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Research Article

PERFORMANCE OF AN SI ENGINE WITH DIFFERENT SPARK PLUGS, VCR AND H_2 ADDITION

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ABSTRACT

Following rapid depletion of fossil fuels and growing efficiency concerns enforce researchers to enhance combustion quality and find alternative fuels for SI engines. For this purpose, various spark plugs are available in the market with different electrode materials. However, they have not been tested together with different engine parameters. In this work, a variable compression ratio (VCR) spark-ignited engine equipped with different spark plugs (conventional, iridium and platinum) tested to determine performance values of brake power and brake specific fuel consumption. Effects of hydrogen enrichment (0%, 2% and 4% by volume fraction) and VCR (8.5:1 and 10:1) were applied to the engine at engine speeds of 1200, 1500 and 1800 rpm during experiments. The results revealed that higher performance values attained with iridium and platinum spark plugs comparing with the conventional spark plug at all hydrogen fractions, engine speeds and compression ratios. Besides that platinum spark plug increased the performance of the test engine more than iridium one.
Keywords: Spark plug, spark ignition, hydrogen fuel, engine performance, gasoline engine.

1. INTRODUCTION

The main energy demand in the world is supplied from fossil-based substances such as petroleum, coal and natural gas. Lack of energy and environmental issues have been becoming more serious along with the development of industry and economy. Especially, the automotive industry is faced with these severe and realistic challenges. Emission regulations and raised fuel costs are among these challenges. Even though the diesel market share is still very high in European Union nations, in the short-term, it is expected that the diesel engine inevitably will lose its share in the market rapidly. Particularly, considering recent emission - cheating scandals, the development of spark-ignition engines are being more and more essential for the future of the automotive industry. From this point, it can be said that the gasoline engine must be developed more and the usage of alternative fuels have to be assessed carefully from different aspects.

The gasoline engine is known for its high power to weight ratio, stable and silent performance, low prices, fewer maintenance needs and costs and feasibilities for CNG and LPG

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fuels comparing with the similar volume of diesel engines. Their utilizations are not critical only for road vehicles, but also power generating applications. However, their thermal efficiencies and torque outputs are lower compared with m odern diesel engines [1]. These main problems limit the widespread usage of gasoline engines such as heavy-duty machinery [2–5].

On the other hand, the above-mentioned problems can be solved by the lean burn which is one of the most effective ways to enhance fuel economy [6–8]. However, today's engines cannot be operated adequately lean because of ignition-related problems such as initiation and propagation of flame as well as potential misfiring. In the future of spark-ignited engine, it is expected that gasoline engines will operate with much higher compression ratios and much leaner fuel-to-air ratios for the sake of combustion enhancement and fuel economy. Furthermore, it will aggravate the electrode degradation and erosion of the spark plugs more [9–11]. To overcome these difficult challenges, the usage of strong and efficient spark plugs is seemed urgent for SI engines.

The spark plug is one of the most vital components in a car with an SI engine. A spark plug is not only responsible for providing reliable combustion initiation but also plays a critical role in obtaining optimum engine performance and stable operation.

The purpose of a spark plug is to ensure controlled combustion of the fuel in the engine. In order to do it, a high voltage generated by the ignition coil is introduced into the combustion chamber and the compressed fuel/air mixture is then ignited by the electric spark passing between the electrodes. Charge volume and density of the spark plug in the combustion chamber is another critical factor that influences engine performance and emission characteristic [12]. With increasing combustion volume, charge density or elongating ignition time, combustion completeness can be enhanced. However, there are some obstacles to improve these features. For instance, to increase charge density, the ignition system needs higher secondary coil voltage to start combustion in an SI engine. Nevertheless, producing the much higher voltage with these conditions would cause higher current passing between the electrodes so more electrode erosion short service lifetime of the spark plug [13].

The voltage and spark plug properties required highly depends on factors such as combustion chamber pressure during ignition, the distance between the electrodes (gap size), cylinder gas temperature, spark location, electrode's geometry, materials that used in the construction of spark plug and manufacturing methods [14–16]. Moreover, operating multiple spark plugs for each cylinder or employing the ignition point at an optimum place inside the combustion chamber could lead to a reduction in flame travel path and develop the combustion. Yet, it is quite difficult to apply multiple spark plugs in multi-cylinder engines, because of the already overcrowded cylinder head by exhaust and intake valves [17].

To improve spark plugs, manufacturers have presented to the market different types of spark plugs with various electrode materials such as yttrium, iridium, platinum, etc. The main purposes of usage of these noble metal materials are rapid attainment of operating temperature, increasing cold starting reliability, enhancing ignition, smooth engine operation and reducing the wear rate of electrodes. Nevertheless, these types of spark plugs that are available in the market must be evaluated in different engine operations from different aspects such as performance characteristics, emission values, electrode erosions and carbon buildup, etc...

Besides hydrogen blending [18–24] and VCR [25–27] are other efficiency development methods studied by many researchers in recent years. Hydrogen usage brings a lot of advantages due to its superior properties. Hydrogen is a colorless, inodorous and zero-carbon emitted fuel when fired with oxygen [28]. The chemical reaction of two hydrogen and oxygen atoms generates energy outputs and the product of the reaction is water only. Characteristic features of hydrogen such as flammability limits, low ignition energy, high burning rate ensure more stable combustion process and engine operation even for ultra-clean air-fuel mixtures. So, hydrogen enables to increase the combustion limits [29]. Hydrogen has a wider flammability range in the air which allows for engine operation with either rich or lean mixtures. Thus, by leaning the air-fuel mixture better fuel economy can be att ainable because of increased combustion completeness of the fuel. In addition to that, lean combustion results in lower NO_x emission because of the lower combustion temperature [30]. On the other hand, usage of the hydrogen in the engine as single fuel constraints the mileage of the vehicle. Besides that, the absence of light, safe and low-cost storage technology are bottlenecks. However, by using hydrogen fuel for dual fuel mode seems more reasonable and driving range problem can be compensated via this method [31] or by the novel investigation on D-EGR that is producing hydrogen fuel from waste gases [32] might expedite usage of H_2 in a road vehicle with SI engine.

On the other hand, the compression ratio is one of the core elements that influence engine performance and design. Engine efficiency can be improved further with a higher compression ratio that enables increment in the expansion ratio allow effective utilization of the fuel. Furthermore, the increment of the compression ratio yields decreased exhaust gas dilution of the fresh mixture which increases cylinder temperature and pressure. This allows shorter ignition delay and combustion duration as a consequence of increased flame speed. Also, the compression ratio increment of an engine is a functional way to attain a wider backfire-free running range of the engine. Besides, increasing the compression ratio minimizes the residual gas amount in the combustion chamber and thereby reduces the possibility of backfire [33].

From these points of view, although there are studies on spark plug gap, electrode erosion, lifetime, location and spark plug quantity, no paper has investigated the effects of spark plugs with different electrode types with different engine parameters on engine performance. Therefore, the main purpose of this study was to determine the effects of iridium and platinum spark plugs on engine performance along with hydrogen enrichment and VCR at different engine speeds and comparing their performances with the engine running with gasoline and conventional spark plug.

2. EXPERIMENTAL METHODOLOGY

2.1. Experimental Setup

Engine tests were conducted on a four-stroke, single-cylinder, naturally aspirated, water-cooled, variable compression engine that can operate with both gasoline and diesel fuel by replacing the engine head. Technical specifications of the engine were given in Table 1 and the schematic representation VCR engine test rig was shown in Fig. 1.

Table 1. Technical specifications of the test engine

Brand – Model	Kirloskar Oil Engines Limited
Model	240 (run both SI and CI)
Configuration	Single-Cylinder Engine
Type	Four Stroke,
Cooling	Water Cooling
Displacement	661 cc
Bore	87.5 mm
Stroke	110 mm
Min. / Max. Operating Speed	1200/1800 rpm
CR range	6:1-10:1
Injection Variation	0-25º BTDC
Spark Timing	MBT
Peak Pressure	77.5 kg/cm^2
Weight	160 kg
Lubricating System	Forced Feed System

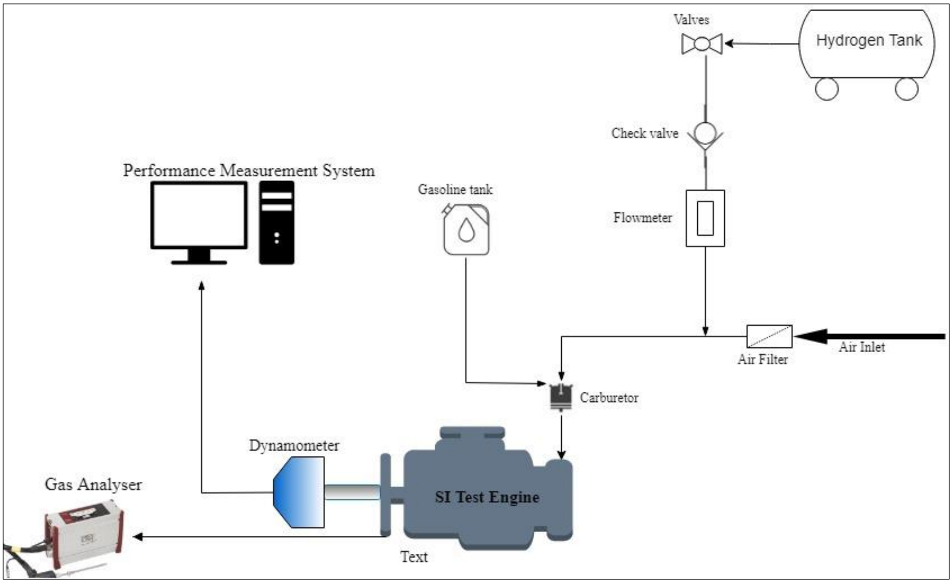

Figure 1. Schematic representation VCR engine test rig

In the experiments, an eddy current dynamometer and a Sa-Beam load cell were used for the determination of torque and power output. The AG series bi-directional eddy current dynamometers can measure engines up to 400kW and it can be adopted with various control systems. Dynamometer load was measured by strain gauge load cell and the engine speed was determined by shaft mounted 360 PPR rotary encoder. The technical specifications of the dynamometer and load cell were given in Table 2 and Table 3.

Table 2. Technical specifications of the dynamometer

Model	AG10
Brand	Saj Test Plant Pvt. Ltd.
End flanges both side	Cardan shaft model 1260 type A
Water inlet	1.6 bar
Hot coil voltage max	60
Continuous current amps	5.0
Load	3.5 kg
Weight	130 kg
Speed max.	10000 rpm

Table 3. Technical specifications of the load cell

Model	60001
Capacity	0-50 kg
Non-linearity	<+/-0.025%
Non-repeatability	<+/-0.010%
Operating temperature range	-20 ^{0}C to +70 ^{0}C
Combined Error	<+/-0.025%

The spark plugs were purchased from the local suppliers and then before mounting the engine, SPGs of each spark plug were equalized and set as 0.7 mm by feeler gauge. The technical specifications of the spark plugs were given in Table 4. Additionally, the spark plug has a nickel center electrode and copper center electrode named "conventional" in this text that.

Table 4. Technical specifications of spark plugs used in the experiments

	Type	Conventional	Iridium	Platinum
SPECIFICATIONS	Brand	BOSCH	NGK	NGK
	Parts No.	UR3DC	CR9EIX	CR9EHVX-9
	Thread Size	10 mm	10 mm	10 mm
	Thread Pitch	1.0 mm	1.0 mm	1.0 mm
	Seat Type	Gasket	Gasket	Gasket
	Resistor	Yes	Yes	Yes
	Resistor Value	5K Ohm	5K Ohm	5K Ohm
	Reach	19 mm	19 mm	19 mm
	Hex Size	16 mm	16 mm	16 mm
	Terminal Type	Threaded Stud	Threaded Stud	Threaded Stud
	Overall Height	ISO	ISO	Bantam
	Original SPG	0.7 mm	0.8 mm	0.7 mm
	Heat Range	8	8	8
	Longevity	30k	40-50k	50k
CENTER ELECTRODE	Material	Nickel	Iridium	Platinum
	Type	Fine wire	Fine wire	Fine wire
	Size	2.5 mm	0.6mm	0.6 mm
GROUND ELECTRODE	Material	Copper	Nickel	Platinum
	Type	Standard	Standard	Standard
	Shape	Taper-Cut	Taper-Cut	Taper-Cut
	Quantity	1	1	1

2.2. Experimental Procedure

Engine performance measurement experiments were executed with two different compression ratios (8.5:1 and 10:1), engine speeds of 1200, 1500 and 1800 rpm to evaluate the effects of spark plugs with different types of electrode material and hydrogen usage. During the experiments, spark timing was set to MBT for all test conditions. The compression ratios and engine speeds were chosen considering original engine operation limits. Conventional, iridium and platinum spark plugs were tested respectively for each experiment condition. Besides, hydrogen was blended through the intake manifold with volume fractions (α_{H_2}) of 0%, 2% and 4% to enhance the combustion of the VCR engine. In consideration of knock, these selected hydrogen blending values are within the limits recommended in the reference [34]. The volume fractions of hydrogen can be calculated by the following equation:

$$\boldsymbol{\alpha_{H_2} = V_{H_2}\left(V_{H_2} + V_{air}\right) \times 100} \quad (1)$$

Before the experimental measurements engine was run 5 minutes with pure gasoline to attain stable operation conditions. Once the engine had warmed up, all experiments were performed approximately at 90 C° "Enginesoft" software was used for logging experimental data. This software logs for 60 seconds when logging starts and at the end of this period gives the average values of experimental data. Each experiment was repeated five times to verify the results. The uncertainty of BP and BSFC measurements were approximately ±2.5% and ±3%, respectively.

As a result of the experiments, brake power (BP) and specific fuel consumption (BSFC) were obtained to evaluate the effects of the applied methods on performance characteristics of a four-stroke, naturally aspirated, water-cooled and spark-ignited test engine.

3. RESULTS AND DISCUSSION

Brake power defined as power output from flywheel or crankshaft of the engine is one of the most critical performance criteria for internal combustion engines as well as BSFC. Figure 2-3 shows the BP output results of the experiments and Figure 4-5 illustrates the BSFC values with different compression ratios (8.5:1 and 10:1) and engine speeds of (1200, 1500 and 1800 rpm).

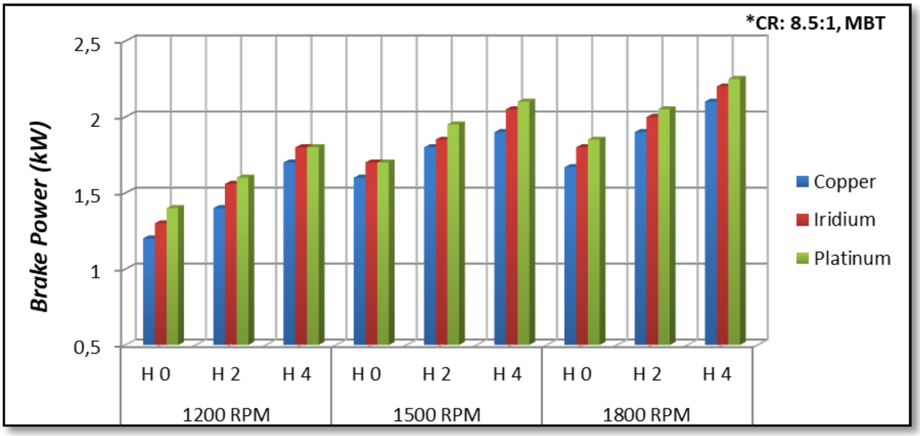

Figure 2. BP values for CR of 8.5:1

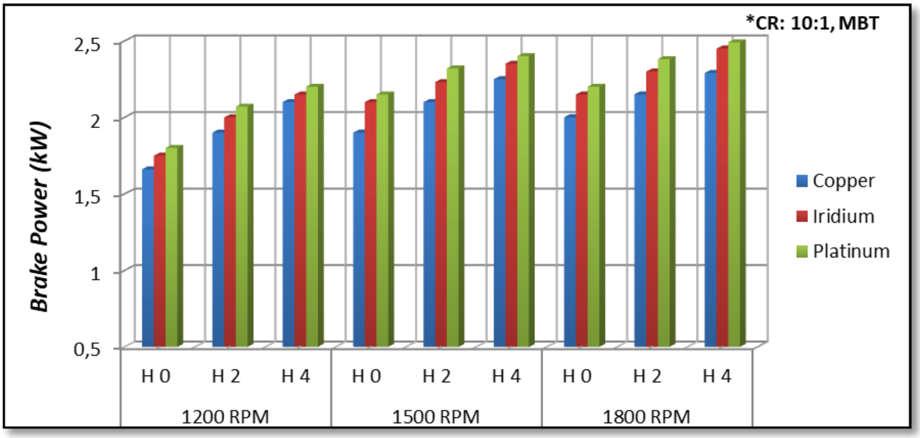

Figure 3. BP values for CR of 10:1

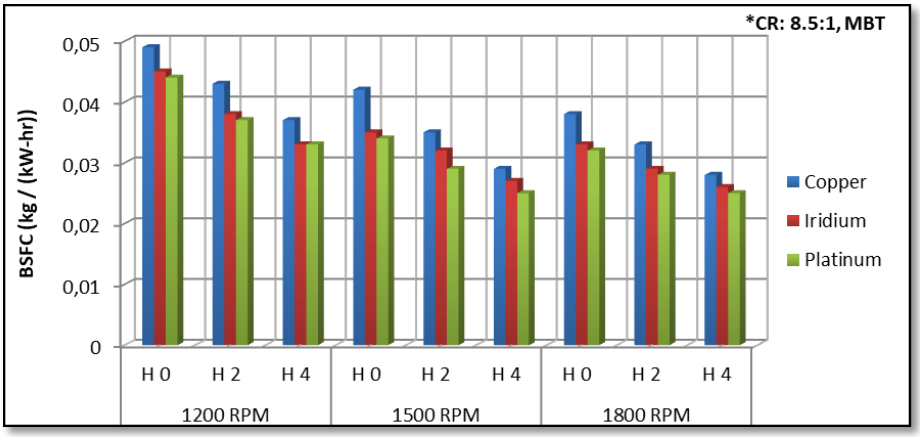

Figure 4. BSFC values CR of 8.5:1

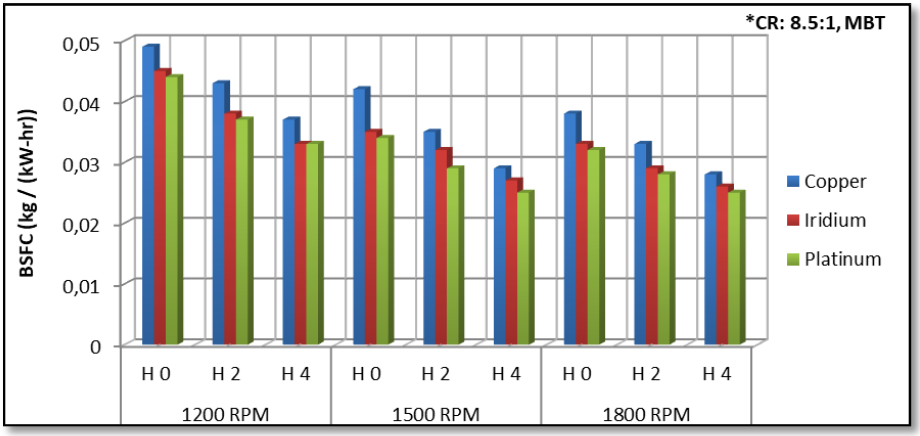

Figure 5. BSFC values CR of 8.5:1

As can be seen from graphs, usage of iridium and platinum spark plugs improved BP and BSFC values at all speeds. Normally, it could be expected vice versa because platinum and iridium spark plugs are less electrically conductive. However, platinum and iridium spark plugs can be produced with smaller electrodes with the help of strong features of platinum and iridium metals. Thereby, this allows early flame propagation [35]. Moreover, platinum spark plug enhanced performance parameters more than the iridium spark plug. For iridium spark plug, between 2.27% - 11.43% and for platinum spark plug between 4.76% - 16.67% increments in BP were obtained. In addition, BSFC values reduced with iridium and platinum spark plugs between 3.45% - 16.67% and 6.45% - 19.05%, respectively.

On the other hand, both hydrogen induction into the combustion chamber and higher compression ratio expedited performance improvement due to enhanced combustion completeness, remarkably as mentioned in [33,36]. Superior chemical and physical properties of hydrogen fuel such as high diffusion and flame speed improved the combustion completeness of the test engine. Furthermore, higher CR permitted the engine to obtain more mechanical energy from the air-fuel mixture. This was the result of higher thermal efficiency created by reaching the same combustion temperature with less fuel, while having a longer expansion cycle, giving more mechanical power output. Besides, performance enhancement depending on spark plugs, higher CR and hydrogen enrichment was slightly lower at higher engine speeds in general.

On the other hand, taking into account the tendency to knock of hydrogen and higher CR, all parameters can be optimized to obtain the best performance considering knock limits in subsequent investigations.

4. CONCLUSIONS

In this study, the performance characteristics of a spark-ignition engine at various compression ratios fuelled with gasoline and hydrogen-enriched gasoline fuels were determined. During the experiments the engine compression ratio was set as 8.5:1 and 10:1 and conventional, platinum and iridium spark plugs performed one by one. Besides, each test condition was executed at different engine speeds of 1200, 1500 and 1800 rpm. According to experimental results, the followings were concluded;

- Changing conventional spark plug with iridium and platinum spark plugs expedited combustion development resulting in enhanced BP, BSFC at all compression ratios, engine speeds and hydrogen fractions.

- Improvement in BP and BSFC was more for platinum spark plug than iridium type.
- •Adopting an iridium or platinum spark plug in the engine can compensate their higher first purchasing cost considering their longevity, too.
- Similar to spark plug changing, hydrogen addition increased BP and reduced BSFC comparing with unhydrogenated fuels.
- Increasing the hydrogen volume fraction triggered variation performance parameters depending on hydrogen's combustion accelerator function.
- Increasing CR improved BSFC and BP values for all test fuels.
- At higher engine speeds, changes in values of performance parameters depending on higher compression ratio, hydrogen addition and changing spark plug type were lower comparing with lower engine speeds.
- The favorable result was obtained for platinum SP, CR of 10:1 and H4 fuel combination.

NOMENCLATURE

BSFC	**:**	Brake Specific Fuel Consumption [kg / kW-hr]
BP	**:**	Brake Power [kW]
BTDC	**:**	Before Top Dead Center
CNG	**:**	Compresses Natural Gas
D-EGR	**:**	Dedicated Exhaust Gas Recirculation
H	**:**	Hydrogen
H 0	**:**	No hydrogen addition
H 2	**:**	Hydrogen addition of %2 by volume fraction
H 4	**:**	Hydrogen addition of %4 by volume fraction
LPG	**:**	Liquefied Petroleum Gas
MBT	**:**	Maximum Brake Torque
n	**:**	Engine Speed [rpm]
CR	**:**	Compression Ratio
rpm	**:**	Revolution per Minute
SI	**:**	Spark Ignition
SP	**:**	Spark Plug
SPG	**:**	Spark Plug Gap
VCR	**:**	Variable Compression Ratio
$\boldsymbol{\alpha_{H_2}}$	**:**	Hydrogen Volume Fraction [%]
$\boldsymbol{V_{H_2}}$	**:**	Hydrogen Flow Rate [L/min]
$\boldsymbol{V_{air}}$	**:**	Air Flow Rate [L/min]

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