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Investigation on the Effect of Intake Manifold Water Injection on the Performance of Single Cylinder Spark Ignition Engine

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ABSTRACT

The emission from combustion of fuels of internal combustion engine have been major part of the air pollutant sources. Emission regulations in developed countries are becoming very strict and trade-off strategies in order to reduce pollutants and it is need to reduce to reduce the fuel consumption. Lean combustion is one of the best ways to reduce the fuel consumption. However, it produces higher NOx emission. The reasons are high combustion temperature and excess of oxygen in cylinder. In order to reduce these conditions, water injection would be used. A decrease in temperature of the combustion process leads to a drop in NOx formation in engines. The use of water injection in the combustion process can be a part of solution to the problem of pollution control and fossil fuel depletion. Water is sprayed into the cylinder or incoming fuel-air mixture, this may lead to effectively reduce the intake temperature. The reduction of intake temperature allows for more aggressive ignition timing to be employed, lead to the increase of power output and improve the fuel efficiency. In this paper, it is presented about the investigated finding results of water injection in the suction stroke of single cylinder four stroke cycle S.I engine. The effects of variable water injected amount on the engine performance under variable load conditions are presented in this paper. The study involved the injection of water into the intake manifold in the suction stroke at the angle from 26˚ ATDC to 78˚ ATDC with specified injection durations with various water injected amounts with one injector type and the another injector type with the variable water injection duration 78˚ ATDC to 130˚ ATDC . According to the tested performance finding results, the injected amount of water 0.065ml/inject is the most suitable water injection amount with the analysis of constant speed with variable load based on better performance.

KEYWORDS: *Water injection, Engine Set up, Injector flow characteristic, Engine Performance, Exhaust emission*

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I. INRODUCTION

One major challenge for today's society is sustainable satisfaction of the energy demand. Engines are the basic mechanical devices and they have numerous applications in various fields. An engine that converts the liberated chemical energy through combustion of a certain fuel, into a mechanical energy which is used to drive a vehicle. In many industrialized countries, fuel economy is a primary concern, yet it cannot be ignored about the health risks from high concentration of airborne. Thus, constrain from legislating bodies combined with the market forces to push engine manufactures towards creating engines that simultaneously use less fuel and produce fewer harmful pollutants. [1].

The main mechanism causing the reduction of NOx emissions seems to be the temperature decreasing of the combustion products as a result of vaporization of the liquid water and consequent dilution of the gas phase species [4]. Many reported, the use of water and water-alcohol injection on aircraft engines as thrust boosters or as power supplements during takeoff and also as coolant to the engine increasing the engine performance [5, 6].

The introducing water technique into engine combustion chamber was proposed by Prof. B. Hopkinson in 1913, to make better internal cooling of the engine and to increase the engine output [1]. Furthermore, the technique was developed to improve the thermal efficiency and to reduce the exhaust emissions, and used as the safety fuel [2]. Combustion temperature reduction is the main cause for reduction in NOx emission. In an internal combustion engine, water injection is a combustion chamber cooling process by adding water to the incoming air-fuel mixture or cylinder. The cooling effects allow the advance in engine ignition timing. Due to higher density and high heat absorption properties of water provide a cooling effect compared to gasoline [12]. Water introduction into engine has been researched in various ways to lower the emissions and increase in engine efficiency.

Nicholls et al. [3] studied theoretical and experimental analysis of injection of water to engine manifold for the reduction of NOx. The author's theoretical studies were based on the chemical equilibrium calculations during combustion peak temperature. They have used water injection during suction, compression and combustion

processes. Theoretical calculations were well matched with the experimental values, presenting up to 90% reduction in NOx [3].

There are various methods of water injection in SI engines such as: inlet manifold water injection, water mixed with fuel (emulsions) and direct injection of water into the combustion chamber. Liquid water is injected into the inlet manifold during suction stroke of the engine is called fumigation. Emulsion is that fuel and water are blended using surfactants to form an emulsion which can be used as an alternative fuel [2].

Direct water injection system carries a dual feed injection nozzle with corresponding water supply system. All the water injection methods such as emulsion, fumigation, and direct water injection have shown the noticeable reduction in NOx and PM emissions. Unlike emulsified fuels, fumigation and direct water injection allow the fuel water percentage to be changed for transient engine running conditions [4].

Water injection is very effective at reducing combustion temperature because of its high latent heat of vaporization. Thus water is an effective strategy for NOx control [11]. Many studies confirm the effectiveness of water addition at lowering NOx emissions. Different studies reported the decreasing of nitrogen in terms of NO, NO_2 or NO_X but the trends are similar. Peters and Stebar [7] stated that the peak NOx level was lowered by nearly 40% with 40 weight (mass) percent water addition to gasoline. They showed that both of their methods (direct manifold water addition and emulsified fuel-water mixture) were equally effective in diminishing NOx emissions. The internal cooling can provide the additional charge for more power output without causing the danger of premature detonation inside the cylinder.

Water may also be used to cool the engine. Weatherford and Quillan [8] concluded that water addition by direct injection was adequate to cool the engine. Modak and Caretto [9] confirmed that water addition could be used to cool internal combustion engines and used a computer program to conclude that the optimal time for direct water injection early in the compression stroke.

Lanzafame investigated the effect of water injection in a single cylinder cooperative fuel research (CFR) engine. The investigation studied the effect of water injection on detonation and the exhaust gas emission. The experimental data shows that the NOx gas emission decrease as the water to fuel mass flow rate increases. Increase in octane number and decrease in NOx results were obtained with water/fuel flow rate in the range from 1to 1.25 and exhaust gas temperature showed a significant decrease as the water injection to mass fuel flow rate ratio was increased [10].

In this paper, it is presented about the investigated finding results of water injection in the suction stroke of single cylinder four stroke cycle S.I engine. The effects of variable water injected amount on the engine performance under variable load conditions are presented in this paper. The study involved the injection of water into the intake manifold in the suction stroke at the angle from 26˚ ATDC to 78˚ ATDC with specified injection durations with various water injected amounts with one injector type and the another injector type with the variable water injection duration 78˚ ATDC to 130˚ ATDC with specified injection durations with various water injected amounts. According to the tested performance finding results, the injected amount of water 0.0065ml/inject is the most suitable water injection amount with constant speed with variable load based on better performance.

II. EXPERIMENTAL SETUP

A. Engine Specification Description

In this study, the experiments were performed on a CL-3900H, single cylinder, four-stroke and spark ignition (SI) gasoline engine. The engine specification is given in Table I.

TABLE I ENGINE SPECIFICATION

Model	CL-3900 H (Start) Corolla
Engine Type	Inclined, Single Cylinder, 4-stroke, air-cooled
Bore × Stroke	70mm×54mm
Speed	3000rpm
Ignition System	Transistorized Ignition
Compression Ratio	8:1
Maximum Output	2.8kW
Dimension	600×440×455mm

B. Water Injection System

The injector drive circuit was used in order to operate the water injector. Moreover, high pressure system is also used in order to compress the water. An electric control circuit unit is utilized in order to control the injector.

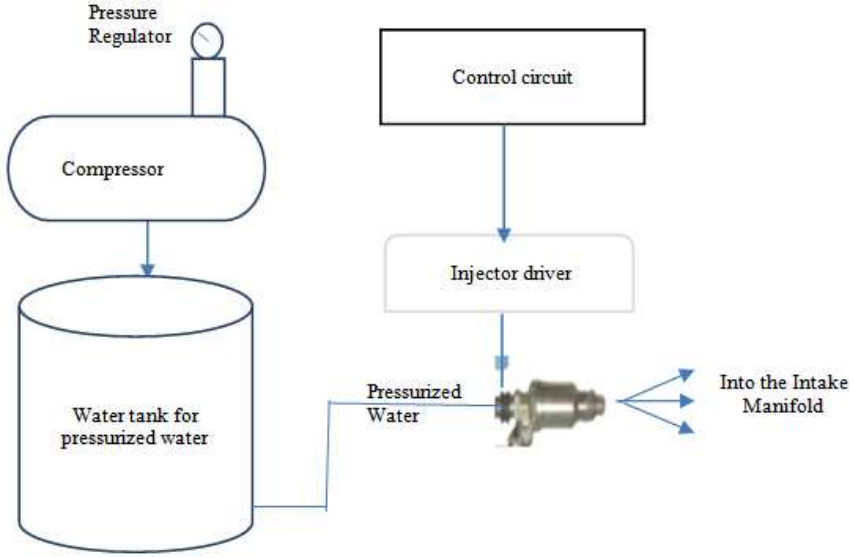

Fig1. Schematic of the Water Injection System

Water is provided to the injector as illustrated in figure 2. Compressed air is directed to a pressure regulator set at 35 psi. Water is connected to the pressurized water. The pressure at which the water was pressurized affects the flow rate of the injector once opened.

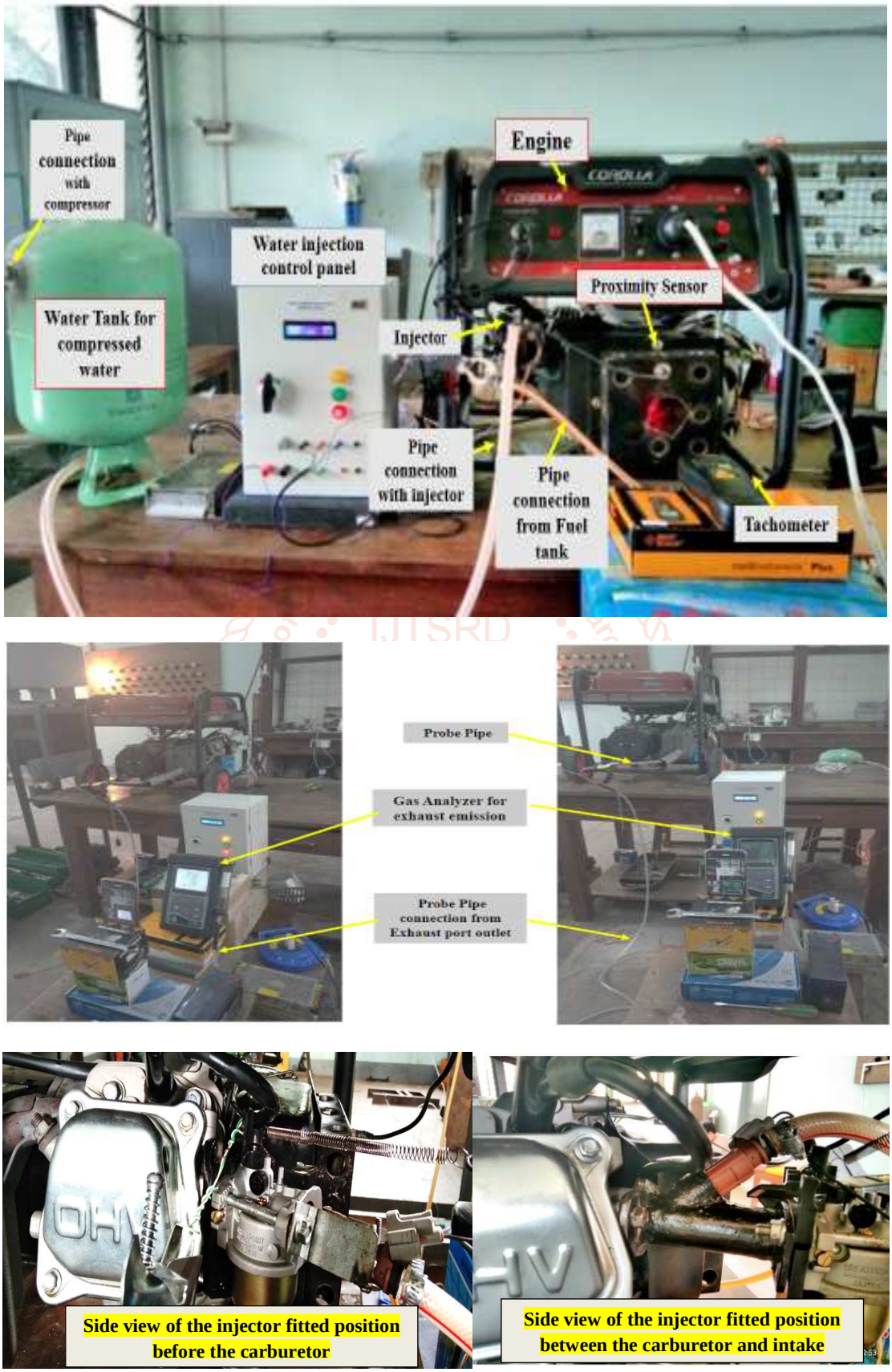

Fig2. Lab view of the experimental set up

C. Flow Characteristics of Water Injector

Before the electronic control unit was designed a simple water injection system was developed in order to determine the injector characteristics.

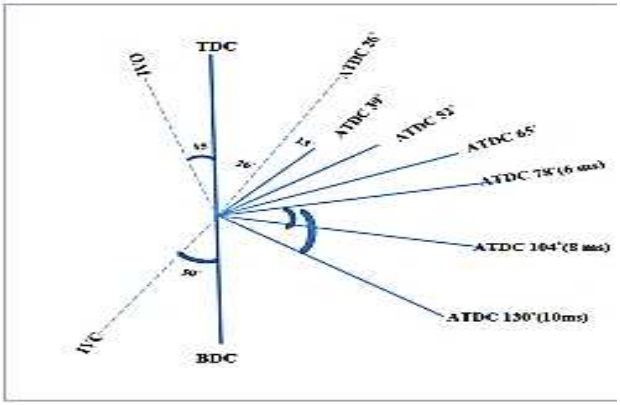

Fig3. Injection timing diagram for water injection

TABLE III WATER INJECTION AMOUNT ON DURATION

	Injector is fitted before the carburetor			Injector is fitted between the carburetor and intake manifold	
Injector type	Teana Injector FBJB101			Lancer injector 4G18	
[injection timing] Pinj=35psi	From 26° ATDC to 52° ATDC	From 26° ATDC to 78° ATDC		From 78° ATDC to 104° ATDC	From 78° ATDC to 130° ATDC
Water injected amount	0.008 ml/inject	0.015 ml/inject		0.005 ml/inject	0.0065 ml/inject

The water is sprayed on mist form into the intake manifold with air-fuel mixture through the nozzle which is located on the throttle body. The injector flow test are carried out and resulted that the injector flows as shown in table 3. The injector required for the inductor of the injector to successfully pull and subsequently also allow the return spring to close the pintle of the injector. The amount of water injection is based on the injection duration and injection pressure. The injector was controlled with a water injector driver designed particularly for this study.

III. RESULTS AND DISCUSSION

In this paper, it is presented that the investigated finding results of engine performance on constant speed of 2100 rpm and variable loads with various water injection amount are compared with petrol engine. According to the tested performance finding results, the amount of 0.0065ml/inject is the most suitable water injection amount based on better engine performance.

A. Brake specific fuel consumption (bsfc)

When water is injected, the brake specific fuel consumption is a little increased compared with petrol only operated engine.

The brake specific fuel consumption (bsfc) is a little increased in the cases of the three types of water injections except the case of minimum water injection amount of 0.005 ml/inject. The decrease percentage is about 6% and most increased percentage amount is 9.6 % at the 200W of brake power.

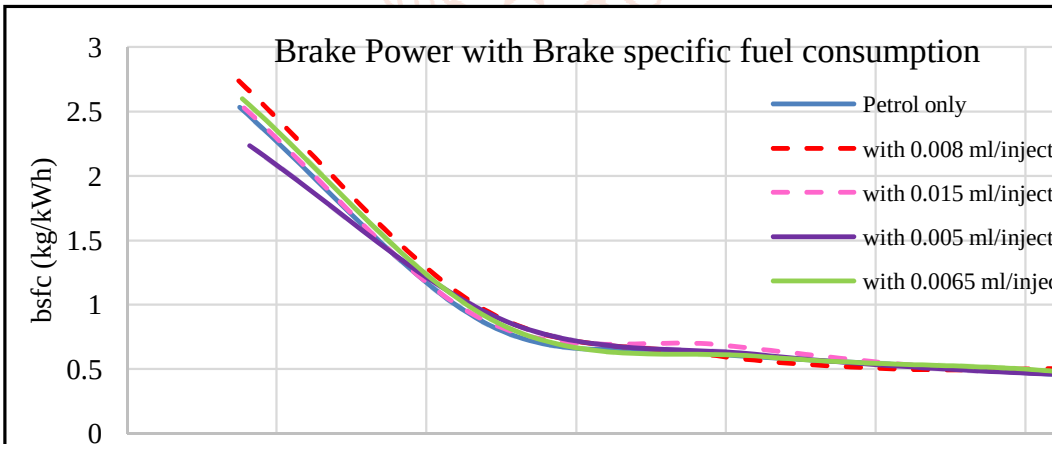

Fig4. Brake power with brake specific fuel consumption with various amount of water injection

The brake specific fuel consumption (bsfc) is increased at small load conditions compared with petrol only operated engine and the bsfc increased rate is gradually drop which is likely to the petrol only operated condition in more nearer to the full load condition.

B. Brake mean effective pressure (bmep)

The brake mean effective pressure (bmep) is not obvious difference in performance effect in compared with petrol only operated and expect the amount of water injection of 0.065 ml/inject which is more nearer to the full load conditions such as 1200W decreased 6% by percentage compared with petrol operating condition.

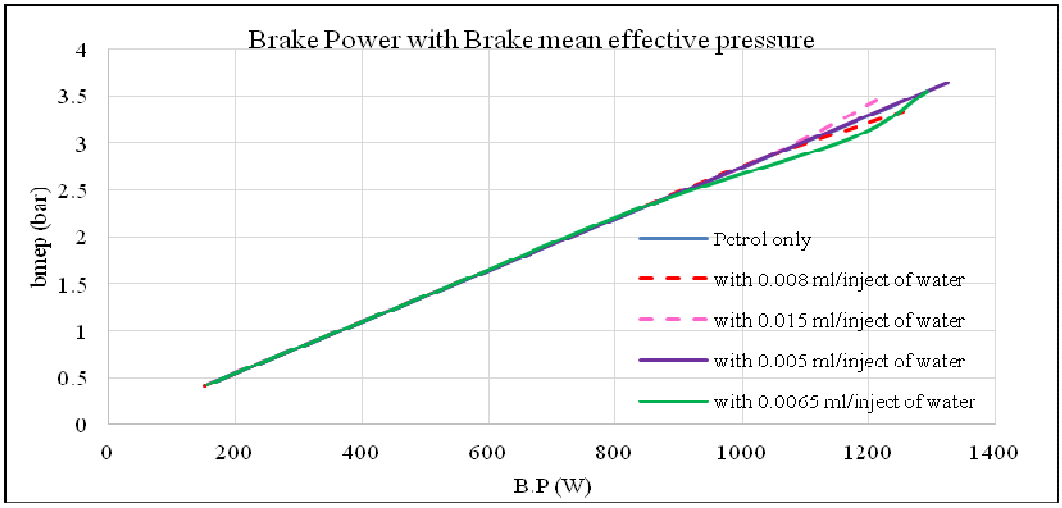

Fig5. Brake power with brake mean effective pressure with various amount of water injection

C. Brake Thermal Efficiency(ηbth)

When water is injected, the brake thermal efficiency is decreased generally compared with petrol. According to the figure, the brake thermal efficiency is not much difference comparing with petrol only operated case.

The most decreased amount is occurred at the 800 W by the amount of about 9% decreased with maximum amount of water injection. Moreover, the brake thermal efficiency is also increased about 8% increased at the 1000 W of Bp.

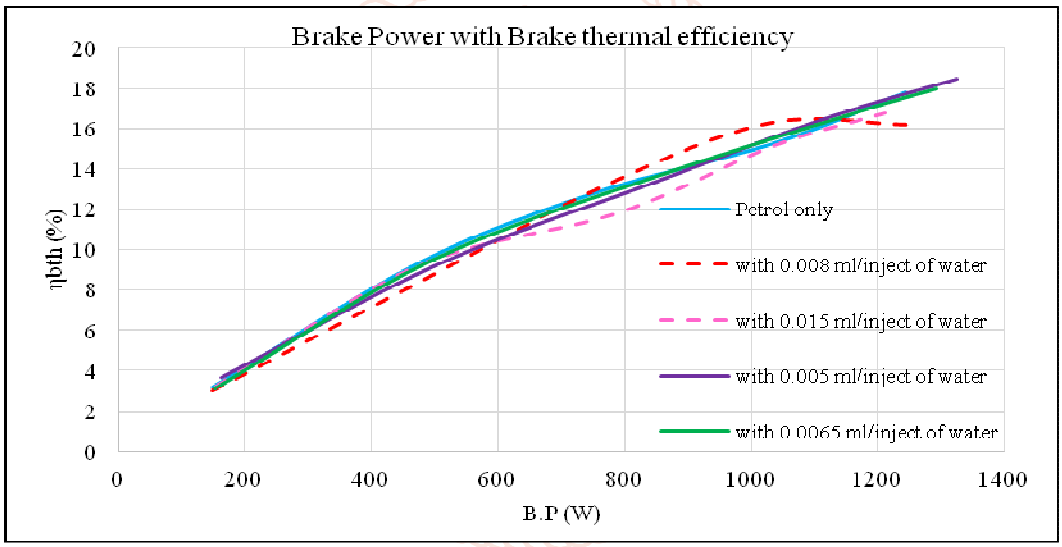

Fig6. Brake power with brake thermal efficiency with various amount of water injection

D. Brake Power (BP)

Generally bp is alittle increased compared with petrol only operated conditions. For the case of 0.0065 ml/inject of water, the bp power is increased markedly about 12 %by percentage at the load case of 1400 W.

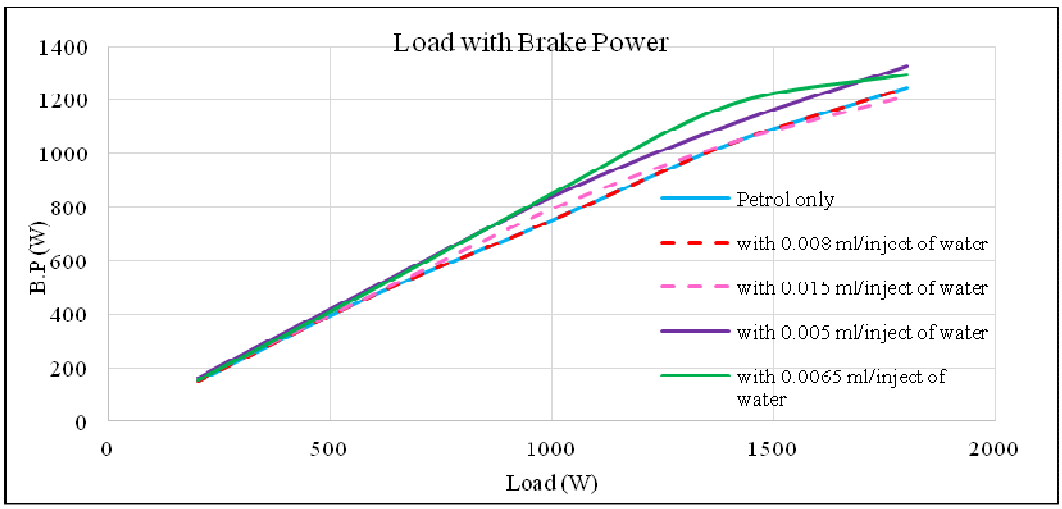

Fig7. Brake power with load with various amount of water injection

E. Exhaust Emissions

Combustion of fuels inevitably leads to combustion end products. Complete combustion of hydrocarbon produces carbon dioxide (CO_2) and water H_2O. Incomplete combustion results in poisonous carbon monoxide CO and in partially oxidized to hydrocarbon. NOx is produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperature. NOx is poisonous, causes acid rain and plays a role in smog.

When nitrogen is released during fuel combustion, it combines with oxygen to create nitrogen oxide (NO) and this further combines with oxygen to create NO_2. Nitrogen dioxide and nitric oxide are referred to together as oxides of nitrogen (NOx). The following emission data figures only showed to the new injector position between the carburettor and intake manifold and water injected amount of 0.005 ml/ inject and 0.0065 ml/inject.

For the case of carbon dioxide (CO_2) emission, the content of CO_2 is increased about 1.75 % at 200W, 0.6 % at 800W and 1 % at 1200W at maximum water injection amount of 0.0065 ml/inject compared with petrol engine operation. Therefore, the carbon dioxide content in exhaust emission is a little increased and the most increased amount is 1.75% at the brake power 200W with maximum water injection amount and also the least decreased amount occur at the minimum water injection amount.

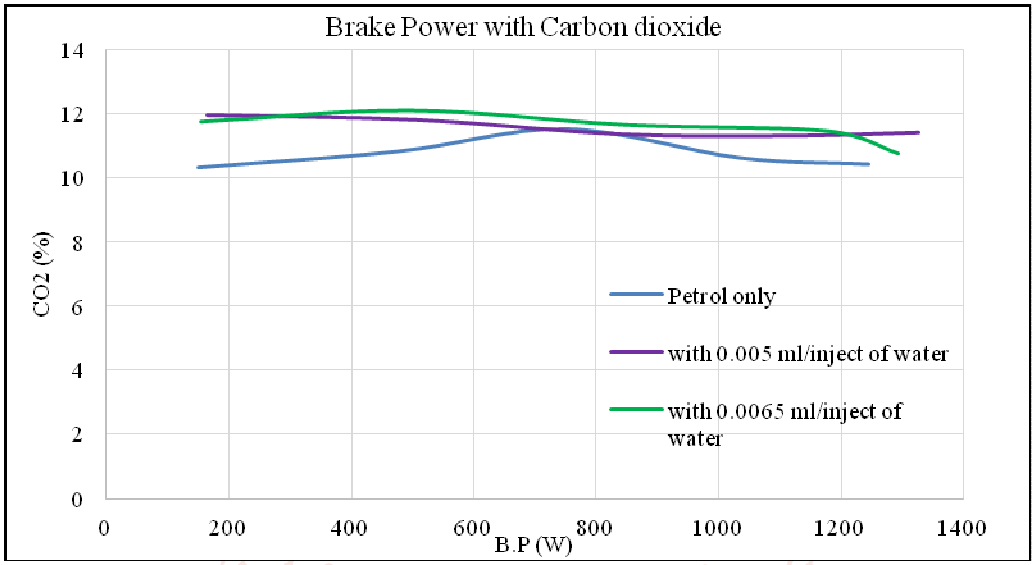

Fig8. Brake power with carbon dioxide emission with various amount of water injection

For carbon monoxide emission, it can be seen that the emission amount is decreased markedly compared with petrol only operated. Generally, carbon monoxide (CO) is decreased when water is injected and the most decreased amount is occur at maximum water injection amount.

Generally, CO is decreased when water is injected and the most decrease amount is occurred at the part load condition by % of around 2.5% at 200W with 0.0065 ml/inject of water.

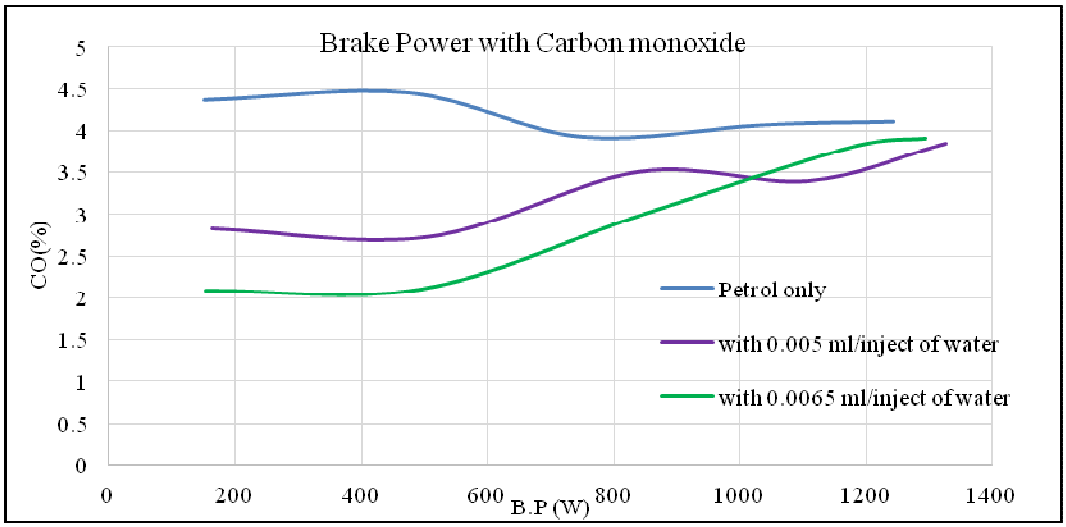

Fig9. Brake power with carbon monoxide emission with various amount of water injection

According to the figure 9, the amount of hydrocarbon (HC) is increased obviously and in the emission amount of maximum water injected is fluctuated. As in the graph, the most increase amount can been seen in minimum amount of water injection. The most increased amount is occur nearer to the full load condition. It is possible to say that HC emission may be decreased at higher in-cylinder temperature, but in this tests HC emission are higher due to lower in-cylinder temperature.

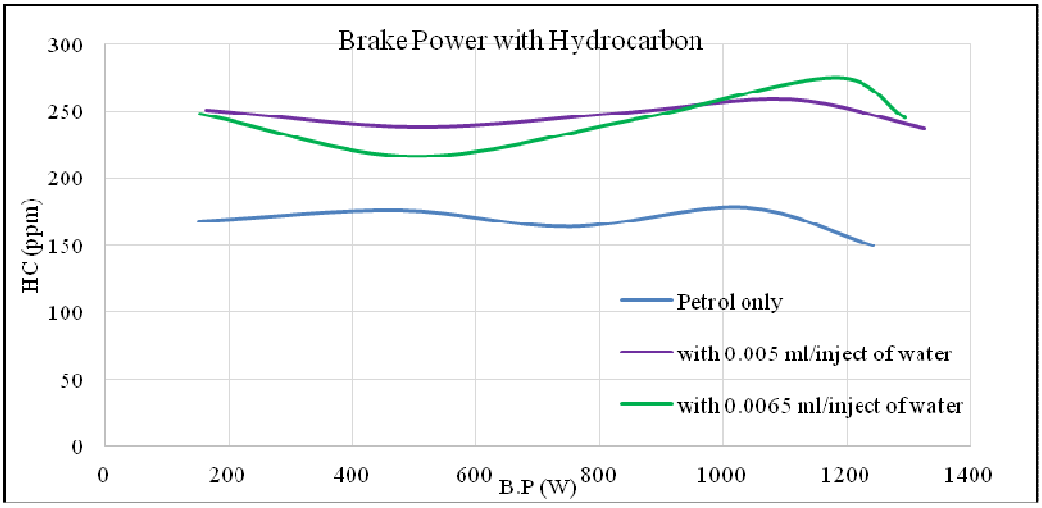

Fig10. Brake power with hydrocarbon emission with various amount of water injection

Combustion temperature reduction is the main cause for reduction in NOx emission. In an internal combustion engine, water injection is a combustion chamber cooling process by adding water to the incoming air-fuel mixture or cylinder.

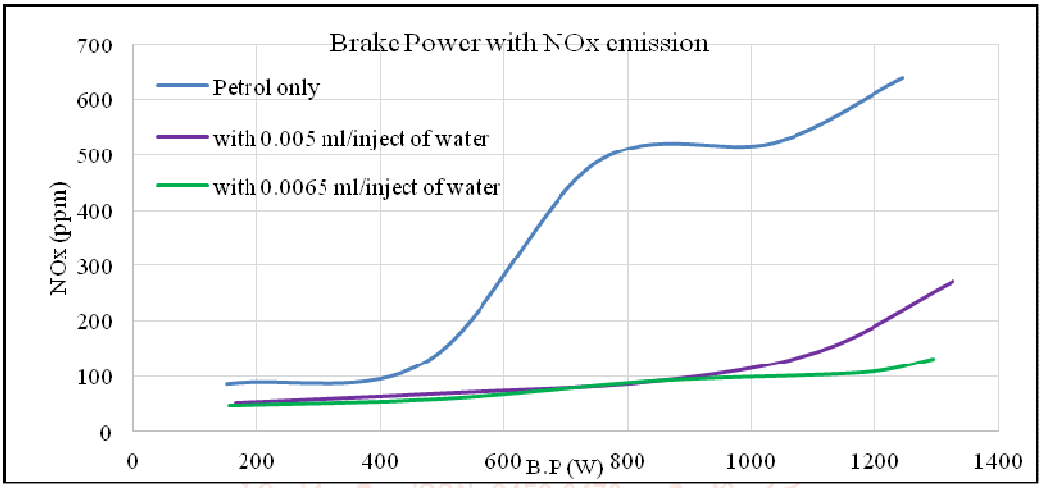

Fig11. Brake power with NOx emission with various amount of water injection

For the NOx emission, it can be reduced by water injection due to reduce in intake temperature. According to the figure 10, NOx emission amount can be reduced conspicuously by water injection and the most decreased amount occurs at the maximum water injection amount of 0.0065 ml/inject and the most reduced amount is around 80% at the 1200W.

IV. CONCLUSION

Based on the experimental results, the main effects of water injection was investigated as follow. It can be reported that the amount of water increases, the brake specific fuel consumption is a little increased compared with petrol only operated engine. The brake specific fuel consumption (bsfc) is a little increased in the cases of the three types of water injections except the case of minimum water injection amount of 0.005 ml/inject. The decrease percentage is about 6% and most increased percentage amount is 9.6 % at the 200W of brake power.

Most experimental results have indicated that the brake specific fuel consumption (bsfc) is a little increase with the increase in engine load, due to the fact that the total energy release increases with the increase of engine load, so the proportion of output power increases. It can also be reported that at higher speed if the amount of water increases, the bsfc is a small increase. Generally brake power is a little increased compared with petrol only operated conditions. For the case of 0.0065 ml/inject of water, the brake power is increased markedly about 12 %by percentage at the load case of 1400 W.

In generally, water is injected, the brake thermal efficiency is decreased generally compared with petrol. According to the experimental results, the brake thermal efficiency is not much difference comparing with petrol only operated case. The most decreased amount is occurred at the 800 W by the amount of about 9% decreased with maximum amount of water injection. It was shown that the injection of water into the combustion chamber carry heat developed and lowering brake thermal efficiency at constant speed.

The carbon dioxide content in exhaust emission is a little increased and the most increased amount is 1.75% at the small part load with maximum water injection amount and also the least decreased amount occur at the minimum water injection amount.

For carbon monoxide emission, it can conclude that the emission amount is decreased compared with petrol only operated. CO is decreased when water is injected and the most decrease amount is occurred at the part load condition by percentage of around 2.5% at 200W with 0.0065 ml/inject of water.

According to the investigated results, the amount of hydrocarbon (HC) is increased and the most increase amount can been seen in minimum amount of water injection. The most increased amount is occur more nearer to the full load condition. So, it is possible to say that HC emission may be decreased at higher in-cylinder temperature, but in this experimental tests HC emission are higher due to lower in-cylinder temperature.

Combustion temperature reduction is the main cause for reduction in NOx emission. In an internal combustion engine, water injection is a combustion chamber cooling process by adding water to the incoming air-fuel mixture or cylinder. For the NOx emission, it can be reduced by water injection due to reduce in intake temperature. NOx emission amount can be reduced markedly by water injection and the most decreased amount occurs at the maximum water injection amount of 0.0065 ml/inject and the most reduced amount is around 80% at the 1200W.

It can be noted that the modification of water injection timing control will be carried out in order to get the optimum engine performance. According to the tested performance finding results, the amount of 0.0065ml/inject is the most suitable water injection amount based on better engine performance. According to the tested performance finding results, the amount of 0.0065ml/inject is the most suitable water injection amount based on better engine performance. Moreover, experimental investigations confirm the advantages of water injection techniques in reduction in emission

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