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Full Length Research Paper

The effects of modified ignition timing on cold start HC emissions and WOT performance of an LPG fuelled SI engine with thermal barrier layer coated piston

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In this study, the effect of modified ignition timing of an LPG fuelled spark ignition engine on cold start Hydrocarbon emission (HC) at the wide open throttle (WOT) conditions performance and emission characteristics were investigated when using a thermal barrier layer (TBL) coated piston. The engine was tested at the variable ignition timing. At the first stage cold start HC emission was measured for the first 180 s. Secondly, the performance and HC emissions were measured at the WOT condition. Cold start HC emission in the TBL piston has been decreased considerable. In the case of using TBL piston and variable ignition timing, at the high engine speed the engine torque and brake power have been increased as 15% at the 2700 rpm. Specific fuel consumption (SFC) was decreased at the variable ignition timing expect for 1500 and 1800 rev min^{-1}. Maximum reduction was observed by 8.5% at the 2700 rpm.

Key words: Hydrocarbon emissions, cold start, thermal barrier layer, liquefied petroleum gas.

INTRODUCTION

Sustaining a clean environment has become an important issue in an industrialized society. The air pollution caused by automobiles and motorcycles is an important environmental problem to be solved. This purpose, internal combustion engines with alternative energy sources within the eco-friendly fuels, researchers have become one of the most important topics (Choia et al., 2005).

As a fuel for spark-ignition engines, alcohols (methanol and ethanol) and LPG have some advantages over gasoline, such as a better anti-knock characteristic and reduced CO and unburned HC emissions (Hsieh et al., 2002). Froman environmental point of view there is an increasing interest among the suppliers to investigate LPG as a transportation fuel. It was found that the liquid petroleum gas, roughly a mixture of propane and butane, which gives a benefit in terms of toxic hydrocarbons emissions and ozone formation due to its composition and CO2 emission levels (Heffel, 2003). Alcohols contain oxygen atoms, therefore they can be considered as partially oxidized fuels (Bayraktar, 2005; Norton, 1990).

Studying the effects of methanol and LPG on pollutant emissions and performance of an engine holds many researchers' interest (Sezer and Bilgin, 2002; Dawood, 1998; Guatam, 2002). During cold start, reducing unburned HC emissions from the modern spark ignition engines with catalytic converter is an important issue. One of the most important sources of unburned HC emissions is the one caused during cold start of the engine when the catalytic converter is not active yet (Martin et al., 2005). The effectiveness of a converter depends on the exhaust gas temperature, which is fairly low during cold-start. As a result, most of the tailpipe hydrocarbons measured during the US 1975 federal test procedure (FTP 75) and ECE cycles have been found to be from the cold part of the tests, before the catalytic converter is warmed up (Henein, 1999; Gallopoulos, 1992). Thus, it is important not only to improve catalyst conversion efficiency but also to reduce directly engine-out hydrocarbon emissions during cold start and warming-up processes. The sources of high cold-start engine-out HC emissions, in the order of their contribution, are: Misfiring, incomplete flame propagation, wall wetting, rich fuel–air charge, crevice storage of the

Nomenclature: SI, spark ignition; **STD,** standard; **TBL,** thermal barrier layer; **WOT,** wide open throttle; **VIT,** variation ignition timing; **FIT,** fixed ignition timing, **TDC,** top dead center.

fuel–air charge and its release, oil dilution with liquid and fuel vapour, wall quenching, poor post-flame oxidation, exhaust valve leakage, inlet valve leakage and lubricating oil.

The order of the contribution of the last seven sources may vary from engine-to-engine, depending on its specific design and operating parameters (Heywood, 1998; Cheng et al., 1993). Much attention has been paid to the study on 'adiabatic' or 'low heat rejection' engines. These studies have been commonly performed on Diesel engines (Bryzik and Kamo, 1993; Assanis et al., 1991; Parlak et al., 2003; Reddy, 1990). However, less study has been undertaken on 'adiabatic gasoline engines (Assaniss and Mathur, 1980; Assaniss and Badillo, 1987; Assaniss, 1992). The works of Assanis et al. (1991) dealing with the use of thin ceramic coatings to improve the spark-ignition petrol engine's performance and emission characteristics are important, being among the few investigations available. It is well known that insulating the combustion chamber components of low heat rejection (LHR) engines can reduce the heat transfer between the gases in the cylinder and the cylinder wall and, consequently, increase the combustion temperature (Assaniss and Badillio, 1992).

The LHR engine concept is based on suppressing this heat rejection to the coolant and recovering the energy in the form of useful work. Thus, a thin ceramic coating applied to spark ignition engines could be a useful means for improving the performance, fuel economy, and exhaust emissions. However, the degree of insulation is an important factor that needs to be ascertained from the view-point of knock free performance.

Parlak et al., (2003) a thermal barrier layer (TBL) was deposited on the top surface of a piston near the crevice to examine the effects on the cold start HC emission at idle and the performance characteristics at the wide open throttle (WOT) conditions for various compression ratios. The aim of TBL coating was to increase unburned charge oxidation near the vicinity of the clearance between the piston and liner during compression and early part of the expansion stroke. Since the crevice is the flame quenching region which is the main source of the cold start HC emissions in spark ignition gasoline engines, the top surface near the crevice was especially chosen for TBL deposition. TBL deposition on this area can also reduce the risk of knocking (Parlak and Ayhan, 2007).

In the present work, a thermal barrier layer (TBL) was deposited on the top surface of a piston near the crevice (not completely coating the top surface of the piston) to examine the effects on the performance and HC emissions at the wide open throttle (WOT) conditions for variation ignition timing at the working with LPG engine. Also released in 180 seconds from the engine cold start HC emission is investigated. As the crevice is the flame quenching region which is the main sources of the cold start HC emissions for spark ignition gasoline engines, the top surface near the crevice was especially chosen as for the place of TBL deposition. Choosing this area also enables to decrease the risk of knocking.

The aim of the TBL is to help increase the unburned charge oxidation near the entrance of the clearance between the piston and liner during compression and early part of the expansion stroke. The performance tests were implemented at six ignition timing (degrees before TDC) 10, 13, 16, 19, 22 and 25 for both Standard and TBL piston cases.

EXPERIMENTAL SETUP AND TEST CONDITIONS

The engine tests were conducted in single cylinder water cooled spark ignition engine with a mechanism that enables to alter compression ratio and ignition timing. The engine specifications are listed in Table 1. The block diagram of the test set-up and the piston with TBL used in the tests are shown in Figures 1 and 2 respectively.

The tests were conducted at two stages. At the first stage, cold start HC emission was measured for the first 180 s. Secondly, the performance and exhaust characteristics were measured under full load condition (WOT) at the engine speeds of 1500, 1800, 2100, 2400, 2700 and 3000 rev min. The the ignition timing was adjusted 13, 16, 19, 22 and 25 crank angles before TDC respectively at the experimental. After conducting the load tests for STD engine, same procedures was adopted for the engine having the piston with TBL.

The TBL coating material on the piston is composed of MgO-ZrO2 which has a low thermal conductivity, thermal diffusivity and a high heat capacitance all of which cause the entrance temperature of the crevice to increase. This is the main reason for the decrease in volumetric efficiency of LHR engines.

To monitor HC emissions for the first 180 s during cold start of the engine, a digital camera was used and the data was continuously transferred to a PC. The time was started after observing the first data on the display of the analyzer.

The engine is coupled to a Ward-Leonard type electric swinging field dynamometer with 10 kW absorbing capacity for measuring the engine brake power. The exhaust sample was taken from a tap located close to the exhaust outlet of the engine. The uncertainty levels of the calculated parameters with respect to the measured ones, which are important for verifying the correctness of the test results, are shown in Table 2.

Atmospheric plasma spray coating method was used to coat the combustion chamber components. As for plasma gas, a mixture of Ar +5% H2 was used. The TBL composed of a 0. 5 mm thick MgO–ZrO2 layer over a NiCrAl bond coat of 0.10 mm thick.

RESULTS AND DISCUSSION

In this study, coating thermal barrier on the piston, working with the LPG at the spark engine, variation of the ignition timing were investigated experimentally on the engine performance and HC emission of the effect. Obtained of the dates from this study were introduced as follows:

Figures 3 to 4 shows that the STD and coated TBL piston on the SI engine, variation ignition timing has been seen torque and brake power of the change. Working with the LPG on the engine the torque and brake power were increased for each engine speed as a result of variable ignition timing. According to STD engine, maximum torque was obtained as 19% at the 2700 rpm with the

Table 1. The engine specifications.

Engine type	Water cooled engine
Cylinder	1
Bore (mm)	84.95
Stroke (mm)	82.45
Displacement (cm^3)	467.07
Compression ratio	4 to 10
Power (kW)	4.5/3000
Speed (rpm)	3400 rpm

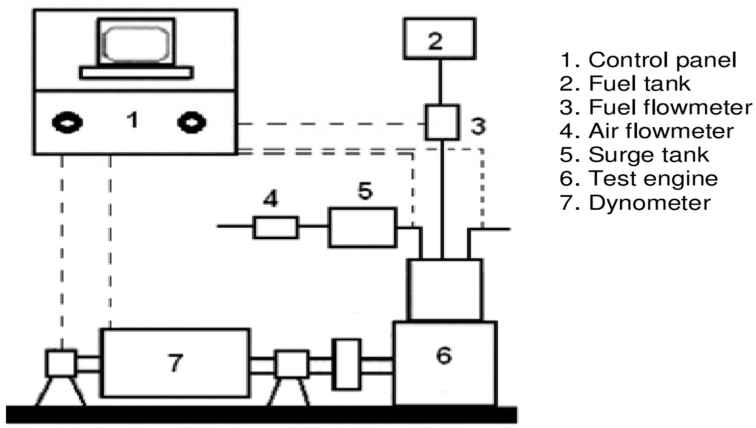

Figure 1. The block diagram of the test engine.

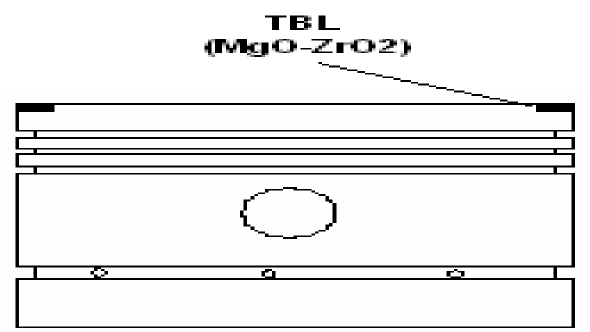

Figure 2. The piston with TBL.

Table 2. The measuring uncertainties in engine performance parameters.

Engine performance characteristics	Errors (±%)
Specific fuel consumption	1.5
Torque	1.1
Brake power	1.3
HC	1 ppm
Temperature	0.1°C

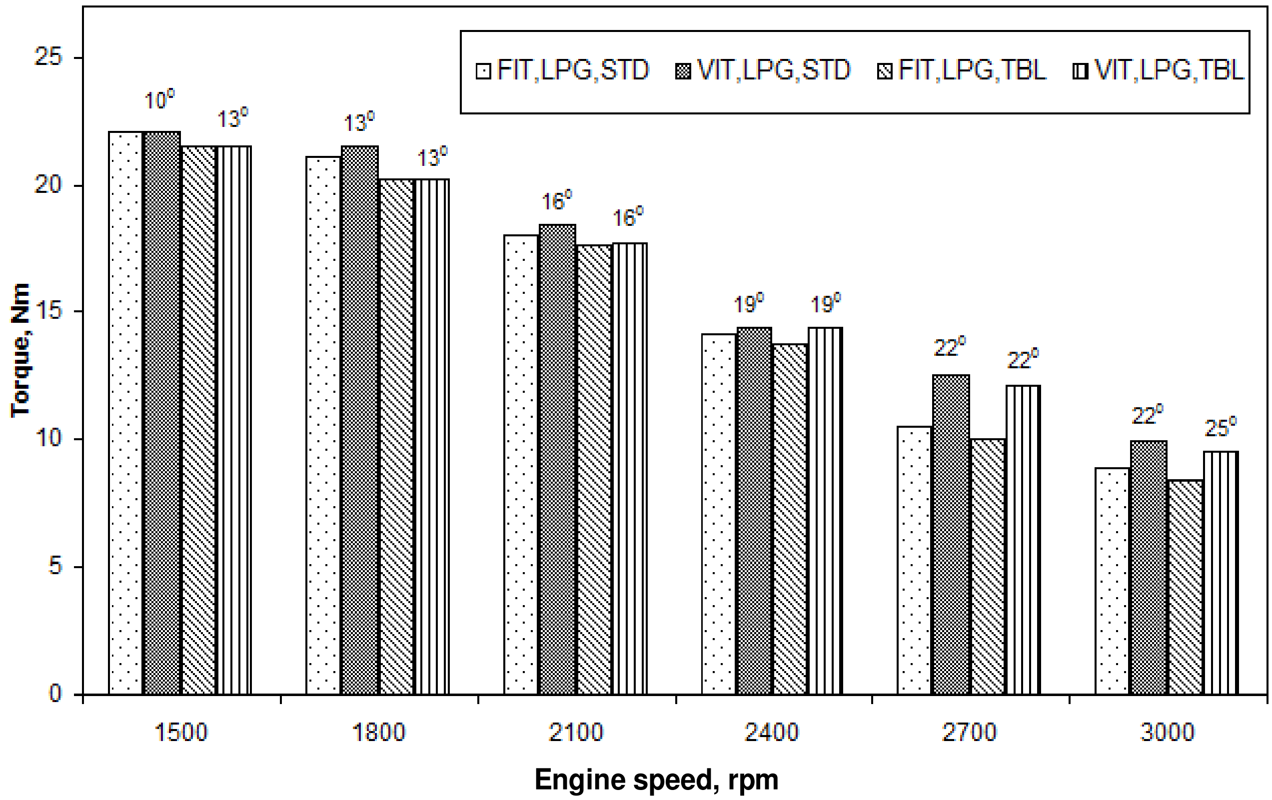

Figure 3. Variation of torque of working with LPG at the engine for various ignition timing.

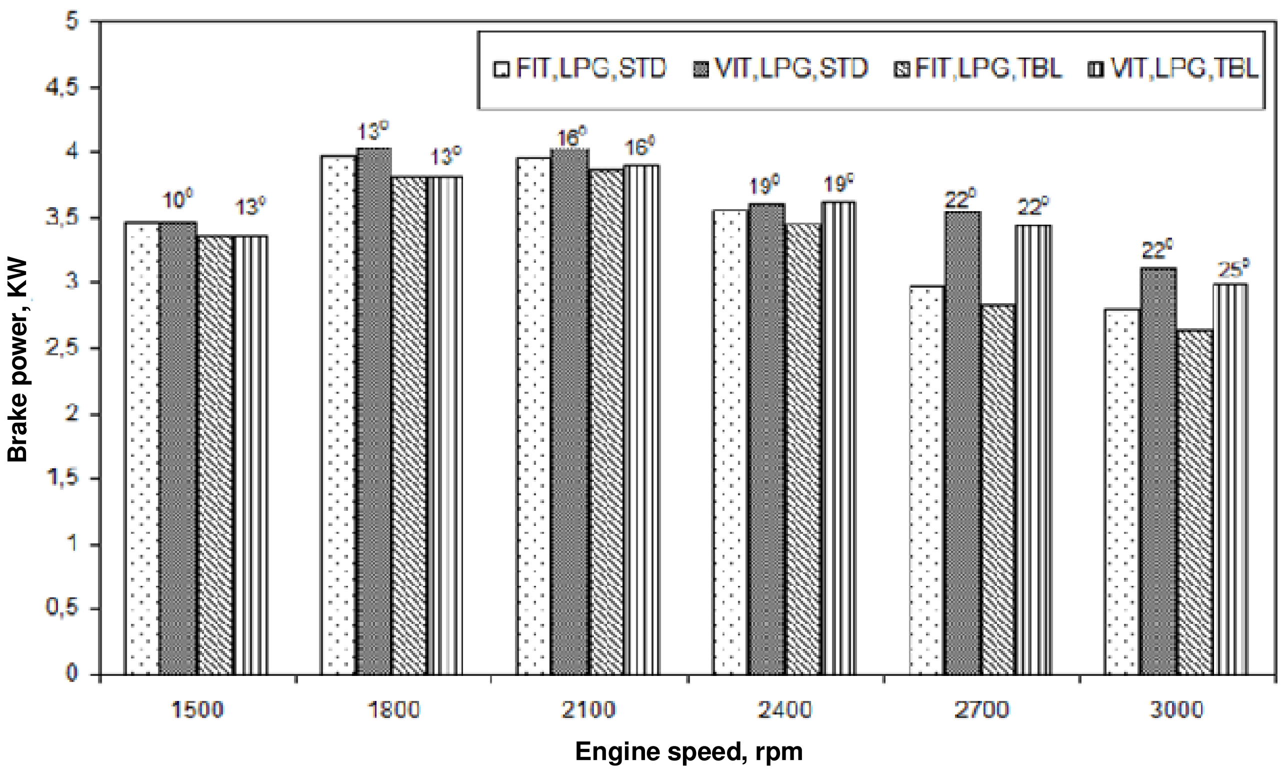

Figure 4. Variation of brake power of working with LPG at the engine for various ignition timing.

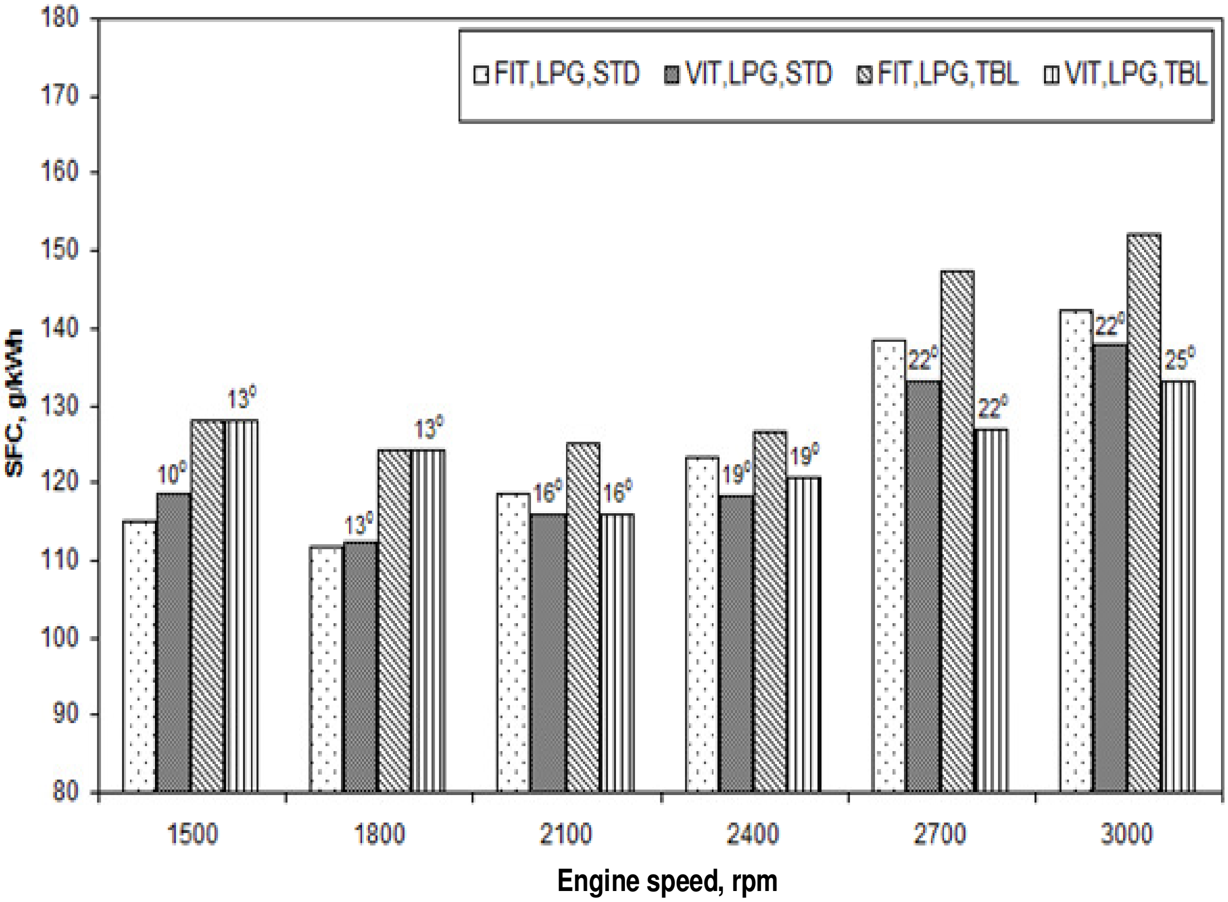

Figure 5. Variation of SFC of working with LPG at the engine for various ignition timing.

STD piston at the 22 crank angle ignition timing. The decrease of the brake power and engine torque on the STD engine may be explained by two main reasons

(i) Because of the low combustion speed of LPG to the low temperature in the combustion chamber.
(ii) The second reason is that ignition capability of LPG has been low.
Depending on ignition timing increasing the temperature in the combustion chamber the combustion speed was improved. Thus leads to increase in engine torque and brake power.

Compared with TBL piston and STD piston, the engine torque was decreased at the low engine speed at the variation ignition timing. However, at the high engine speed it was increased. The maximum increase in the engine torque of the variable ignition timing was found as 15% at the 2700 rpm. Increasing of the maximum engine torque was at the 22 crank angle ignition timing. For the fixed ignition timing, at the TBL piston the engine torque and brake power have been decreased. For the reason decreases, in the engine torque and brake power; decreasing volumetric efficiency as the TBL piston leads to an increasing in the inlet temperature.

Specific fuel consumption (SFC) increased for the TBL piston in the range of 2 and 11% compared to that of STD piston. However, expect for 1500 and 1800 rev min^{-1} SFC was decreased at the variable ignition timing. Maximum reduction was observed by 8.5% at the 2700 rpm. At this engine speed the ignition timing was 22 crank angle. As can be seen in Figure 5, variation of SFC working of LPG at the engine. The cold start HC emissions of the standard engine were compared with those of the engine with TBL piston for the first 180 s. The ignition timing was the same for both engines. The results are shown in Figure 6. In the case of using TBL piston, significant reductions in HC emission have been observed after the engine started at idle at 1200 rev min^{-1} engine speed. In the case of using TBL piston, the reduction in HC ranges of 29% for the first 20 s. HC emissions were decreased for the rest of the time at the TBL piston. HC emission decreases due to the increased combustion chamber temperature.

HC emissions of TBL piston engine depending on

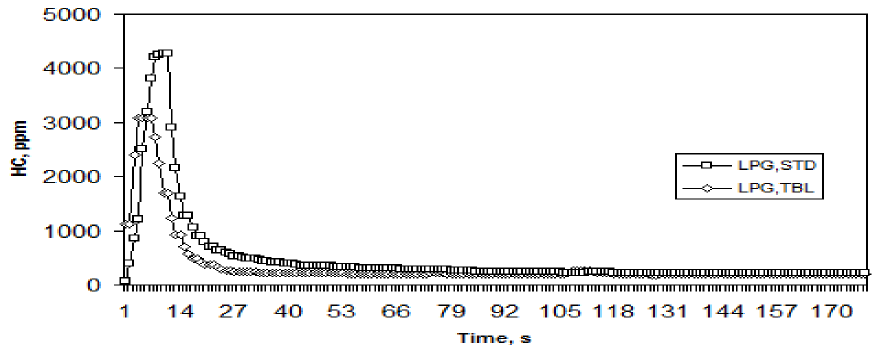

Figure 6. Variation of cold start HC emissions of standard and TBL piston at engine speed of 1200 rev min^{-1}.

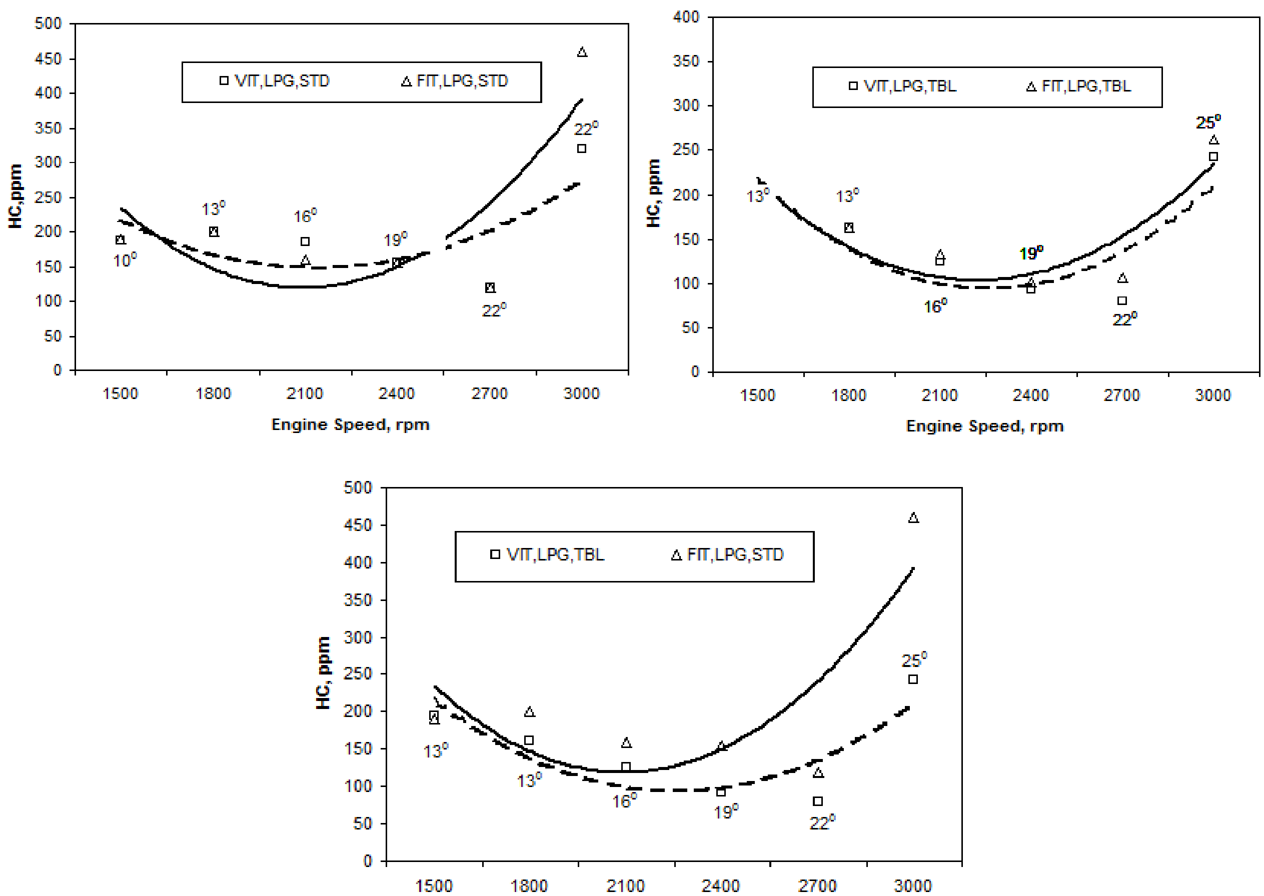

Figure 7. Variation of HC emissions of standard and TBL piston for various ignition timing.

engine speed at WOT for various ignition timing decreased significantly as shown in Figure 7.

For the fix ignition timing HC emission decreased the whole engine speed. However, decreasing the variable ignition timing was more than fix ignition timing of the change. Maximum reduction was observed by 47% at the 3000 rpm.

CONCLUSIONS

As a result of TBL, oxidation reactions on the top surface of the piston near crevice and combustion temperature increased. The increase in combustion chamber temperature contributes to reduce the cold start HC emissions and HC emissions at WOT conditions.

However, increased the combustion chamber temperature volumetric efficiency is decreased. This, leads to decreasing the engine torque and brake power.

In the study, in order to avoid the negative impact of the TBL piston was applied to the variable ignition timing. In the case of using TBL piston and variable ignition timing in the SI engine, at the high engine speed the performance can not be observed poor. The increase was found as 15% at the 2700 rpm. HC emissions also considerably decreased at cold start and at WOT conditions.

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