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Effect of Static Spark Timing on the Performance and Emissions of a Spark Ignition Engine Using CNG

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Abstract. In this paper, studying the effects of static spark time on the performance and emissions of a spark ignition engine using compressed natural gas. Engine performance and emissions were measured repeatedly at different static ignition time (15° BTDC, 18° BTDC, 21° BTDC and 24° BTDC) with fixed coolant temperature (90°C± 2°C). the results showed that advancing the static ignition time with CNG from 15° BTDC to 24° BTDC at the full load increased the brake power, brake torque, brake thermal efficiency and hydrocarbon by 4.07%, 4.67%, 3.58% and 4.89% respectively, while carbon monoxide and volumetric efficiency doesn't change effectively at the full and half load conditions.

Keywords: Spark Timing, CNG, Emissions, Brake Power, Volumetric Efficiency.

List of Abbreviations

Symbol	Definition	Symbol	Definition
BTDC	Before Top Dead Center	DI	Direct Injection
CNG	Compressed Natural Gas	CNGDI	Compressed Natural Gas Direct Injection
CO	Carbon Monoxide	RON91	Research Octane Number 91
CO ₂	Carbon Dioxide	RON95	Research Octane Number 95
NO _x	Nitrogen Oxides	BP	Brake Power
BTE	Brake Thermal Efficiency	CA	Crank Angles
BSFC	Brake Specific Fuel Consumption	MBT	Maximum Brake Torque
HC	Hydrocarbons		

1. Introduction

One of the most important factors, which affect the performance of spark ignition engines, is the ignition timing for optimizing efficiency and emissions [1]. The development of the spark ignition engine has achieved a high level of success in the early years, increasing engine power and engine working reliability were the principal aims for engine designers. In recent years, however, ignition timing has brought increased attention to development of advanced SI engines for maximizing



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performance [2]. Zareei and Kakaee, 2013[3] carried out an investigation for studying the effects of ignition timing of a spark- ignition engine using different initial timing and engine speeds on engine performance experimentally. The results show that ignition timing can be used as an alternative way for predicting the performance of internal combustion engines. The best results were obtained at 31° BTDC for 3400 rpm. Volumetric efficiency, BMEP have increased with rising ignition timing. HC with advance of ignition timing increased, O₂, CO₂, CO has been almost constant, and the lowest amount NO_x is obtained at 10°BTDC [3]. Munde Gopal and Dalu Rajendra, 2013[4] presented the effect of ignition timing on the performance of single cylinder spark ignition engine fueled with gasoline, CNG and B20. The BSFC of CNG was less than that of the gasoline and slightly less than the B20. BSFC decreased with the increase in load for all fuels used. Brake thermal efficiency (BTE) increased with all loading conditions as BSFC decreased. CNG showed higher BTE as compared to B20 and gasoline while B20 showed higher BTE as compared to Gasoline. Advancing the Ignition timing had decreased the exhaust gas temperature, by using B20 and CNG as a fuel. The exhaust gas temperature was higher compared with gasoline at all ignition timing. The percentage of Hydrocarbon (HC) emission was increased with advancing the ignition timing. However, with increasing in load there was a reduction in Hydrocarbon emission. The hydrocarbon emission for CNG was smaller in comparison to Gasoline and B20 at all ignition timing. Evaluating the performance characteristics based on thermal efficiency, showed that the experimental results indicated that the best performance using CNG as a fuel at 27° BTDC ignition timing. Furthermore, the results supported that medium performance using B20 as a fuel, and poor performance using gasoline as a fuel at 27° BTDC ignition timing [4]. Ebrahimi and Mercier, 2010[5] carried out tests with the spark timing adjusted to the maximum brake torque timing in various equivalence ratios and engine speeds for gasoline and natural gas operations. The results showed that natural gas operation caused an increase of about 6.2% in BSFC, 22% in water temperature difference between outlet and inlet engine, 3% in exhaust valve seat temperature, 2.3% in brake thermal efficiency. A decrease of around 20.1% in maximum brake torque, 6.8% in exhaust gas temperature and 19% in lubricating oil temperature when compared with gasoline operation. The equivalence ratio of maximum MBT was higher than the equivalence ratio of maximum BTE for natural gas and gasoline operations [5]. Devi et.al, 2013[6] evaluated whether variable ignition timing can be effect on exhaust emission and engine performance of a spark ignition engine. The study describes some results of research in the area of spark ignition engine and is assessed by studying its performance and emission characteristics relative to that of conventional ignition engine using gasoline and methanol blended gasoline as fuels at different ignition timings. Experiments were conducted at different Ignition timings. The results have shown that performance of methanol blended gasoline engine performed comparatively well over pure gasoline engine less than 25 to 29° BTDC ignition timings. The results have shown considerable performance improvement in brake thermal efficiency, volumetric efficiency, decrease in exhaust gas temperature, as well as reduction in HC, and CO emission [6]. Hassan et.al, 2010[7] worked on Experimental investigations of performance and exhaust gases, concentration at various ignition and injection timing for high compression engine fueled with compressed natural gas (CNG) engine. The engine implements central direct injection (DI) method. All injectors are positioned within a certain degrees of spark plug. It is called as CNGDI engine. The results showed that, Low CO concentration occurs at late injection timing and the lowest emission is 0.011% when we applied 300 BTDC of ignition at 3600 CA injection timing. The most influential factor for CO development is ignition timing. Complete combustion occurs at (3000 EOI, 250-280 BTDC) as illustrated in the CO₂ and O₂ contour [7]. Gailis and Pirs, 2014[8] studied experimentally the effect of ignition timing on emissions from a four-cylinder port injection spark ignition engine using gasoline and E85 fuel. Results showed that the exhaust gas temperate increased with ignition timing retard and was higher when the gasoline was used, comparing to E85 fuel. The nitrogen oxides emissions were reduced by 5-18% for engine out and 25-42% for tailpipe emissions using E85 fuel at nominal spark timing comparing to maximal brake torque timing [8]. Binjuwair and Alkudsi, 2016[9] experimentally analyze and evaluate the influence of varying the spark timing on the performance and emission characteristics of a single cylinder, four-stroke spark ignition (SI) engine fuelled by two grades of gasoline used in Saudi Arabia, RON91 and RON95. The experimental results showed that as the spark timing increases, the brake power (B.P) and the brake thermal efficiency

(BTE) increase for both fuels. It is observed that bp and BTE of RON95 is higher than that of RON91. The specific fuel consumption (BSFC) decreases with increasing in spark timing for both fuels [9]. Shi et.al, 2016[10] investigated the effect of spark timing on combustion and emissions of a hydrogen direct injection stratified gasoline engine. The engine was operated at 1500 rpm and excess air ratio at 1.2. It was found that when the hydrogen volume fraction was raised from 0% to 10%, and the hydrogen injection timing was 110° CA BTDC a good stratified effect was achieved. The spark timing was varied from 4° to 16° CA BTDC. This test demonstrated that the brake thermal efficiency first rose and then fell with the spark advance angle increased. In addition, it increased with the increase of hydrogen volume fraction. Postponing the spark timing caused the maximum instantaneous heat release rate increase. The peak cylinder pressure and the maximum rate of pressure rise increased with spark advance angle increase. Postponing the spark timing also caused NO_x, HC and CO emissions to decrease. When the hydrogen volume fraction increased, the NO_x emissions rose, and the HC and CO emissions dropped [10]. Nitnaware and Suryawanshi, 2016[11] showed the effects of 0%, 5%, 10% and 15% blends of hydrogen with Compressed Natural Gas on multi-cylinder bi-fuel spark ignition engine using sequential port fuel injection system. The results obtained that at wide open throttle position Maximum Brake Torque (MBT) spark timing shown improvement in performance parameters with reduction in NO_x emission. MBT spark timing increased with increase in speed and decreased with increase in hydrogen addition for all fuel blends. Hydrocarbon (HC) and carbon monoxide (CO) emissions rose up with decrease in equivalence ratio and reduced with increase in HCNG blends. Hydrogen addition had shown rise in peak pressure, increase in heat release rate and decrease in combustion duration. The optimum MBT spark timing observed for 5% hydrogen blend at 2500 rpm is 25° CA BTDC for compromise with oxides of nitrogen (NO_x) and performance output [11]. Finally, the main objective of this research is to studying the effect of static ignition timing on the engine performance and emissions with constant coolant temperature at half and full loads.

2. Experimental Methodology

Experimentation was carried out on a spark ignition engine which was modifies by specified equipments to operates on two types of fuel. Basically, engine connected to a hydraulic dynamometer through a propeller shaft and an air surge tank was connected to the engine intake manifold, gas digital analyzer was used to perform analysis of exhaust gases. Performance characteristics such as brake power, brake torque, brake specific fuel consumption, brake thermal efficiency, volumetric efficiency and exhaust emissions were measured.

3. Engine Specifications and Experimental Setup

Main specification of the internal combustion engine used and test rig instrumentations are described below as the following:-

Table 1. Engine Specifications

Engine Model	G4EH
Engine Type	Gasoline
Displacement (cm ³)	1341
Number of Cylinder	4
Compression Ratio	9.5
Bore (cm)	7.15
Stroke (cm)	8.35
Ignition Timing	9° ± 5° BTDC

Spark Plug Gap	1.1 mm
Max. Power (kW@ rpm)	61.78@5500
Max. Torque (N.m@ rpm)	116.7@3000
Cycle	Four
Fuel System	MPI

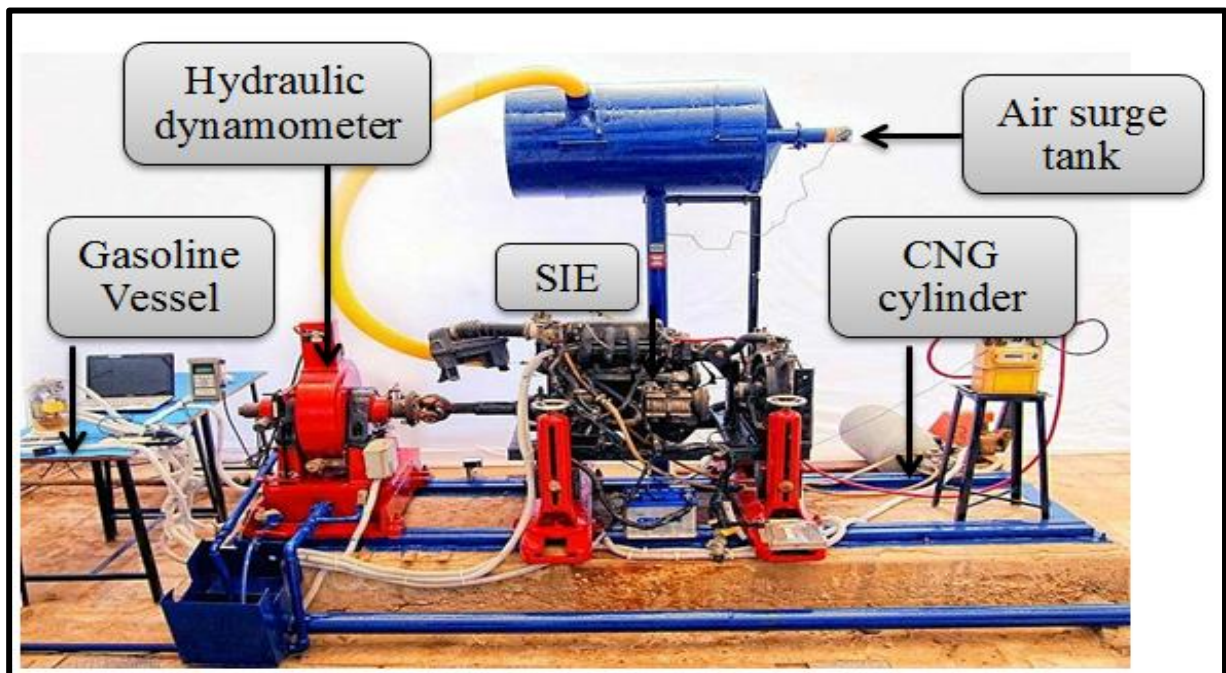


Figure1. Test Rig Apparatus.

4. Results and Discussion

The engine performance and emissions were measured at different static ignition timing (15° BTDC, 18° BTDC, 21° BTDC and 24° BTDC) with fixed coolant temperature ($90^\circ\text{C} \pm 2^\circ\text{C}$). The results obtained will be discussed in the following section.

4.1 The Effect of Static Ignition Timing on Volumetric Efficiency.

As is evident in figures 2 and 3 the effect of the static ignition timing on the volumetric efficiency at the full and half load operating conditions. The static ignition timing doesn't show any significant changes on the volumetric efficiency for the both cases. With the different ignition timing, the spark occurs before the TDC by several degrees, at which both valves were closed and the spark timing has no effect on the air amount in the cycle.

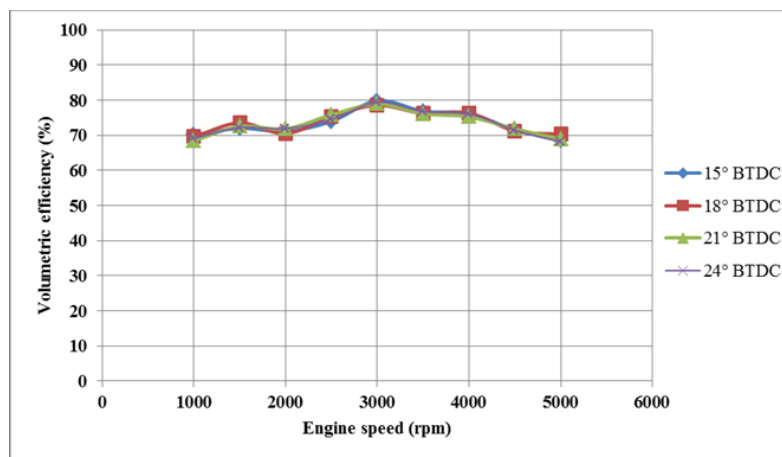


Figure 2. Volumetric efficiency versus engine speed at full load with different static ignition timing using CNG.

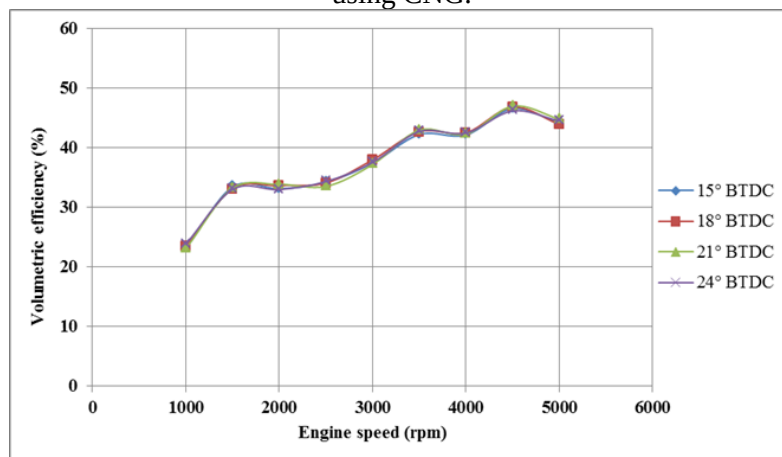


Figure 3. Volumetric efficiency versus engine speed at half load with different static ignition timing using CNG.

4.2 The Effect of Static Ignition Timing on Brake Torque and Brake Power

The effect of different static ignition timing on the brake torque and power at the full load condition has shown in figures 4 and 5. It has been observed that advancing the static ignition timing increased the brake torque and brake power throughout all the speed range. As the static ignition timing is advanced, the greatest portion of the combustion process occurs near TDC which gives higher BMEP as reported in [12]. Although advancing the spark timing increased the brake torque and power, the excessive spark timing advancing has negative effect on the engine performance. Too much spark timing advancing increases the pressure earlier while the piston is moving towards the TDC at the compression strokes which increases the negative work during the cycle.

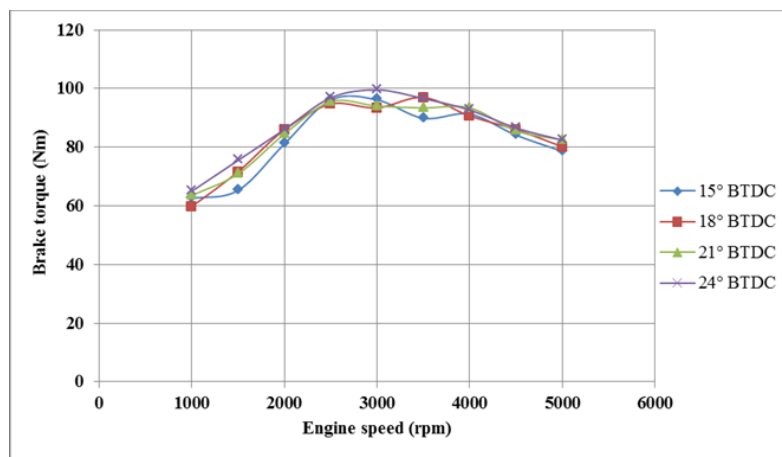


Figure 4. Brake torque versus engine speed at full load with different static ignition timing using CNG.

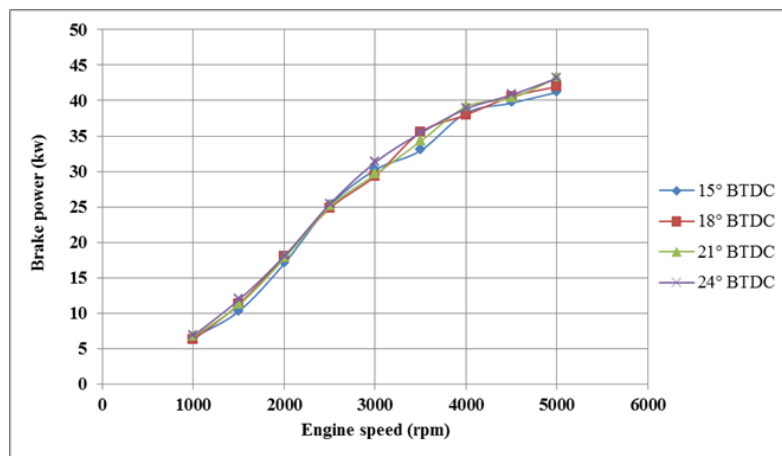


Figure 5. Brake power versus engine speed at full load with different static ignition timing using CNG.

4.3 The Effect of Static Ignition Timing on Brake Specific Fuel Consumption and Brake Thermal Efficiency

Advancing the static ignition timing increases the BTE and reduces the BSFC with the all engine speeds as it is shown in figures 6 and 7. This is due to that the CNG has longer delay period and lower flame speed than the other hydrocarbons. Moreover, advancing the ignition timing when the engine run with CNG ensures that more amount of the mixture is burned near the TDC which give higher pressure and temperature at earlier crank angles and increase the useful work from the same amount of the fuel. The engine thermal efficiency measures the capability of the engine to convert the fuel chemical energy into a mechanical work, so higher BTE and lower BSFC was noticed with advancing the static ignition timing.

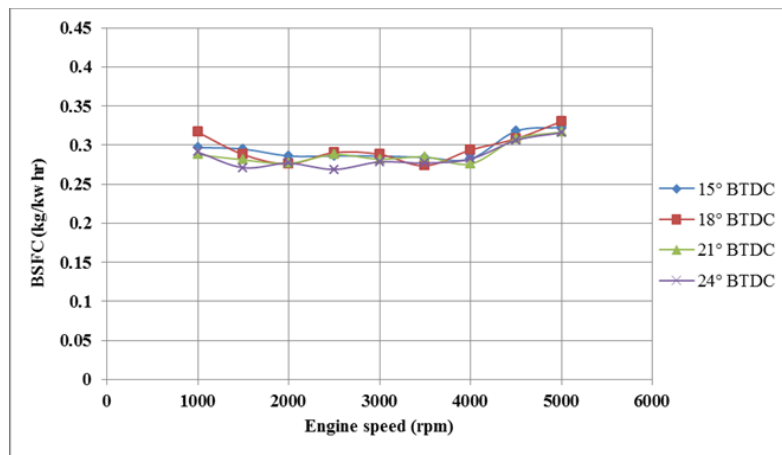


Figure 6. Brake specific fuel consumption versus engine speed at full load with different static ignition timing using CNG.

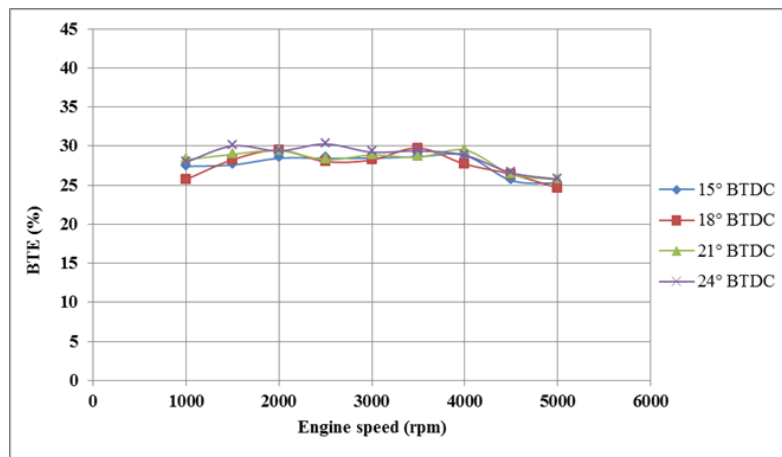


Figure 7. Brake thermal efficiency versus engine speed at full load with different static ignition timing using CNG.

The Brake Specific Fuel Consumption and Brake Thermal Efficiency at the half load condition with different static ignition timing using CNG presented in figures 8 and 9. The results show that retarding the static ignition timing reduces the BTE and increases the BSFC because the maximum pressure occurs at later crank angles after TDC. Retarding the maximum pressure point reduced the network produced during the cycle as the piston is already moving downwards.

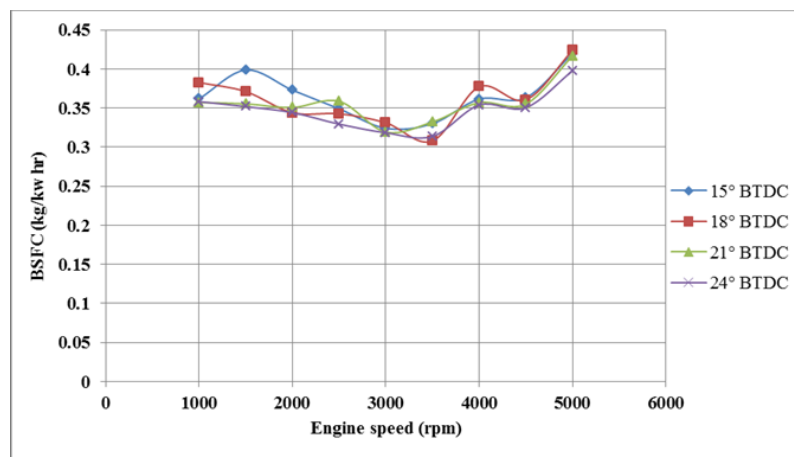


Figure 8. Brake specific fuel consumption versus engine speed at half load with different static ignition timing using CNG.

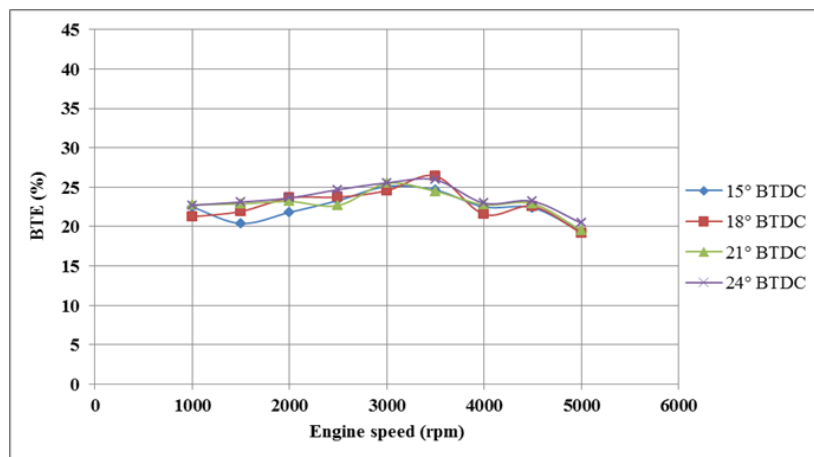


Figure 9. Brake thermal efficiency versus engine speed at half load with different static ignition timing using CNG.

4.4 The Effect of Static Ignition Timing on Exhaust Emissions

Figures 10 to 12 show the effect of the static ignition timing on the exhaust emissions at the full load condition. Advancing the static ignition timing increases the unburned hydrocarbon and slightly reduced the carbon dioxide. Carbon monoxide doesn't changes significantly by changing the static ignition timing. Retarding the static ignition timing reduces the unburned hydrocarbon by increasing the fraction oxidized during the expansion and exhaust stroke due to the higher burned gas temperature [12].

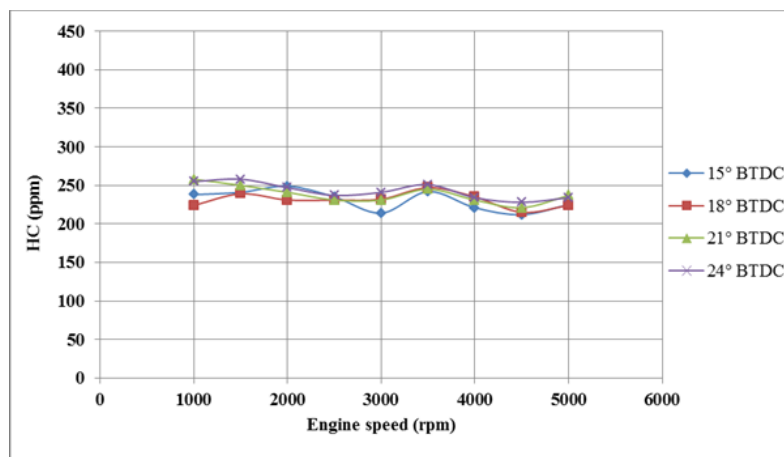


Figure 10. Hydrocarbon emissions versus engine speed at full load with different static ignition timing using CNG.

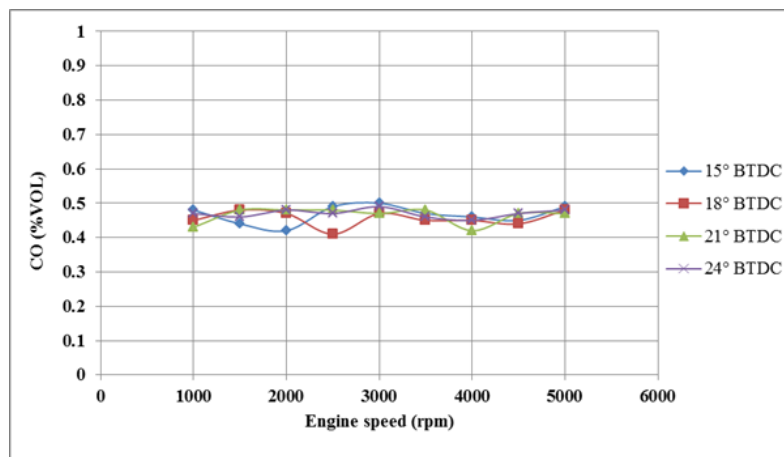


Figure 11. Carbon monoxide emissions versus engine speed at full load with different static ignition timing using CNG.

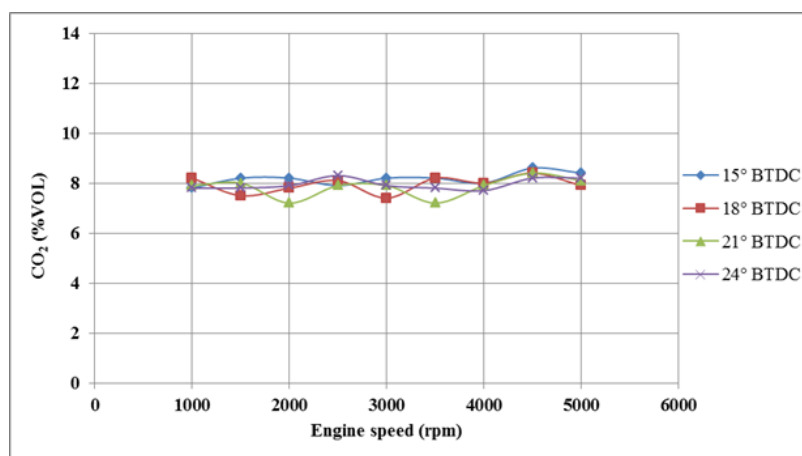


Figure 12. Carbon dioxide emissions versus engine speed at full load with different static ignition timing using CNG.

Finally, the effect of the static ignition timing on the exhaust emissions at half load condition is shown in figures 13 to 15. It has been observed that advancing the static ignition timing using CNG at half

load increased the unburned hydrocarbon and has an unsubstantial effect for the carbon monoxide and carbon dioxide. Advancing the static ignition timing increases the maximum pressure near the TDC which pushes more of the fuel- air mixture into the crevices volumes and increases the unburned hydrocarbon by the quench effect [3].

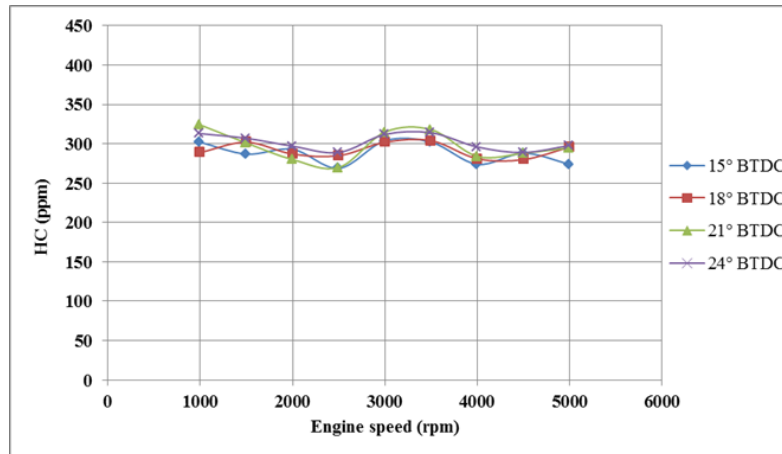


Figure 13. Hydrocarbon emissions versus engine speed at half load with different static ignition timing using CNG.

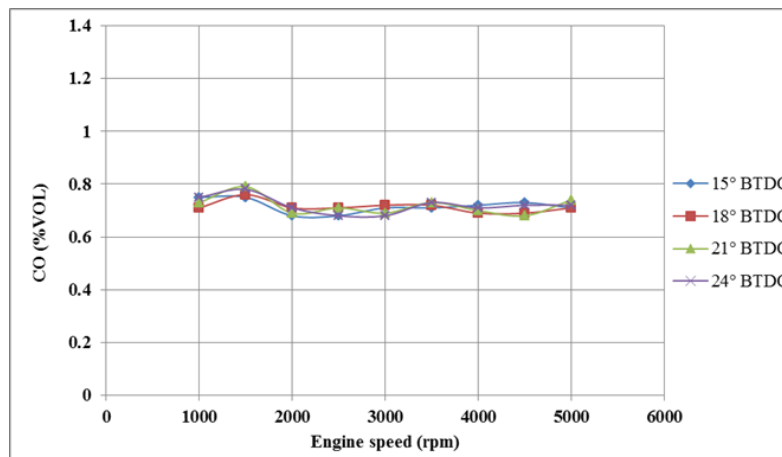


Figure 14. Carbon monoxide emissions versus engine speed at half load with different static ignition timing using CNG

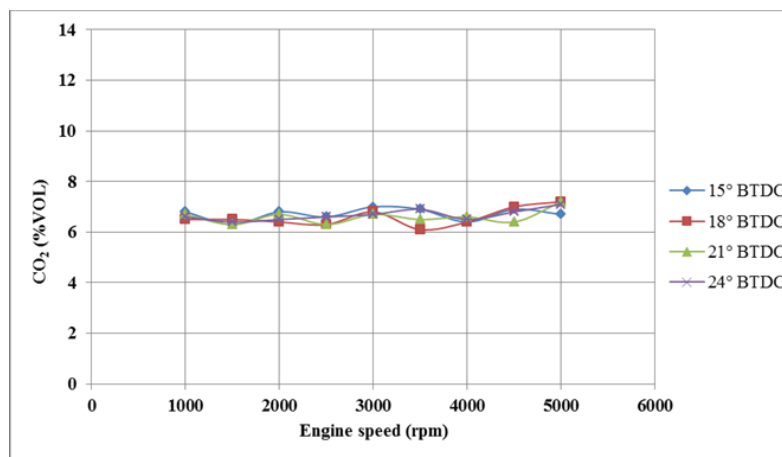


Figure 15. Carbon dioxide emissions versus engine speed at half load with different static ignition timing using CNG.

5. Conclusion

- 1- The static ignition timing doesn't show any significant changes on the volumetric efficiency for the both cases. With the different ignition timing, the spark occurs before the TDC by several degrees, at which both valves were closed and the spark timing has no effect on the air amount in the cycle.
- 2- Advancing the spark timing increased the brake torque and power, the excessive spark timing advancing has negative effect on the engine performance.
- 3- Advancing the static ignition timing increases the BTE and reduces the BSFC with the all engine speeds.
- 4- At the full load condition, advancing the static ignition timing increases the unburned hydrocarbon and slightly reduced the carbon dioxide. Carbon monoxide doesn't changes significantly by changing the static ignition timing.
- 5- It has been observed that advancing the static ignition timing using CNG at half load increased the unburned hydrocarbon and has an unsubstantial effect for the carbon monoxide and carbon dioxide.

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