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Water Injection Effects on the Performance of Four-Cylinder, LPG Fuelled SI Engine

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Abstract

The purpose of this study is to investigate experimentally the effect of water injection to intake manifold on the engine performance and exhaust gas temperatures of a commercial engine. A four stroke, four-cylinder SI engine was used for conducting this study. Water injections were used with five different water to fuel mass ratios: 0, 0.125, 0.2, 0.33 and 0.5 at constant load and variable engine speed ranging from 1000 to 4500 rpm.

The results indicate that the addition of water into the intake manifold reduces the compression work. The engine torque, power and brake thermal efficiency increase as the water to fuel mass ratio increases. The average increase in the brake thermal efficiency for 0.5 water to fuel mass ratio is approximately 2.4% over the use of pure LPG for the engine speed range studied. It was also found that the proper brake specific fuel consumption and exhaust gas temperature decrease as the ratio of water to fuel increases.

Keywords: Engine performance; Spark ignition engine; Water addition; LPG

Introduction

Water injection, as a separate liquid or emulsion with liquid fuels, or as a vapour, has been thoroughly researched [1-5]. Present research for reducing harmful emissions and increasing thermal efficiency of internal combustion engines has shown that the water addition to the engine directly or water emulsified fuels is a promising way to accomplish these tasks.

It has been demonstrated experimentally that the water addition produces some significant effects on the combustion of liquid fuels. Harrington [1] concluded that knock can be suppressed, hydrocarbon emissions will slightly increase, NO_x emissions will decrease, CO does not change.

Significantly fuel and energy consumption rate are increased with small amounts of water addition. Lanfazame [2] measured a reduction in compression work when performing experiments on a single-cylinder CFR engine with water addition. He also reported that water injection really represents a new way to avoid detonation and to control NO_x formation in SI engines.

Several engine tests using water/fuel emulsions have been conducted. Abu-zaid [3] concluded that the addition of water in the form of emulsion in fuel improves the combustion efficiency in the diesel engine, hence the performance of the engine.

Several different methods of water addition have been developed [4,5]. These studies have shown that further reduction of harmful emissions is still possible. While the effects of water addition to internal combustion engines has been an active area of research in recent years, some of these studies have only measured external effects on exhaust emissions, and fuel consumption. It is apparent that a little information is available on the systematic investigation of the effects on the engine performance. LPG has been commonly used as one of the cleanest alternative fuel for auto-engines for more than 40 years. The aim of the present work is to investigate experimentally the effect of the water injection on the performance of a LPG fuelled SI engine.

Experimental Instrumentation and Procedure

Four cylinders, four strokes SI engine used in the present experimental work was shown in figure 1 where as the specifications of the engine are presented in table 1. Engine torque was measured by a hydraulic dynamometer and an inductive clamp measured the instantaneous speed. The cylinder pressure measurements were made by a piezoelectric quartz high-pressure transducer and the signal from the transducer was converted from charge to voltage by a charge amplifier. The output of the charge amplifier was displayed by a digital oscilloscope. The engine crank angle was measured using an encoder where the signal was used to trigger the cylinder pressure. A thermocouple was installed in the exhaust port to measure the exhaust gas temperature. Additionally, a thermocouple was installed into the exhaust manifold to measure the temperature of charge. The ignition timing was monitored and measured as a function of crank angle by capacitive coupling pickups with the high voltage pulse associated with the spark event. Water and fuel flow rates were measured by using two electronic balances. Home-made software was used to measure water and fuel flow rates on the computer serial ports. Water was injected into suction port using a gasoline injector. This injected water was in the form of an ultra-fine mist. The amount of water injection rate was controlled by varying water supply pressure and/or by an adjustable valve controlled via a step motor by using a parallel computer port.

Type	Four cylinder engine
Bore	76 mm
Stroke	71.5 mm
Swept volume	1297 cc
Cooling system	Water cooled
Compression ratio	7.8

Table 1: Engine specifications.

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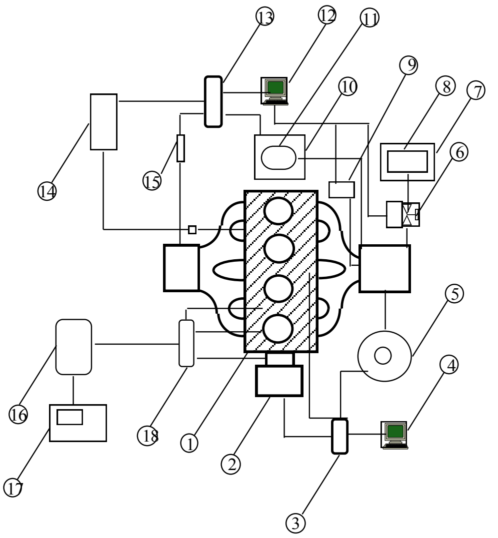

Figure 1: Schematic diagram of experimental apparatus.

Measurement (%)	Maximum errors
Exhaust Temperature (K)	3.4
Engine Speed (RPM)	1.0
Torque (N-m)	0.1
In Cylinder Pressure (kPa)	0.4
Crank Angle (degrees)	0.36
BSFC (%)	1.33
Brake power (%)	0.15
Thermal Efficiency (%)	1.3

Table 2: Uncertainties of measurements.

Throttle valve was also adjusted for each speed using another step motor and by means of same parallel port. Two computers collected all the data from experiments as indicated in figure 1.

For each run, the engine was started on pure LPG and then switched to the test water to arrange fuel mass ratio. All tests were performed at constant load and variable engine speed and MBT (Maximum brake torque) ignition timing. At each operating condition, the dynamometer load, speed, exhaust gas temperature, fuel and water flow rates were recorded after allowing sufficient time for the engine to stabilize. The experiments for each case were replicated in a test point until the difference between two measurement values falls within 5% error. Averaging was performed to minimize the effects of variations than this error level. Calibration check of the devices was made two times that were before and after each successive test.

The engine test system is made up of several different transducers and data acquisition system. The error due to data acquisition system used in this study is on the order of 0.02% for 12 bit system and is considered negligible when compared to the other sources of error. The errors in the measurements of the basic quantities and estimated uncertainties, calculated by the method proposed by Kline and McClintock [6], are summarized in table 2.

Results and Discussion

The effect of water addition on engine horsepower, brake specific fuel consumption, brake thermal efficiency and the exhaust gas temperature were studied. The effect of water addition on the engine output torque and brake power for various speeds are shown in figure 2 and 3. Both of the torque and the brake power intensities strongly depend on the engine speed. At low speed, torque increases to reach a maximum as the engine speed increases, and then, as engine speed increases further, torque decreases for all cases as shown in figure 2. The torque decreases because the engine is unable to ingest a full charge of air at the higher speeds. It is clear from figure 2 that as the mass ratio of water to fuel increases, the engine torque increases. Water injection significantly affects the burn rate. Harrington [2] found that the water-gasoline mixture with respect to gasoline for a single cylinder engine have slower burn rates. Peak pressure position (PPP) occurs too late due to the lowered combustion rate as a result of water injection. The spark advanced the peak pressure position back to its optimal value during the tests. This helps to increase the output torque with water injection. The effect of the water injection on the engine power is shown in figure 3. The brake power increases to a maximum and then decreases at higher speeds. This is mainly because friction losses increase with engine speed and become the dominant factor at very high speeds. Figure 3 shows that the power increases slightly as the water to fuel mass ratio

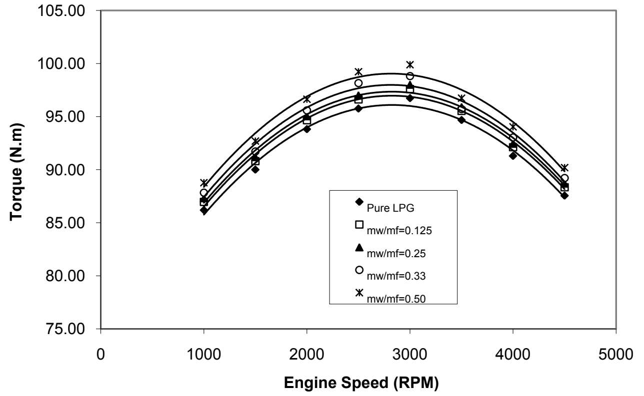

Figure 2: Effect of water injection on engine torque output.

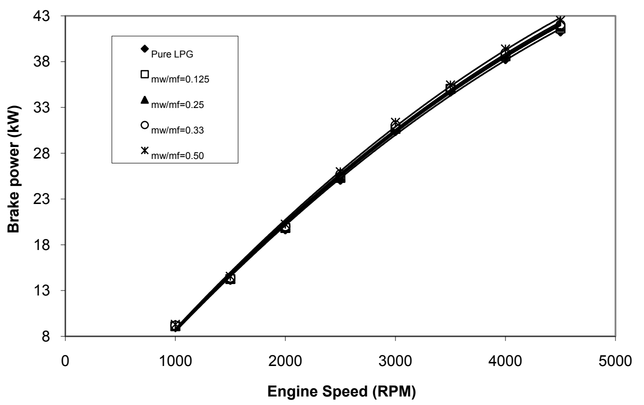

Figure 3: Effect of water injection on engine power output versus.

increases. The increase in power output is a result of several different combustion variables are affected by water injection. Water injection leads to increase in both ignition delay period and combustion period due to slower burn rates [2]. Thus, the charge requires less compression work than the LPG alone due to the longer ignition delay during the compression stroke. This helps to reach the peak pressure after TDC to produce more power output during the expansion stroke.

The variation of brake specific fuel consumption with engine speed for the different water to fuel mass ratio is shown in figure 3. The BSFC decreases to a minimum as the engine speed increases at low engine speed, and then begins to increase at high speeds. At low speeds, the longer time per cycle allows more heat loss and lower combustion efficiency resulting in fuel consumption goes up for the power produced. Fuel consumption increases at high speed because of greater friction losses. Figure 3 shows that as the water to fuel mass ratio increases, the BSFC decreases. The minimum BSFC value occurs when the water to fuel mass ratio is 0.5. Injected water leads to burn more fuel due to longer ignition delay and suppression of thermal dissociation due to lower mean cylinder temperature. Increase in specific heat and molecular weight of the burned gas and the heat absorption of water during the intake stroke yielded to a decrease in the mean cylinder temperature.

Figure 5 shows the effect of water addition on the brake thermal efficiency. As expected, the maximum increase in brake thermal efficiency occurs when 0.5 of water to fuel mass ratio is occurred, and this is due to the fact that the BSFC is minimum at the same time, as

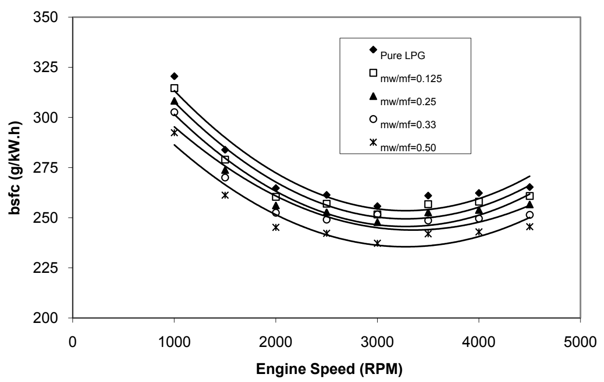

Figure 4: Effect of water injection on brake specific fuel consumption.

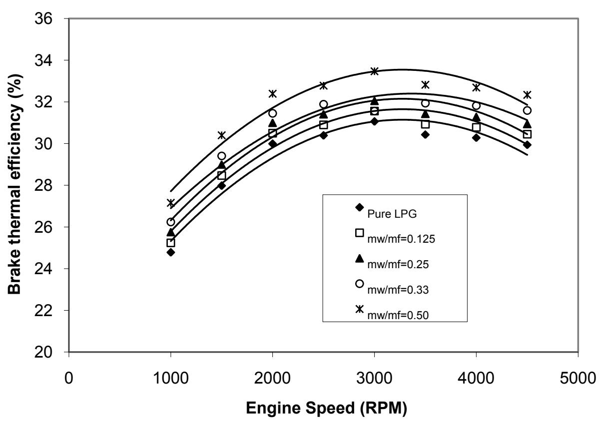

Figure 5: Effect of water injection on brake thermal efficiency.

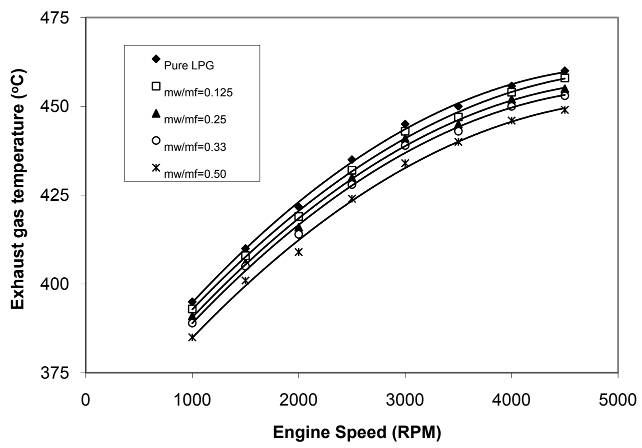

Figure 6: Effect of water injection on mean exhaust gas temperatures.

shown in figure 4. The average increase in brake thermal efficiency for 0.5 of water to fuel mass ratio is approximately 2.4% over the use of LPG alone for the engine speed range studied.

The variation of the exhaust gas temperature with engine speed for the different water to fuel mass ratio is shown in Figure 6. It is clear that as the water to fuel mass ratio increases, the exhaust gas temperature decreases. The heat absorbed by the additional water can explain the decrease in the exhaust temperature, because latent heat of the water will lead to absorb heat and so cool the charge. Lower exhaust gas temperature is an indication of a lower mean cycle temperature temperature through the engine cycle.

Conclusions

The present experimental research investigates the effect of water injection on the engine performance and exhaust gas temperatures for a commercial SI engine. The following conclusions were drawn from this investigation:

1. As the water to fuel mass ratio increases up to 0.5, the engine torque, power and brake thermal efficiency values increase.
2. The BSFC and the exhaust gas temperature decrease as the water to fuel ratio by mass increases.

Acknowledgements

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