Performance Study on Twin Plug Spark Ignition Engine at Different Ignition Timings

Narasimha Bailkeri[1], Krishna Prasad S[2], Shrinivasa Rao B.R[3]

Department of Mechanical Engineering, NMAM Institute of Technology, Nitte 574110, India

Abstract: ***The present paper describes some results of research in the area of twin spark ignition engine. The potential of dual plug spark ignition engine is assessed by studying its performance and emission characteristics relative to that of single plug ignition engine using gasoline as fuel at different ignition timings. A new dual ignition engine has been developed by introducing two spark plugs at suitable locations. Experiments were conducted at different load conditions and three different ignition timings. The results have shown that performance of dual plug engine is comparatively better than the conventional single plug ignition engine under all three ignition timings. The results have shown considerable performance improvement in power output and thermal efficiency, as well as reduction in BSFC, HC, and CO emission in dual plug mode of operation.***

Keywords: Engine performance, Ignition timing, Exhaust emission, Twin plug SI engine.

1. Introduction

Rapid combustion is the basic requirement for knock free operation of an S.I engine. The important attributes of rapid combustion as discussed in detail by James N Mattavi [1] can be summarized as – improved tradeoff between efficiency and NO_X emissions, greater tolerance towards EGR (exhaust gas recirculation) or excess air, reduction in c-b-c fluctuations of engine power, which can improve vehicle drivability and greater knock resistance, thereby allowing fuel economy with higher compression ratios.

Multiple ignition system is one of the techniques to achieve rapid combustion. Multiple spark plug engines often use the initiation of flame propagation at two or more number of points in the combustion chamber depending on the number of spark plugs employed. If two plugs are employed the flame front travels from two points in the cylinder and the effective distance to be travelled by each flame is reduced. The concept of dual plug spark ignition is under consideration for more than last three decades. Several experimental studies were made in the area of dual ignition engines regarding optimization of spark plug location and to prove their efficient operation at part loads, extended EGR tolerance, extended lean misfire limit and relatively clean burning compared with single spark ignition systems [2] – [10]. Masonari Harada et al., [2] for example conducted experimental study on Nissan NAPS-Z engine which combines a fast burn combustion system and a heavy EGR system to realize low exhaust emission and high fuel economy. They found remarkable reduction in combustion duration due to rapid burning by shortening the distance of flame propagation achieved with the adoption of dual spark plugs. Even with 20% EGR, combustion duration was almost equal to that of conventional engine without EGR. R.W.Anderson et al., [3] also conducted experiments on twin plug engine and found improved combustion stability resulted from increased initial burning rate. M.M.Gosal et al., [6] conducted experimental investigations relating to the use of CNG on a dual spark ignition engine. It was found that lean misfire limit was extended by 10 to 15% as effective flame travel distance was reduced considerably (almost halved), thus increasing rate of combustion and ensuring the complete combustion of lean mixtures. They also found power enhancement and higher thermal efficiency with dual ignition especially at part loads. Also it was found that CO emission reduced by 25 to 30% and HC emission by 22 to 25%. A Ramtilak et al., [9] conducted experimental investigations on 150 DTS-i (digital twin spark ignition) engine and noticed the benefits like higher compression ratio, improved fuel economy, increased specific output per liter, increased torque, better drivability and reduced emission levels due to rapid combustion brought by twin spark plugs. Harish Chandra [10] showed experimentally that dual ignition system is advantageous in engines operating under the "conditions unfavorable to ignite" like poor fuel-air mixture quality or with significant misfiring. Effect of ignition timing on the performance of conventional engine with single plug, studied by few researchers [11] – [12] is also considered for reference. This brief review indicates that use of twin ignition sources accelerates the burning rate which in turn reduces the combustion duration. Thus the twin spark plug operation tends to improve the engine stability and efficiency, leading to smoother engine operation and reduced pollutants concentration in the exhaust. In the present work effect of ignition timings was analyzed in detail with respect to engine performance and emission parameters. Experiments were conducted with simultaneous, advanced and retarded Ignition timing of the secondary plug ($\pm 5^0$) with respect to that of original spark plug and also with single plug mode of operation for comparison.

2. Engine Modification, Experimental Set Up and Test Procedure:

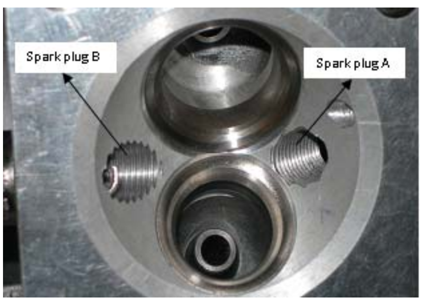


Figure 1: View of cylinder head with provision for twin plug

Experiments were conducted on a four-stroke air cooled petrol engine with necessary modifications to accommodate dual plugs. The fins over the engine dissipate heat to the surrounding air, thus preventing the overheating of the engine. A fan is provided to blow air over the engine fins for effective cooling. The inlet and exhaust valves are operated by cam shaft driven by crank shaft. The engine specifications are given in Table 1**.** Apart from the original spark plug 'A', whose diameter is 14mm, one more 14mm hole is threaded in the engine cylinder head diametrically opposite to it, to fit the second spark plug 'B' as shown in Figure1.

Table 1: Specifications of the Engine

Number of cylinders	1
Number of strokes	4
Cooling	Air cooled
Rated power	6kW @ 7500rpm
Cylinder diameter	0.053m
Stroke length	0.045m
Compression ratio	9.5
Orifice diameter	0.013m
Dynamometer	Eddy current type
Dynamometer arm length	0.185m
Coefficient of discharge for air flow orifice	0.64

The original spark plug 'A' is made to fire as per the ignition timing set by the manufacturer. It is a centrifugally advanced ignition system where the ignition timing varies with speed. The ignition timing is 10^0 BTDC at 1300 rpm and 32^0 BTDC at 4000 rpm. The spark plug 'B' is connected to a battery coil capacitor-discharge ignition system. Spark timing of spark plug 'B' is varied by using a spark timing variation unit fitted on to the engine shaft. The position of TDC and graduations of 1^0 are marked on either side up to 40^0 before and after TDC. This helps in setting the correct ignition time for the spark plug 'B'. The ignition time for plug 'B' is set manually.

To measure the air flow rate, an orifice tank is used. The pressure difference across the orifice is indicated by a manometer fitted to the tank. By noting the difference in water level in the two limbs of manometer the air flow rate can be calculated. The rate of fuel consumption is calculated by recording the time taken for consumption of 10 cc of fuel using a graduated burette.

The engine is directly coupled to an eddy current dynamometer. The dynamometer has the capacity to absorb the maximum power that can be produced by the engine. The brake power produced by the engine is measured by the dynamometer and is displayed on a digital load indicator.

The engine test rig is a computerized test rig. It is fitted with sensors to measure mean effective pressure, exhaust gas temperature, rate of fuel consumption, air flow rate, speed of the engine and a load sensor on the dynamometer unit. A PC loaded with necessary engine software is connected to the control and measuring unit of the engine. The data from the sensors is directly fed to the computer in appropriate form and the engine software processes all the information required like speed, load, torque, brake power, indicated mean effective pressure, brake mean effective pressure, indicated power, air consumption, fuel consumption, air-fuel ratio, specific fuel consumption, mechanical efficiency, brake thermal efficiency, indicated thermal efficiency, volumetric efficiency and exhaust gas temperature. This information can be stored for a particular test period, which is usually 1 minute and the recorded values are average values for this 1 minute of test period.

The schematic diagram of the engine set up is shown in Figure 2**.**

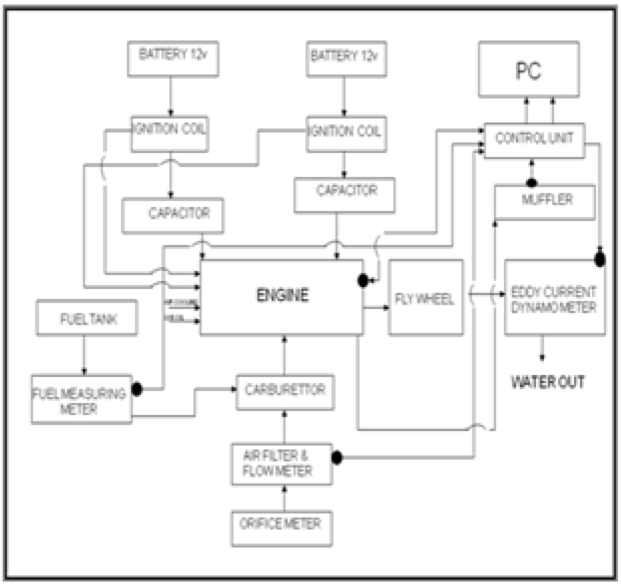


Figure 2: Schematic layout of engine test set up

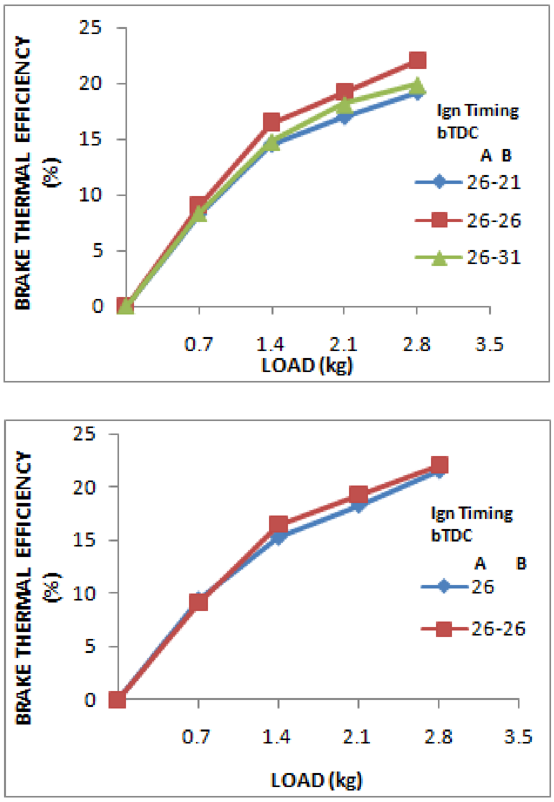


Figure 3: Variation of BTE with load for (a) Twin plug under different ignition timings (b) Comparison with Single plug

An exhaust gas analyzer was used to indicate the value of CO in %, NOx and UBHC in ppm present in the exhaust gas. The exhaust gas analyzer was initially tested for leakage and then allowed to warm up for 60 seconds. After that the hose pipe of the analyzer was inserted into the tail pipe of the engine. The reading displayed was then recorded. In the first round, experiment was conducted at 3000 rpm. The original spark plug 'A' was made to ignite at its standard ignition timing of 26^0 BTDC and the spark timing of other spark plug 'B' is also set for 26^0 BTDC to ensure that both the plugs fire simultaneously.

In the second round, ignition timing of the spark plug B was advanced by 5^0 (31^0bTDC) and retarded by 5^0 (26^0 bTDC).

The test was conducted separately in single plug and dual plug mode of operation at different load conditions. The different load conditions were 0%, 25%, 50%, 75% and 100% of the full load capacity of the engine.

3. Results and Discussions

Results obtained from the experiments conducted on single and double plug modes with three different ignition timings, namely, 26º-26º bTDC, 26 º-31º bTDC and 26 º-21º bTDC using pure gasoline are presented in the form of graphs in Figures 3 to 7.

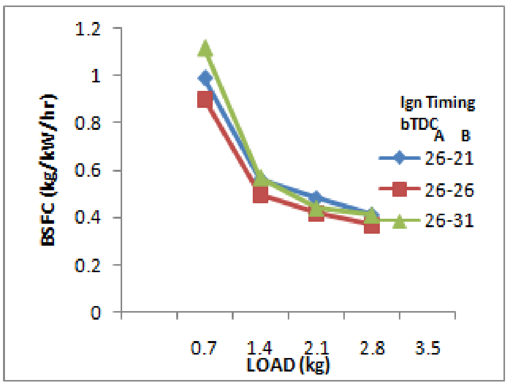
3.1 Performance parameters

3.1.1 Brake Thermal Efficiency (BTE)

The variation of brake thermal efficiency with load and the three ignition timings is shown in Figure.3 (a) for the twin plug mode of operation. From the graph following observations can be made,

- BTE increased with load for all the three ignition timings.
- It was observed that, BTE was maximum at simultaneous ignition timing of both the plugs (26^0-26^0 bTDC). As the ignition timing of plug B was advanced (26^0-31^0 bTDC) BTE reduced by --% and as it was retarded, (26^0-21^0 bTDC) BTE reduced by --%. This is due to the fact that the combustion of the unburned mixture is equally shared by the two plugs at the optimum ignition timings of 26^0-26^0 bTDC. Also the initiation of the spark at two places simultaneously reduces the flame travel distance ensuring faster and more complete combustion.

3.1.2 Brake Specific Fuel Consumption (BSFC)



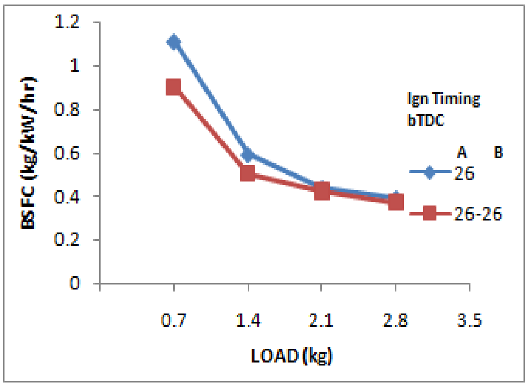
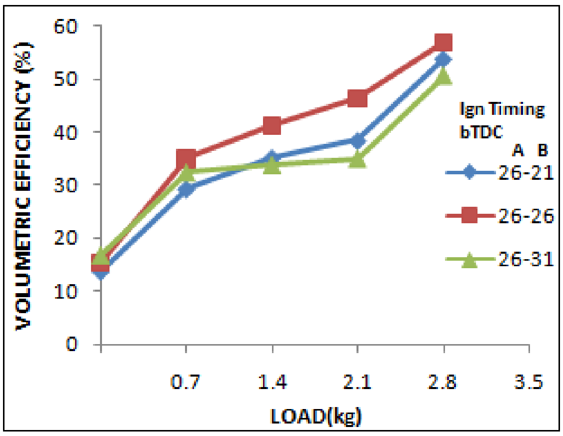


Figure 4: Variation of BSFC with load for (a) Twin plug under different ignition timings (b) Comparison with Single plug

Figure 4 (a) shows the variation of BSFC with load as well as with three ignition timings for twin plug mode of operation and Figure. 4 (b) shows the comparison with single plug mode of operation.

- BSFC decreased with load and was minimum at full load in both modes of operation, which confirms the maximum efficiency in this condition.
- As BSFC curve is mirror image of efficiency curve, it is lowest for the simultaneous ignition timing of 26^0-26^0 bTDC at full load.
- Figure.4 (b) shows wider gap in BSFC values between single and twin plug modes at lower loads. This indicates that mixture required at lower loads in twin plug mode is fairly lean.

3.1.3 Volumetric Efficiency



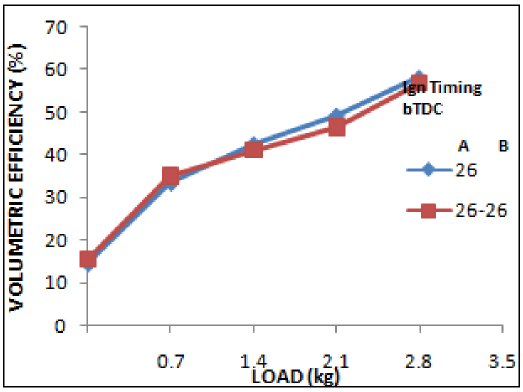
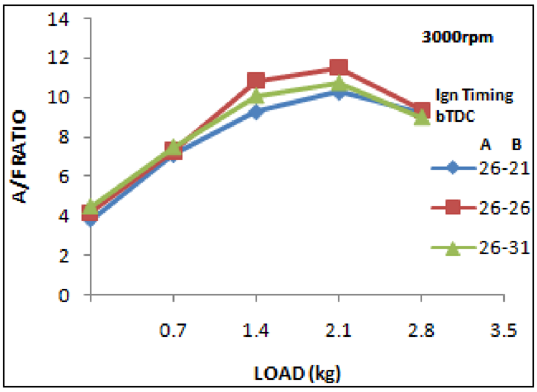


Figure 5: Variation of Volumetric efficiency with load for (a) Twin plug under different ignition timings (b) Comparison with Single plug

The variation of volumetric efficiency with load as well as with three ignition timings for twin plug mode of operation is shown in Figure.4 (a) and Figure.4 (b) shows the comparison with single plug mode of operation. Following observations are made.

- Volumetric efficiency was maximum for the simultaneous ignition timings of 26^0-26^0 bTDC
- It was observed that volumetric efficiency increased with load in all cases due to quantitative type of governing in carburetted engines.
- Volumetric efficiency in general was slightly less in case of twin plug operation relative to single plug mode. This is due to the fact that, rapid combustion in twin plug mode increases cylinder wall temperature which in turn results in higher combustion temperatures.

3.1.4 Air- Fuel Ratio



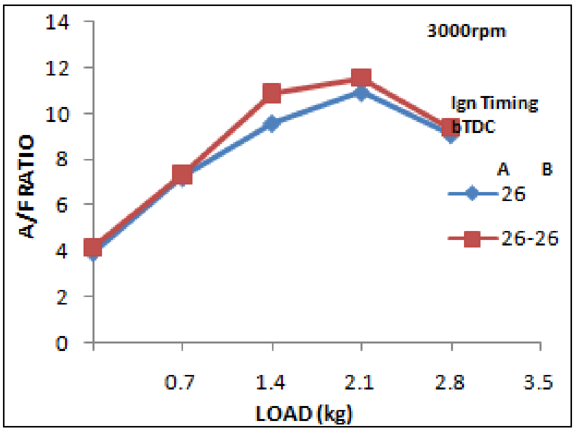
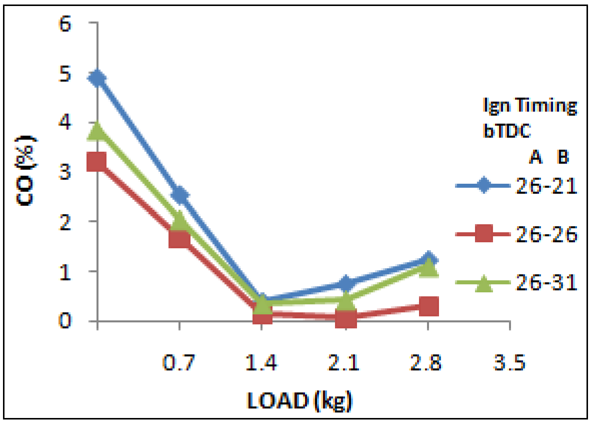


Figure 6: Variation of A/F ratio with load for (a) Twin plug under different ignition timings (b) Comparison with Single plug



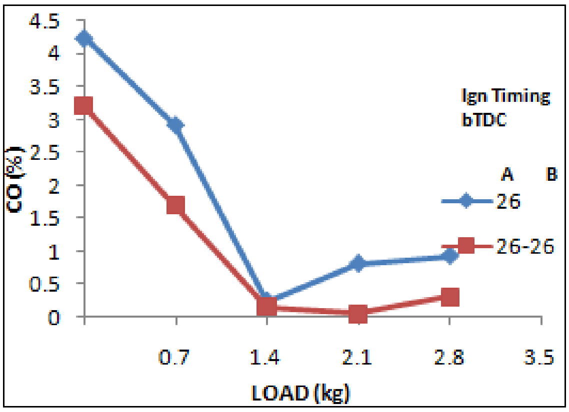


Figure 7: Variation of CO emissions with load for (a) Twin plug under different ignition timings (b) Comparison with Single plug.

Figure 6 (a) depicts the variation of A/F ratio with load as well as with three ignition timings for twin plug mode of operation and Figure. 4 (b) shows the comparison with single plug mode of operation.

Following observations are made.

- A/F ratio increased with load, reached maximum at 75% of full load and then decreased owing to requirement of rich mixture at full load in all three ignition timings.
- Maximum A/F ratio was observed at optimum ignition timings of 26^0-26^0 bTDC, which is --% more than that at

26^0-31^0 bTDC and --% more than that at ignition timing of 26^0-21^0 bTDC.

- A/F ratio in twin plug mode is higher than that at single plug mode, which confirms combustion of leaner mixture in this mode of operation.

3.2 Emission parameters

3.2.1 Carbon Monoxide (CO) emission

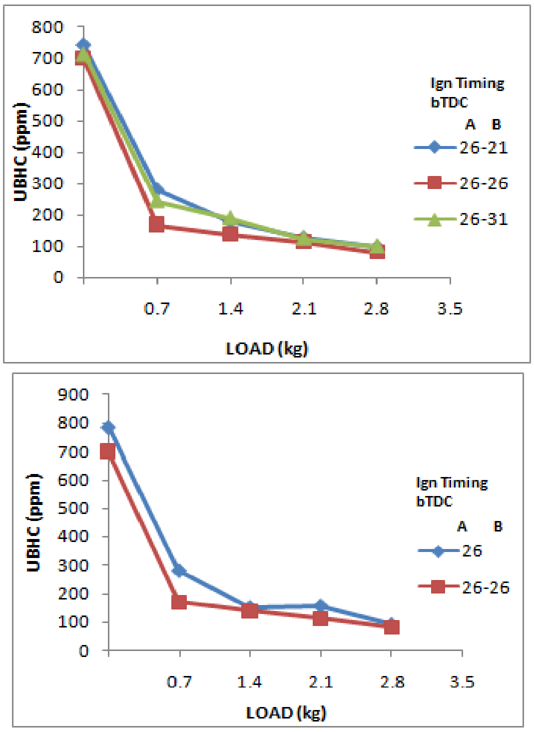
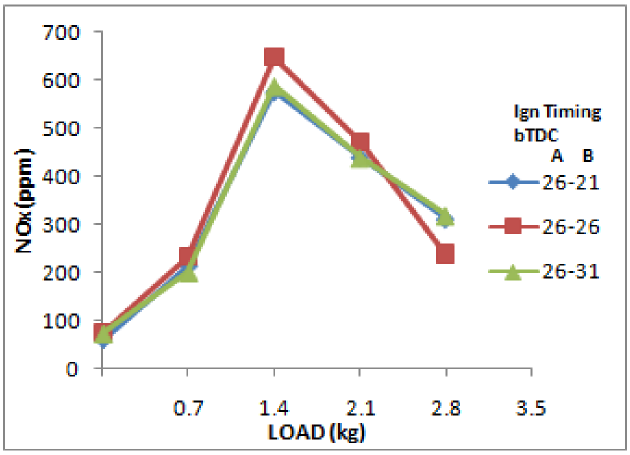


Figure 8: Variation of UBHC emission with load for (a) Twin plug under different ignition timings (b) Comparison with Single plug



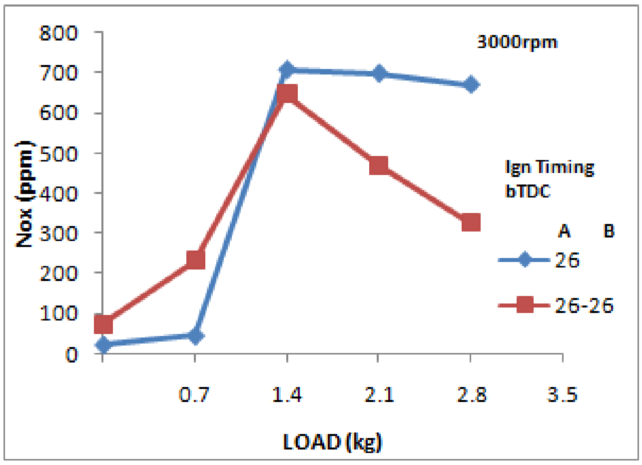


Figure 9: Variation of NOX emission with load for (a) Twin plug under different ignition timings (b) Comparison with Single plug

The main reasons for higher CO emissions are either incomplete combustion or rich mixture.

Figure 6 (a) shows the variation of CO emission with load as well as with three ignition timings for twin plug mode of operation and Figure. 6 (b) shows the comparison with single plug mode of operation. The following observations are made.

- Minimum CO emission was observed for the ignition timing of 26^0-26^0 bTDC. This is due to requirement of leanest mixture at this ignition timing.
- CO emission decreased with increase in load and reached minimum at 75% load and then again increased in all three cases.
- At lower loads higher CO emission was observed due to incomplete combustion. As the load increased, CO emission decreased due to more complete combustion of fuel. At full load, combustion requires rich mixture, hence CO emission was increased.
- Figure. 6(b) indicates that CO emission in twin plug mode is considerably reduced both at lower loads and higher loads, as compared with single plug mode. It clearly indicates better part load performance in twin plug mode of operation. Rapid rate of combustion in twin plug mode resulted in higher combustion temperature, which promoted oxidation of CO, hence CO emission was found to be less.

3.2.2 Un Burnt Hydrocarbon (UBHC) emission

UBHC emission increases either due to incomplete combustion or due to higher quench layer concentration (or thickness).

- Minimum HC emission was found for the simultaneous ignition timings of 26^0-26^0 bTDC, at full load.
- UBHC concentration decreased with increase in load for all the three ignition timings, owing to increasing engine temperature, which decreased the quench layer thickness.
- Also in twin plug mode, UBHC emission was 18% lower when compared with single plug mode, due to higher cylinder wall temperature.

3.2.3 NO_X emission

The favorable conditions for NO_X emission are oxygen availability and peak temperature. Figure.9 (a) and (b) respectively show the variation of NO_X emission with twin plug under the three ignition timings and comparison of the same with single plug mode of operation. Following observations can be made.

- Higher NOx emission was observed for the ignition timing of 26^0-26^0 bTDC, as both favourable conditions for NO_X emission exist in this ignition timing.
- The NOx emission increased from no load and reaches maximum at 75% load and then decreases in all three cases.
- Rapid combustion of the fuel increases temperature inside the engine cylinder. At high temperature nitrogen reacts with oxygen to form its oxides. Hence at twin plug mode higher NO_X emission was observed. At full load, the increase in F/A decreased NOx emission.

4. Conclusion

Following salient conclusions are made from the comprehensive investigation on the performance and emission characteristics of a twin spark plug S.I engine, made to run under different ignition timings and load conditions.

- Brake thermal efficiency was maximum at simultaneous ignition timings of 26^0-26^0 bTDC.
- BSFC was minimum for the ignition timing of 26^0-26^0 bTDC. Both advanced and retarded ignition timings of secondary plug lowered BTE and increased BSFC.
- Maximum Air-Fuel ratio and volumetric efficiency were observed for the ignition timing of 26^0-26^0 bTDC.
- CO and UBHC emissions are minimum for the ignition timing of 26^0-26^0 bTDC.
- Higher NO_X emission was observed for the ignition timing of 26^0-26^0 bTDC.
- On the whole, simultaneous ignition timings of both the spark plugs at 26^0-26^0 bTDC, at 3000 rpm gave best results with respect to performance and emission parameters, except for slight increase in NOx emission.

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Author Profile

Narasimha Bailkeri recieved B.E. degree in mechanical engineering from NMAM Institute of Technology, Nitte in the year 1990. He Obtained his Master's degree in the area of "Energy Systems Engg" in NMAM Institute of Technology, Nitte in 2005. He is also pursuing Ph.D under VTU in the area of Combustion Engineering. He has 22 years of teaching and currently working as Assistant Professor in the department of Mechanical Engg, NMAMIT, Nitte

Krishna Prasad S received B.E degree in Mechanical Engineering in the 2010 from NMAMIT Nitte. He obtained Master's degree in the area of 'Energy System Engineering' in 2012 from NMAMIT Nitte. He is currently working as Assistant Professor in the department of Mechanical Engg, NMAMIT, Nitte.

Shrinivasa Rao B. R obtained his B.E in Mechanical Engineering, from Malnad College of Engineering, Hassan. He obtained his M.Tech in Heat Power Engineering from KREC (NITK) Surathkal. He obtained his Ph.D in Mechanical Engineering, from NITK Surathkal in I.C. Engines in 2005. He has more than 24 years of teaching and research experience. He has more than 50 research papers in National/ International Journals and Conferences. He is currently guiding 5 Ph.D Scholars. He is Life Member of The Institution of Engineers (I), ISTE and Combustion Institute (I). He is currently working as Professor in the Department of Mechanical Engineering,NMAMIT,Nitte