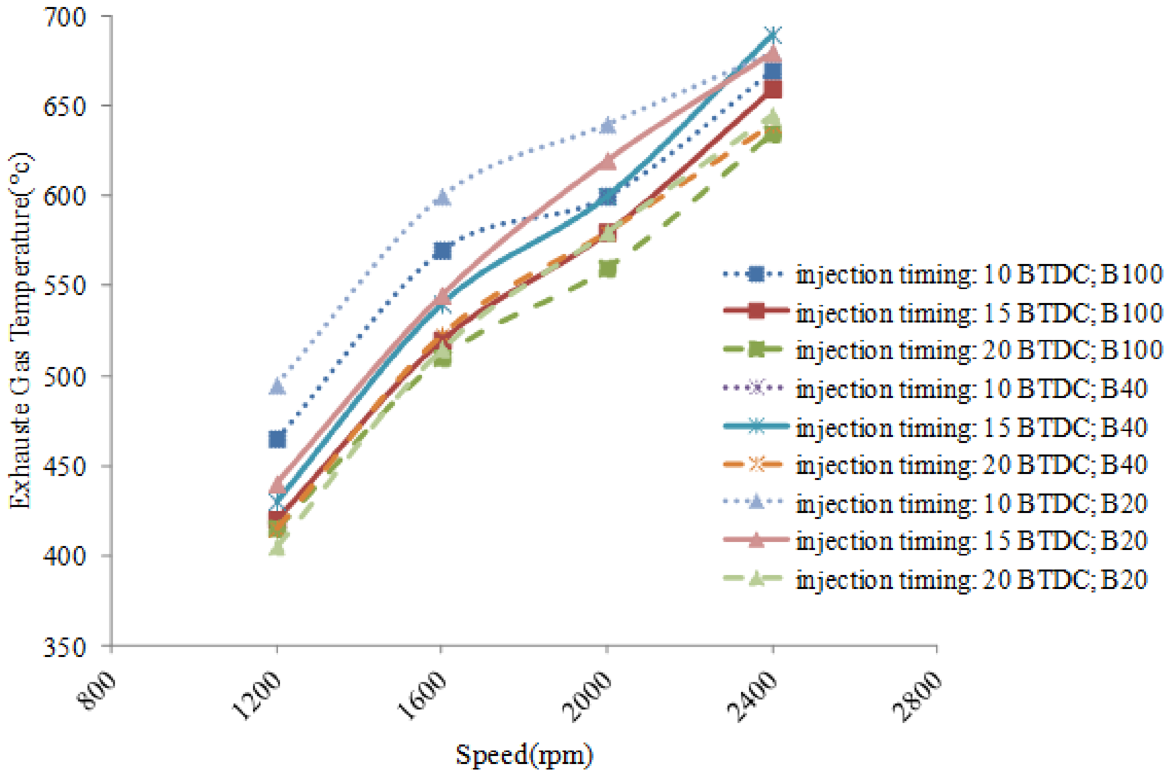

Figure 5. The exhaust gas temperature versus engine speed

CONCLUSION

In this study, the effect of fuel injection timing on performance of a DI diesel engine was investigated experimentally using environmental friendly diesel-biodiesel fuel blends. Based on the research work findings, the following conclusions could be drawn:

- With advancing the engine fuel injection timing, the peak cylinder occurred closer to TDC and therefore engine produced a higher mean effective pressure (mep) to do work and the value of the engine torque increased.
- For biodiesel and its blends with diesel fuel, by retarding the fuel injection timing, comparing to the standard injection timing, the brake specific fuel consumption (BSFC) was increased. On the other hand, advancing the fuel injection timing reduced the specific fuel consumption (BSFC).

- Advancing the engine fuel injection timing increased the cylinder peak pressure for all diesel-biodiesel fuel blends.
- The exhaust gas temperature was decreased for all fuel blend ratios by advancing the engine fuel injection timing which is an indication of complete combustion. The exhaust gas temperature was found to be more than the usual fuel injection timing setting by retarding the fuel injection timing to 10 BTDC, which is an indication of incomplete combustion.

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