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RESEARCH ARTICLE

Design and experimental investigations on six-stroke SI engine using acetylene with water injection

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Abstract

In the present study, a four-stroke cycle gasoline engine is redesigned and converted into a six-stroke cycle engine and experimental study has been conducted using gasoline and acetylene as fuel with water injection at the end of the recompression stroke. Acetylene has been used as an alternative fuel along with gasoline and performance of the six-stroke spark ignition (SI) engine with these two fuels has been studied separately and compared. Brake power and thermal efficiency are found to be 5.18 and 1.55% higher with acetylene as compared to gasoline in the six-stroke engine. However, thermal efficiency is found to be 45% higher with acetylene in the six-stroke engine as compared to four-stroke SI engine. The CO and HC emissions were found to be reduced by 13.33 and 0.67% respectively with acetylene as compared to gasoline due to better combustion of acetylene. The NO_x emission was reduced by 5.65% with acetylene due to lower peak temperature by water injection. The experimental results showed better engine performance and emissions with acetylene as fuel in the six-stroke engine.

Keywords Acetylene fuel · Six-stroke engine · Exhaust heat recovery · Water injection · Engine performance

Abbreviations

SI	Spark ignition
CO	Carbon monoxide
HC	Hydrocarbon
NO_x	Nitrogen oxides
CO_2	Carbon dioxide
LPG	Liquefied petroleum gas
CA	Crank angle
TDC	Top dead center
NDIR	Non-dispersive infrared radiation
MEP	Mean effective pressure
FC	Fuel consumption
BP	Brake power
BTE	Brake thermal efficiency

Nomenclature

W_{net}	Net work (watt)
V_{disp}	Displacement volume (m^3)
N	Speed (RPM)
n_s	Number of crank revolution
P	Power (Watt)
T	Torque (N-m)

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Introduction

Today, the world is facing a crisis of fossil fuel and environmental degradation. The spark ignition (SI) engines used in transportation as well as in small power generation running on conventional fossil fuels are emitting pollutants such as HC, CO, CO_2, and NO_x. The global warming is particularly

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Table 1 Comparison of physical and combustion properties of acetylene and gasoline

Properties	Acetylene	Gasoline
Composition	C_2H_2	C_8H_{18}
Density kg/m3	1.092	800
Auto ignition (°C)	305	246
Stoichiometric air-fuel ratio	13.2	14.7
Calorific value (kJ/Kg)	56,000	44,000
Ignition energy(mJ)	0.017	0.8

increased by CO_2 greenhouse gas. Natural gas, liquefied petroleum gas (LPG), hydrogen, acetylene, producer gas, alcohol, and vegetable oil are promising alternative fuel for an internal combustion engine (Venkata Sundar Rao et al. 2018) (Bae and Kim 2017) (Othman et al. 2017). Total or partial replacement of conventional fuels has been developed and introduced. Many gaseous fuels can be produced from renewable sources in nature. Gaseous fuels are suitable for spark ignition engines due to high self-ignition temperature. The use of acetylene as an alternative fuel for CI and SI engines is an appropriate field of research to obtained desirable performance and reduced emissions (Choudhary et al. 2018) (Abedin et al. 2013). Acetylene is a colorless gas, smelling like garlic, and can be produced from calcium carbide (CaC_2) as well as synthesized from natural gas. With high flame speed, fast energy release, and high combustion capability, acetylene can be used as alternative fuel in SI engine. For initiation of ignition, it required minimum ignition energy with-in flammability range, as shown in Table 1.

In the reciprocating engines, the six-stroke engine is considered more fuel efficient and less pollutant as compared to two-stroke and four-stroke engines. Many studies have been done and various designs were developed for six-stroke engines. The design is basically based upon the addition of one steam power stroke and an exhaust stroke to the conventional four-stroke engine. The alternative cycle approach for the internal combustion engine is of Miller and Atkinson cycle. It was reported that in these cycles thermal efficiency is increased and power output is decreased along with a decrease in specific fuel consumption. Thus, six-stroke engine is considered a hybrid engine. The effect of water injection quantity and injection timing on engine performance and exhaust emission in six-stroke engine was analyzed (Arabaci et al. 2015; Arabaci and İçingür 2016). In an experimental study two extra strokes were added to the four-stroke engine to convert it in to the six-stroke engine. These two strokes were worked on steam cycle and the extra air was delivered in the cylinder at the end of conventional exhaust stroke. Unlike four-stroke engine, second expansion stroke obtained at 1080° crank angle (°CA) and the cycle was completed (Griffin 1889).

Schimanek (1932) reported increased power output via increasing the volumetric efficiency. He incorporated two extra steam strokes in the conventional four-stroke SI engine. Dyer (1984) discussed the six-stroke engine in more detail. He mentioned that, due to use of waste heat, the engine efficiency is increased. The exhaust process was more efficient and cooling system can be simplified in a six-stroke engine as compared to the four-stroke engine. The peak cylinder pressure was reported to be higher with water injection into hot gases during the fourth stroke, followed by many variants on related cycles with more detailed description of mechanisms and recovery cycles (Shukla and Alimi 2015; Tibbs 1976; Larsen 1988; Singh 2003; Nash 1889; Williams and Fiveland 2011, 2015). Conklin and Szybist (2010) proposed the addition of two extra strokes to the conventional four-stroke engine cycle to increase the thermal efficiency. The additional power stroke was obtained by partial exhaust process along with water injection in the cylinder. Waste heat recovery has been compiled in two folds: (i) injected water was heated by using coolant heat and (ii) water was vaporized in cylinder by absorbing heat of hot gases during the fourth stroke. To investigate the performance with this modification, a thermodynamic model of exhaust gas compression, water injection, and expansion was used.

Kiran (2013) and Manglik (2014) were done the theoretical study on converting four-stroke conventional engine into six-

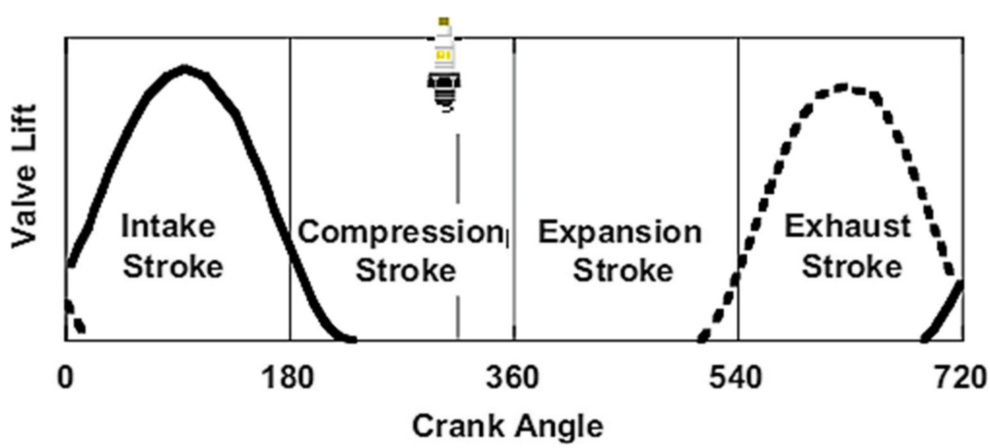

Fig. 1 Schematic of intake and exhaust valve timing for gasoline engine (Conklin and Szybist 2010)

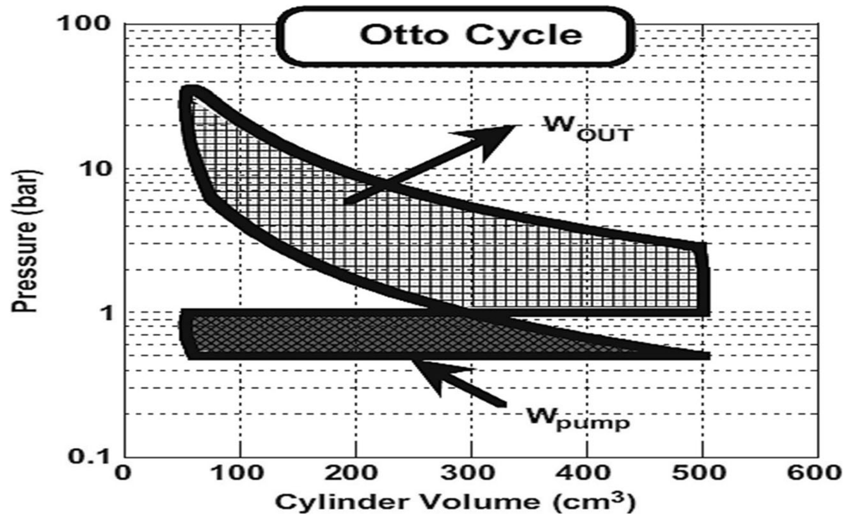

Fig. 2 Pressure-volume diagram for a gasoline engine (Conklin and Szybist 2010)

stroke engine. They have worked on the waste heat recovery from internal combustion engine.

The efficiency of conventional Otto or diesel cycle was improved by incorporating two additional strokes. The four strokes include (1) suction stroke, (2) compression stroke, (3) power stroke, and (4) exhaust stroke. Figure 1 shows a schematic intake and exhaust valve actions and Fig. 2 shows pressure-volume diagram for a four-stroke gasoline engine respectively (Conklin and Szybist 2010).

The two additional strokes were incorporated in modified cycle that increases the work output per unit of fuel consumed. These two strokes comprise trapping and recompression associated with water injection and expansion of resulted mixture of steam and gases. By closing the exhaust valve before the normal crank angle degree, the residual gases were trapped in the cylinder before top dead center (TDC). To increase the pressure, water was injected into trapped recompressed exhaust gases which also provide the latent heat of vaporization to the water. More work was produced from this increased pressure by another expansion stroke. The modified sequence of strokes has been shown in Fig. 3 and the corresponding pressure-volume curve is shown in Fig. 4.

Figure 5 represents exhaust lift, intake lift, and pressure versus crank angle curve, where recompression and water injection are clearly shown.

Therefore, the thermal efficiency of the engine was increased by an additional power stroke without any additional amount of fuel.

Some of the patent were awarded for the new six-stroke engine cycle designs that incorporate the two-stroke steam cycle with the four-stroke cycle. The first patent was in the name of Dyer (1920), followed by others with modifications in very similar cycles with more detailed explanation of component and recovery modes. The exhaust stroke was utilized during crank angle (CA) 540–720°, and water was injected at the end of the stroke.

In addition, a complete exhaust stroke is a preferred configuration. The engine cycle described here uses water injection to absorb the latent heat of vaporization from the gases in the cylinder during the fourth stroke and convert into steam. Figure 6 shows the schematic of pressure trace for exhaust recompression and steam injection of thermodynamics state.

The (Szybist and Conklin 2012) was converted a single cylinder, four-stroke, spark ignition engine into the six-

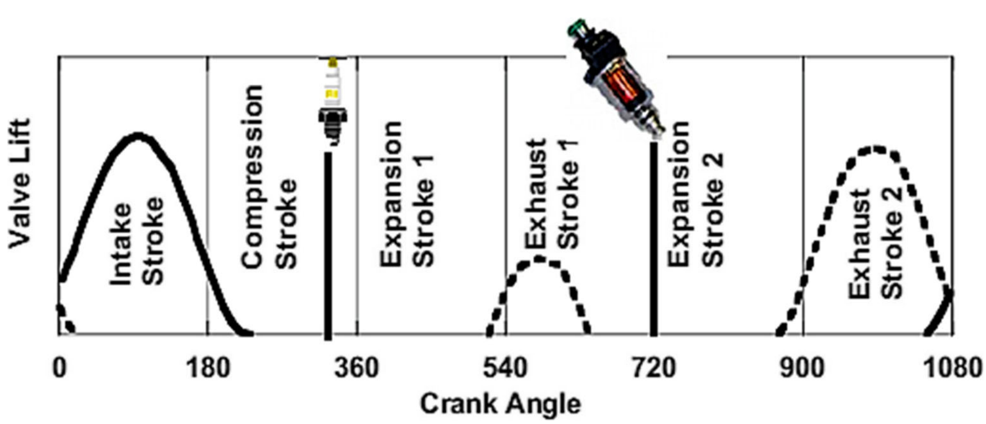

Fig. 3 Schematic of intake and exhaust valve timing for six-stroke engine (Conklin and Szybist 2010)

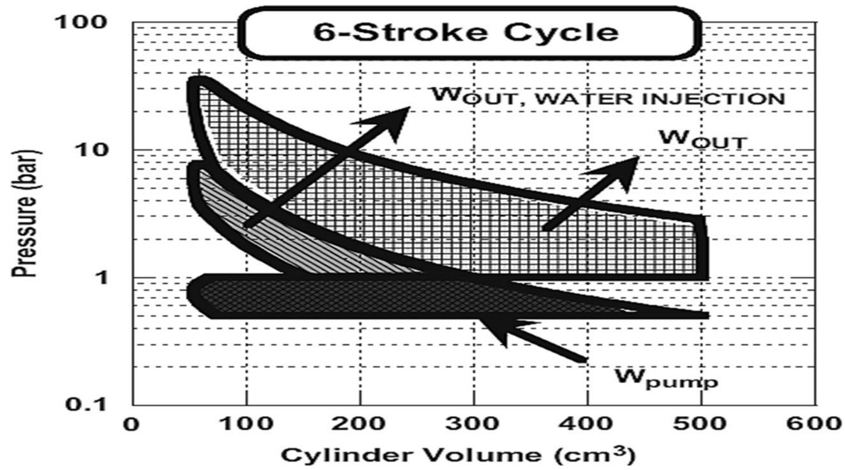

Fig. 4 Pressure-volume diagram for a six-stroke engine (Conklin and Szybist 2010)

stroke engine to investigate its performance with water injection. It was reported that the increased efficiency of six-stroke cycle engine is due to heat recovery from engine exhaust (in the cylinder) and from coolant (to heat water prior to injection). The six-stroke engine is an efficient mean of in-cylinder waste heat recovery with water injection in the fourth stroke.

It can be observed from the literature that very few work was done on the investigation of the performance of a six-stroke engine. Particularly, investigation of a six-stroke SI engine using acetylene fuel is missing in the literature. This made a motivation for present work on a six-stroke SI engine using acetylene.

To convert four-stroke engine into six-stroke engine, a crankshaft to camshaft gear ratio was modified. For this modification, the camshaft and mating gears were remanufactured. The high-pressure direct injector was mounted in the cylinder head in order to inject the water into the cylinder directly. Spark timing was modified to a definite degree manually (from 35 to 25° CA). The experiment was conducted at the stoichiometric condition and full load using acetylene as a test fuel. The water was injected at the end of the fourth stroke to maintain the temperature of the combustion chamber. The produced steam enhanced the power output and thus increased the efficiency and reduced the emissions of CO, NO_x, and HC. The performance and emissions of a modified six-stroke SI engine with varying speed are presented in this work.

Experimental setup and methodology

A modified single cylinder, six-stroke, air-cooled, spark ignition Bajaj Pulsar 180-cm^3 model engine as shown in Table 2 was used in the present study.

Due to extra expansion stroke with water injection, the thermal efficiency of the six-stroke engine is comparatively

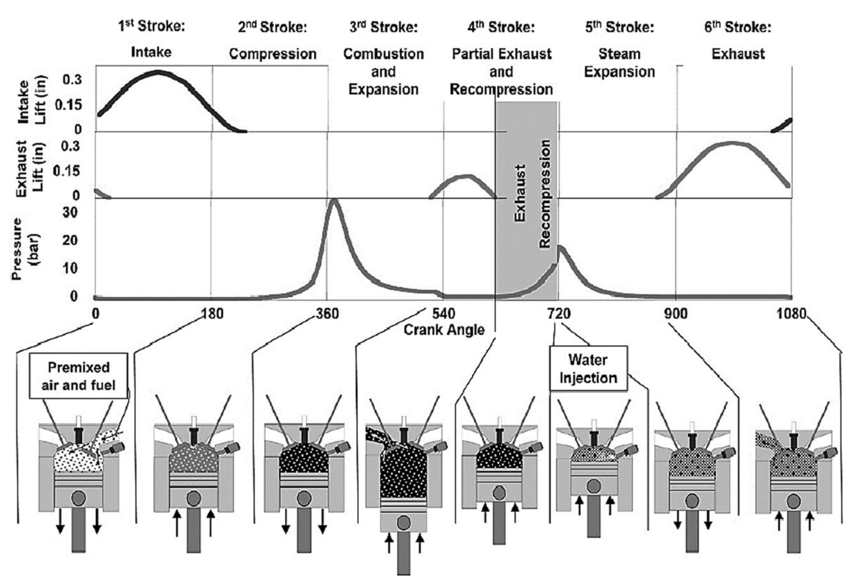

Fig. 5 Exhaust lift, intake lift, and pressure versus crank angle curve for the six-stroke engine (Conklin and Szybist 2010)

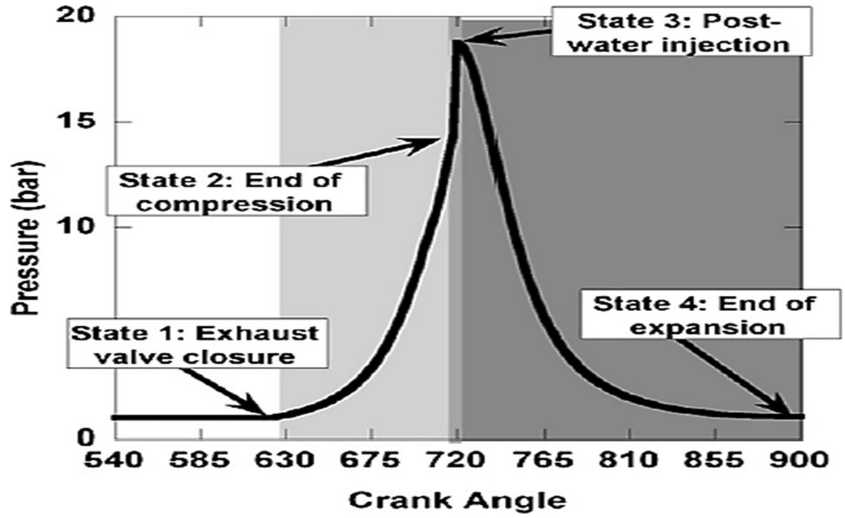

Fig. 6 Schematic of pressure trace for exhaust recompression and steam injection depicted thermodynamics state (Conklin and Szybist 2010)

higher as compared to the four-stroke engine. Extra expansion stroke helps in converting more energy into useful work.

Acetylene was introduced into the intake manifold by a non-return valve arrangement through a flame trap. The flow of acetylene is regulated through a calibrated gas flow meter.

The basic working principle followed by a six-stroke engine remains the same as that of a conventional four-stroke engine with the addition of two extra strokes operated by steam power. The extra power was generated by the use of waste heat of in-cylinder gases in fourth stroke.

The heat evolved in the exhaust stroke (i.e., fourth stroke) used for sudden expansion of the steam to create a second power stroke (i.e., fifth stroke), in which the piston was pushed downward and provide the power to rotate the crankshaft for another half cycle.

With the use of acetylene, the heat generated in the fourth stroke is at very high temperature. The injected water in fourth stroke also helps to control the temperature in the combustion chamber. Thus, use of acetylene as a fuel in six-stroke SI engine with water injection would be a feasible option. In three complete cycles of the crankshaft, fuel was injected at once similar to the four-stroke cycle. That means for the same amount of fuel, more power can be generated in a six-stroke engine. The pictorial view and schematic of the modified six-stroke engine are shown in Figs. 7 and 8. The distilled water was used to inject into the combustion chamber where it is converted into superheated steam and causes to expand the volume and forces on the piston down for the additional power stroke.

The working of the six-stroke engine is described as follows:

Suction stroke (*I stroke*): during the first stroke, the downward movement of the piston sucks air-acetylene mixture in the cylinder from the carburetor through the open inlet valve.

Compression stroke (*II stroke*): during the second stroke, the piston moves upward, thus compressing the charge. Both the inlet valve and exhaust valve are closed and the air-fuel mixture is compressed.

Expansion stroke (*III stroke*): during the third stroke, the expansion of the gases due to the heat of combustion exerts a pressure on the cylinder and piston. Both valves remain closed. The piston moves from the top dead center to bottom dead center.

Recompression stroke (*IV stroke*): in the fourth stroke, the piston moves from the bottom dead center to top dead center. Both the inlet and exhaust valve were closed. When the piston reaches to the top dead center, water injector injected water in the combustion chamber which is converted into steam.

Steam power stroke (*V stroke*): during the fifth stroke, the steam initiates the second power stroke. Both valves

Table 2 Specification of the engine from the manufacturer

Model	Bajaj Pulsar (180 cm^3)
Displacement	178.2 cm^3
Valve system	Overhead
Bore	63.5 mm
Stroke	56.4 mm
Cylinder	1
Max. power	17 kW
Max. torque	14 Nm
Valve per cylinder	2
Fuel delivery system	Carburetor
Fuel type	Acetylene
Compression ratio	9.5:1
Cooling system	Air cooled

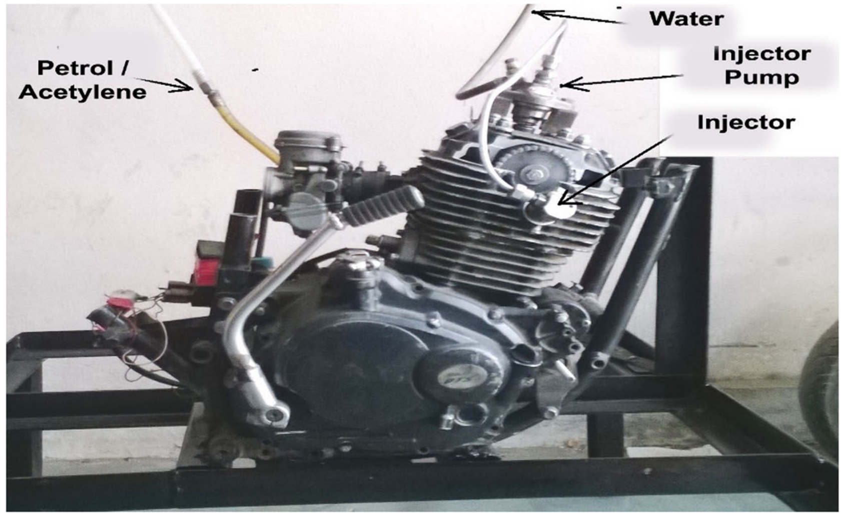

Fig. 7 The modified six-stroke engine used for study

remain closed. The piston moves from the top dead center to bottom dead center.

Exhaust stroke (*VI stroke*): during the sixth stroke, the piston moves from the bottom dead center to top dead center. The inlet valve remains closed. The exhaust valve was opened and the exhaust gases were released. Figure 5 shows the working of the six-stroke engine.

Exhaust gas temperature was measured by a chromel-alumel K-type thermocouple. The exhaust gases CO, HC, and NO_x were measured by using a gas analyzer model ZSJ (21C1-E-0032). The basic principle of measuring CO and HC is non-dispersive infrared (NDIR) and electrochemical method is for NO_x measurement.

Crankshaft to camshaft ratio modification

In a four-stroke engine, the crankshaft gear rotates at 720° and the camshaft gear rotates at 360° in one complete cycle. In a six-stroke engine, the crankshaft gear must rotate at 1080° and the camshaft gear at 360° in one complete cycle. Thus, the gear ratio is 3:1, i.e., for every three revolutions of the crankshaft, the camshaft rotates once. Water injection system is also controlled by the camshaft. The view of the modified sprocket with 33 teeth is shown in Fig. 9.

In the Pulsar 180-cm^3 (four-stroke) engine, the ratio of the timing chain is 1:2, i.e., 16 teeth in crankshaft and 32 teeth in the camshaft. For a six-stroke engine, the ratio of the timing chain is 1:3, hence 11 teeth in the crankshaft and 33 teeth in the camshaft. The view of the modified crankshaft to camshaft gear ratio is shown in Fig. 10.

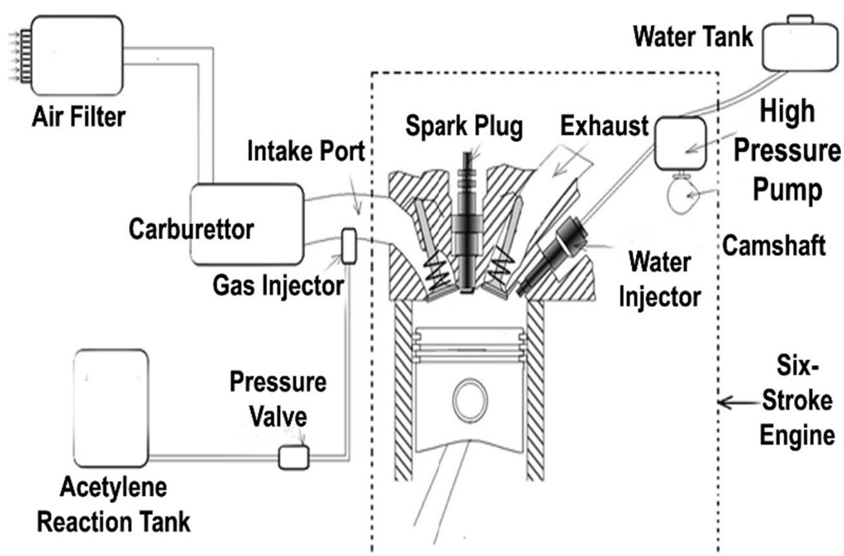

Fig. 8 Schematic of the six-stroke engine

Fig. 9 The modified sprocket with 33 teeth

Camshaft modification

In a four-stroke engine, the angle between two lobes of the camshaft is 90°, i.e., the exhaust valve cam is 90° ahead of intake cam valve, whereas in modified camshaft for a six-stroke engine, the exhaust cam valve should be 60° ahead of the intake cam valve. So, the angle between the two lobes of the camshaft in a six-stroke engine should be 60°. The view of the modified camshaft is shown in Fig. 11.

Water injection system

Water injector assembly, which is similar to injector assembly of diesel engine, should be fixed at the cylinder head. For this, particular modification was made at the cylinder head. The spray of water through injector will be done with the help of a pump. The proper amount of water with optimum pressure was controlled by camshaft.

To store water, a separate tank was arranged. It was having similar capacity of the fuel tank. The view of modified water injector pump arrangement is shown in Fig. 12.

Thermodynamics of additional power stroke

The analysis is done by using the first law of thermodynamics, given as (Pulkrabek 2004; Heywood 1988; Martyr and Plint 2007; Çengel and Boles 2008):

$$\text{Energy in} - \text{Energy out} = \text{Change in energy} \tag{1}$$

Effect of additional power

The net effect of the expansion work of the fifth stroke and compression work of the fourth stroke by the displacement volume is an addition to the increased mean effective pressure (MEP) due to early exhaust valve closer and water injection. MEP is a hypothetical pressure acting on the piston throughout the entire power stroke and the outcome is of same amount of work produced in the cycle (Ramos Da Costa et al. 2012; Özkan et al. 2013).

Analysis of combine combustion and water injection

The mean effective pressure can be presented by following equation:

$$\text{MEP} = \frac{W_{\text{net}}}{V_{\text{disp}}} \tag{2}$$

where W_{net} (work net) is the product of mean effective pressure (MEP) by the displacement volume (V_{disp}).

The MEP and displacement volume of the engine are the two parameters that describe the effectiveness of the engine to produce the power. Power is the product of torque and speed; only an analysis for power is presented here.

$$P = \frac{W_{\text{net}}}{n_s} N \tag{3}$$

Fig. 10 The modified crankshaft and camshaft gears

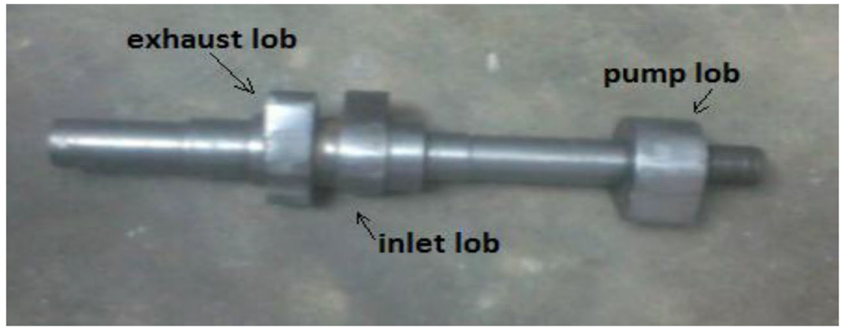

Fig. 11 The modified camshaft

where N represents the rpm. of engine and n_s represents the number of crank revolution for each power stroke in the cycle. For a two-stroke cycle, n_s is 1, for a four-stroke cycle, n_s is 2, and for the six-stroke cycle is 3.

$$P = \frac{\mathrm{MEP}_{\mathrm{net}} V_{\mathrm{disp}}}{3} N = \frac{V_{\mathrm{disp}}}{3} \left(\mathrm{MEP}_{\mathrm{combustion}} + \mathrm{MEP}_{\mathrm{steam}}\right) N \quad (4)$$

From Eq. (3), if MEP of the steam expansion ($\mathrm{MEP}_{\mathrm{steam}}$) is equal to one-half of the combustion MEP ($\mathrm{MEP}_{\mathrm{combustion}}$) at the same engine speed, then the power developed by the six-stroke cycle would be equal to the power of the four-stroke combustion cycle.

The experiments were conducted at four different RPM values (1000, 3000, 5000, and 7000) in order to investigate the effect of variation of speed on engine performance and emissions. Initially, the observation of four-stroke engine with gasoline was noted down for fuel consumption and thermal efficiency. Then, it was modified into six-stroke cycle engine and observations for fuel consumption, thermal efficiency, and CO, HC and NO_x emissions were noted for gasoline and acetylene operation and were compared.

The aim of this study is to investigate the performance and emissions of a six-stroke engine using acetylene as operating fuel. The performance and emission characteristics of six-stroke acetylene engine were compared with four-stroke conventional gasoline-based engine along with modified six-stroke gasoline engine.

Error analysis

Errors in the experiment may be introduced from observation, working-temperature, type of instrument, calibration of measuring devices, and test procedure. The correctness of the experiment is found by uncertainty. An uncertainty calculation was performed using the method described by (Nayyar et al. 2017)

The percentage uncertainty of fuel consumption, brake power, and brake thermal efficiency was calculated using various instruments given in Table 3.

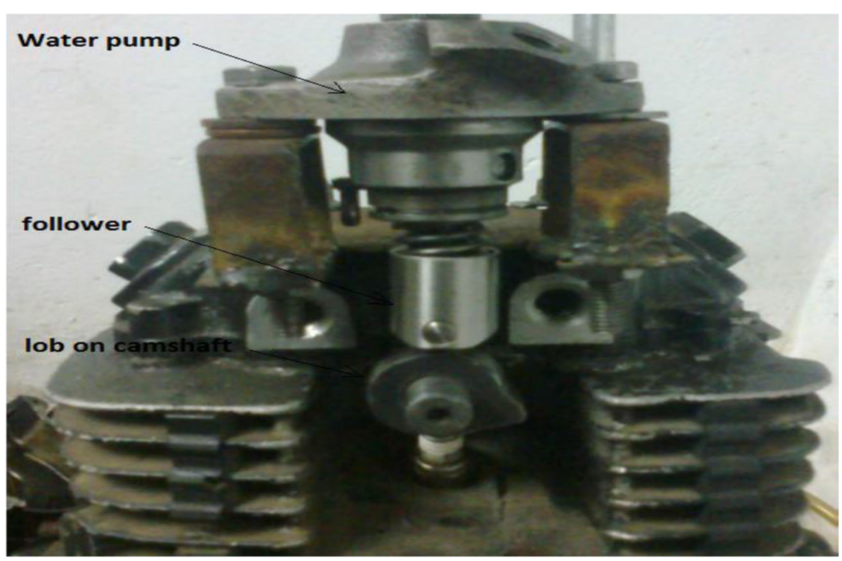

Fig. 12 The modified water injector pump arrangement

Table 3 List of instruments, its range, and its percentage uncertainty

Instruments	Range	Percentage uncertainty
Gas analyzer	CO 0–10%	+ 0.2 to − 0.2
	HC 0–12,000 ppm	+ 0.2 to − 0.2
	NO_x 0–4000 ppm	+ 0.2 to − 0.2
Speed measuring unit	0–10,000 rpm	+ 0.1 to − 0.1
Burette for fuel measurement	–	+ 1 to − 1
Digital stop watch	–	+ 1 to − 1

$$\text{Total uncertainty of measurements in experiment} = \text{square root of} \left\{ \begin{array}{l} (\text{uncertainty of FC})^2 + (\text{uncertainty of B.P})^2 + (\text{uncertainty of BTE})^2 \\ + (\text{uncertainty of CO})^2 + (\text{uncertainty of HC})^2 + (\text{uncertainty of NOx})^2 \end{array} \right\} = \sqrt{\left\{(1)^2 + (0.2)^2 + (1)^2 + (0.2)^2 + (0.2)^2 + (0.2)^2\right\}} = 1.47\%$$

The total uncertainty for the whole experiment is obtained to be ± 1.47%.

Results and discussions

In the present work, the four-stroke conventional gasoline engine is modified into six-stroke engine. The six-stroke engine produced more power than the four-stroke engine as well as addition of acetylene enhances power than gasoline operation. Due to using the waste exhaust heat, the power output and thermal efficiency is increased in the six-stroke operation. The part of waste exhaust heat has been converted to useful work in six-stroke engine during both gasoline and acetylene operation. The thermal efficiency of six-stroke engine was observed 45% higher than that of the four-stroke engine when operated on same fuel, i.e., gasoline. The thermal efficiency of the six-stroke engine with acetylene was observed to be 1.55% higher as compared to gasoline.

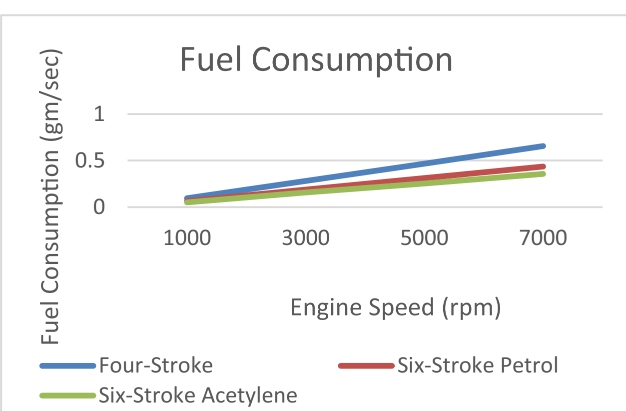

Fig. 13 Fuel consumption vs engine speed

Fuel consumption

The calorific value of fuel is the amount of energy that is contained in 1 kg of fuel. The fuel power of an engine is the product of fuel consumption to the calorific value of fuel and is calculated as follows:

$$\text{Fuel power} = \text{Fuel consumption} \times \text{Calorific value of Acetylene}$$

In a six-stroke engine for a given speed, fuel is injected in every three revolutions of a six-stroke cycle in comparison to a four-stroke engine, where fuel is injected in every two revolutions. Variation of fuel consumption with speed of engine is shown in Fig. 13.

It can be observed from Fig. 8 that the fuel consumption for a six-stroke cycle engine is lesser than four-stroke cycle engine. Also, the acetylene mode was observed more fuel economical than that of gasoline mode. The six-stroke gasoline

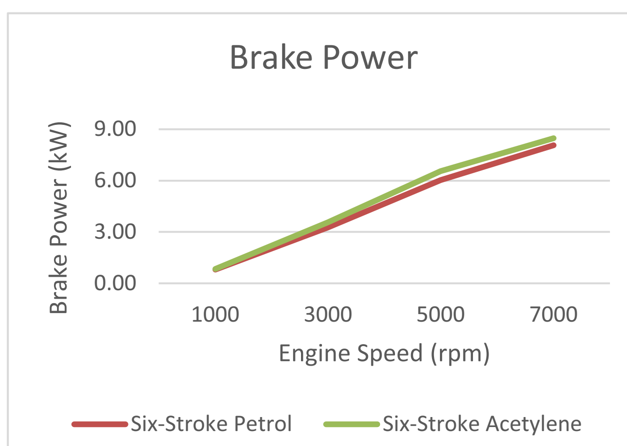

Fig. 14 Brake power vs engine speed

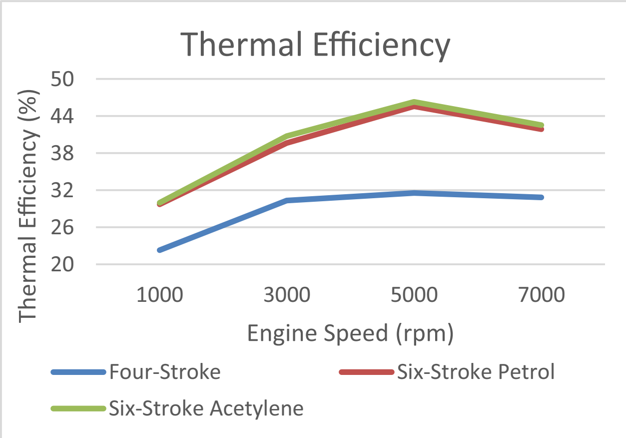

Fig. 15 Thermal efficiency vs engine speed

cycle shows 45% reduction in fuel consumption than the four-stroke cycle at all engine speed and six-stroke acetylene cycle shows 1.8% reduction than six-stroke gasoline engine cycle.

Brake power

The variation of brake power with engine speed is shown in Fig. 14. Prony brake dynamometer was used to measure the brake power of engine.

$$\text{Brake power (kW)} = (2 \times \pi \times N \times T)/60000$$

The brake power of six-stroke engine running on acetylene was found to be higher than six-stroke engine running on gasoline. At 1000, 3000, 5000, and 7000 rpm, the increment in brake power was observed of 3.15, 8.94, 8.74, and 5.18% respectively.

Brake thermal efficiency

The amount of heat available in fuel converted into shaft work is calculated through brake thermal efficiency. Figure 15 shows a variation of brake power with speed for six-stroke engine. The thermal efficiency of six-stroke acetylene engine is increased by about 1.55% than the six-stroke gasoline engine at full load and maximum speed. It can be observed that the use of acetylene as main fuel in and the water injection improve the engine performance. No unusual combustion or detonation was observed during the whole operation with acetylene. The probable reason of this is that the injected water cools the combustion chamber walls and maintains the temperature of the chamber.

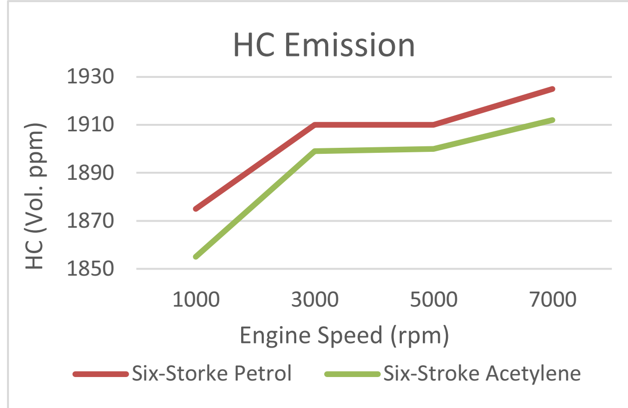

Fig. 17 HC emission vs engine speed

Carbon monoxide emission

Carbon monoxide is produced due to incomplete combustion. To reduce the carbon monoxide emission, excessive air at lean burn condition could be provided. However, the main cause of CO emission is because of insufficient oxygen and low temperature at the end of combustion. Figure 16 shows that the emission of CO decreased in six-stroke acetylene engine as compared to six-stroke gasoline engine. The probable reason of this decrement in CO is complete combustion due to better mixing of acetylene with air and availability of oxygen in fuel. The maximum reduction in CO emission was observed

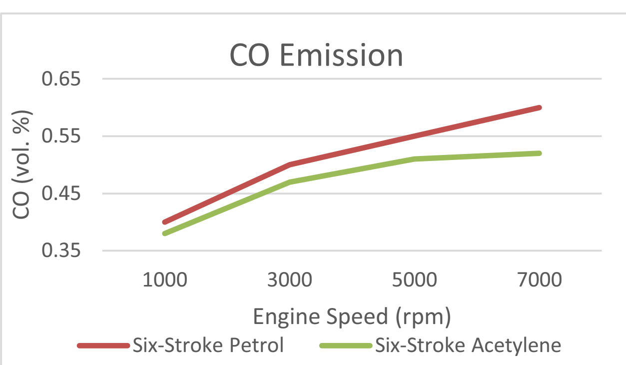

Fig. 16 CO emission vs engine speed

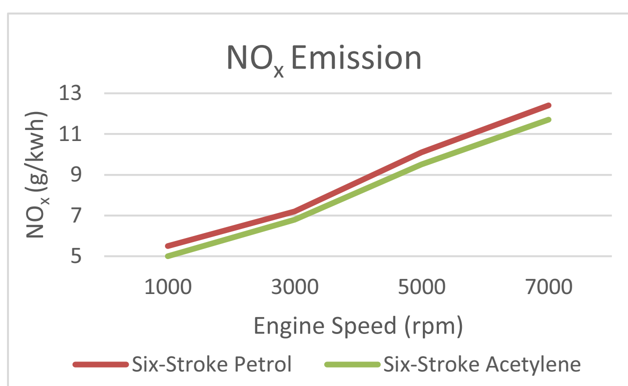

Fig. 18 NO_x emission vs engine speed

13.33% for six-stroke acetylene cycle engine as compared to six-stroke gasoline cycle engine at rated load and speed.

Hydrocarbon emission

Figure 17 illustrates the variation of HC emissions for six-stroke engine with speed. It can be observed that HC emission deceased for acetylene operation as compared to gasoline operation in the whole range of speed. The decrement in HC emission can be justified with the same explanation stated for reduced CO emission along with altered production of HC species with acetylene and H_2O. The reduction in HC emission was observed 0.67% for six-stroke acetylene cycle engine as compared to six-stroke gasoline cycle engine at rated load and speed.

NO_x emission

Figure 18 shows the variation of NO_x emission with speed. It can be observed from Fig. 18 that NO_x emission decreases slightly with the acetylene as compared to gasoline. The NO_x formation mainly depends on the combustion temperature and duration of sustaining that temperature. The use of water injection lowers down the temperature in the cylinder and is probably the reason for the lowering of NO_x emission with acetylene. The maximum reduction in NO_x emission was observed 5.65% for six-stroke acetylene cycle engine as compared to six-stroke gasoline cycle engine at rated load and speed.

Conclusions

The experiments were conducted to study the performance and emission characteristics of acetylene gas-operated six-stroke cycle engine. The following conclusions were drawn based on the experimental results:

1. The fuel consumption for the six-stroke acetylene cycle engine was reduced by 1.8 and 45% as compared to six-stroke gasoline cycle engine and four-stroke gasoline cycle engine respectively at a rated speed and load.
2. The brake thermal efficiency for the six-stroke acetylene cycle engine was increased by 1.55 and 45% as compared to six-stroke gasoline cycle engine and four-stroke gasoline cycle engine respectively at rated speed and load.
3. A reduction in CO and HC emission with six-stroke acetylene engine as compared to six-stroke gasoline cycle engine was observed to be 13.33 and 0.67% respectively.
4. The NO_x emission was decreased by 5.65% with the six-stroke acetylene cycle engine as compared to the six-stroke gasoline cycle engine.

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