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Study of Exhaust Gas Temperature of S I Engine using Water Injection

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Abstract

Objectives: In this paper an experimental study is carried out to reduce the exhaust gas temperature of a Spark Ignition (SI) engine by injecting water in the intake manifold. **Methods/Statistical Analysis:** The reduction of exhaust gas temperature decreases the NOx emissions. To achieve this, an experimental setup was fabricated to spray water using a small compressor at the intake manifold. A solenoid valve is used to regulate the water injection; the solenoid valve was in turn controlled by an electrical circuit. The temperature of exhaust gas was measured continuously using 'J' type thermocouple and digital temperature indicator. **Findings:** Injection of water just after the carburettor in the intake manifold reduced the overall temperature of the cylinder due to higher latent heat of vaporization. As the temperature inside the cylinder is reduced, harmful emissions such as NOx and CO are reduced thus bringing down the pollution to a greater extent. **Applications/Improvements:** In order to reduce the pollution caused due to automobile emission can be controlled by injection of water in the intake manifold.

Keywords: Exhaust Gas, Reduction, SI Engine, Temperature Emission Reduction, Water Injection

1. Introduction

The internal combustion engines are used extensively for various applications. These include locomotives, electric power generation, automobiles and pumping water for irrigation. Injecting water at the intake dates back to the 1940's, where engine manufacturers are in need to suppress the knock of aircraft engines at high power. In the turbo era of 1980s injecting water was enabler of high power density for F1 engines[1]. The problem associated with engine knocking, made the engine manufacturers to lower the compression ratio in order to suppress the in-cylinder pressures. It is obvious that reducing the compression ratio will compromise the thermal efficiency. Therefore, water injection is another alternative for suppression of knock. When water was injected into the cylinder at an angle of 640° Crank Angle (CA) for a duration of 10° CA and found that 15% water injection by mass gave the best engine performance[2]. It was also found that a decrease in the NOx and soot emissions due to water injection. Homogeneous Charge Compression Ignition (HCCI) is one of the most effective ways to increase the thermal performance of the engine and to reduce the emissions of engines like Nox and soot compared to other conventional methods in a gasoline engine[3]. Reduction of CO_2, other particulate matter emissions and improvement in the gasoline engine efficiency was achieved using Reformed Exhaust Gas Recirculation (REGR)[4]. The principle involved in REGR is recovery of energy from the hot exhaust gases using endothermic catalytic reforming of gasoline. Two promising techniques like cooled exhaust gas recirculation and water injection were investigated to prevent knocking and fuel economy of turbocharged gasoline engines[5]. The results revealed that due water injection in the intake manifold, the latent heat of water evaporation enhanced the knock resistance, and also resulting in increased BSFC benefits. Pressure Vs Time characteristics were recorded on a single-cylinder engine, the experimental analysis on the ratio of water to fuel mass flow rate was varied in the range of 0 to 1.5. The NOx emissions from the engine confirmed the extent to which the injection of water is effective in reducing the engine emissions[6]. The condensed water injection concept demonstrated a potential for increase in efficiency of

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3.3% – 3.8% on a stoichiometric combustion concept in the context of minimum specific fuel consumption[7]. The optimum quantities of water injection were 0.015 ml to 0.031 ml of water per cycle on a SI engine of 592 cc, Water injection investigation on the SI engine was performed by varying spark advance in order to determine the Maximum Brake Torque (MBT) and it was found to be increased by 16 %[8]. The water – gasoline emulsion in lean burn SI engine was experimented on NOx treatment[9]. It was also reported that, with suitable water concentration of 5% by weight the emulsion water-gasoline has positive effect on reduction of NOx emission. Reduction in hydro carbon (HC) emission from two-stroke spark ignition engine with double injectors mounted on the cylinder barrel for injecting liquefied petroleum gas (LPG) was developed and compared with manifold[10]. It was reported that 80% reductions in Hydro Carbon (HC) emissions at 25% and 100% throttle positions were compared to the manifold injection method. At full throttle the maximum brake thermal efficiency was also increased from 19.7% to 25.2%, also the Nitrogen Oxide (NO) emissions were found minimum for fuel injected using two injectors. Studies on reduction of NO_x, HC and CO emissions of a prototype catalyst, for lean and stoichiometric conditions at different loads, speeds, and air fuel ratio were performed, the results reveal that the reduction in CO and HC emissions over the prototype catalyst was about 90–95% while the maximum NO_x emissions reduction under lean engine operating conditions was approximately 35–55%[11]. Water containing acetone-butanol-ethanol and blends of gasoline were investigated in an SI engine and enhancement of engine torque and reduction in emissions like CO, un-burnt hydrocarbon and NOx was observed[12]. The effects of octane number on the performance and emissions of a SI engine was studied[13], in the experiment the concentrations of NOx, CO and total hydrocarbon emissions were measured. It was observed that NOx and CO emissions of Research octane number 91 are higher than Research octane number 95 in most cases except at high engine speed with direct injection system. The experimental investigation of the characteristics of combustion and emission in an internal combustion Rankine cycle engine under different water injection laws was analyzed[14]. From the experimentation it was observed that higher period of injection and pressure resulted in increased thermal performance and indicated mean effective pressure. Also the stability of engine was better at less water injection pressure and injection duration. Lower HC and NOx emissions occurred for less duration of water injection and better atomization. Thus from the literature it was inferred that injecting water at the intake manifold, provided a means of cooling inside the engine, this is because of high latent heat of vaporization and it resulted in the reduction of emission and also enhanced the resistance of the knocking in SI engine. Compressed Natural Gas (CNG) was used as an alternative fuel to overcome the problem of emission, apart from higher compression ratio, higher octane number, the CNG is used avoid knocking. The HC and CO emission characteristics are better for CNG compared to petrol[15]. Considerable improvements were observed in exhaust emissions like CO and HC (except NOx) for biodiesel fuel blended with diethyl ether in an engine coated with the ceramic material lanthanum zirconate by plasma spray technique[16]. It was found that HC and CO emission for vegetable oil under preheated mode is lesser than vegetable oil under non preheated mode; however, for preheated vegetable oil NOx emission is higher. For preheated vegetable oil the CO_2 emission is higher than unheated vegetable oil and diesel. Thus the vegetable oil neutralizes emission of CO_2, and there for there will not be any addition of fresh CO_2 emission. Preheated vegetable oil is a promising alternate for mineral diesel[17]. It was also proved that by the usage of biodiesel as fuel the emission of NOx have increased, while turbocharger has decreased the NOx levels. There is reduction of HC emissions when biodiesel and turbocharger are used[18].

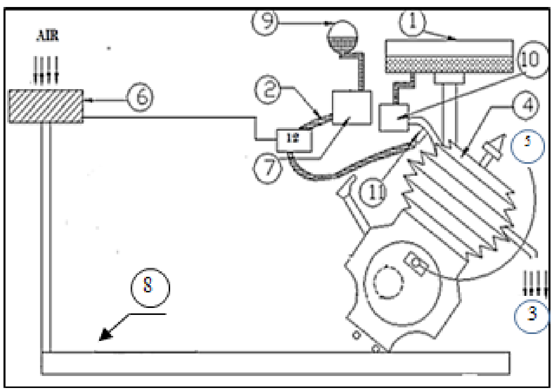
2. Experimental Setup

In this experimental study an experimental setup was fabricated to inject water injection in a single cylinder SI engine. The engine used for analysis is TVS Centra two wheeler engine of 100cc. The complete technical specification of the experimental setup is provided in Table 1.

Table 1. Technical specification

Sl No	Equipment	Description
1	Engine	TVS Centra, 100cc, single cylinder, air cooled, SI engine, 1 No.
2	Solenoid valve	220 V AC Solenoid. EVI 7/9
3	Air compressor	Reciprocating, 10 bar (Max), 60 lit/min
4	Electrical circuit	0-12V, 3 A, Step down transformer, with relay, capacitor and diode.

Separate tank for injecting water was made and atomised water (with the help of an air compressor) was blended to the air fuel mixture in the intake manifold of the engine. A solenoid valve was used to regulate the proportion of water blended with the air fuel mixture. The solenoid and air compressor was in turn controlled by an electric circuit. The actuation of the solenoid valve and air compressor was done after a time delay of 5 minutes, i.e initially for first five minutes the engine was operated with petrol alone. After five minutes the blending of water to the air fuel mixture was done. The detailed experimental setup is indicated in the Figures 1a and 1b. The electrical circuit comprises of a step down transformer and a full wave rectifier which transforms the 220V AC to 12V DC. The solenoid valve operates directly on 220 V AC current while the air compressor is operated at 12V DC. The detailed electrical circuit is depicted in Figures 2a and 2b. Water injected in the intake manifold gets atomized due to the compressed air; the latent heat of vaporization of water reduces the temperature of the incoming air and the combustion chamber. The amount of water blended was varied manually by a regulator in the solenoid valve. The purpose of electric circuit is to keep the air compressor and the solenoid valve in standby as the engine operates initially. The exhaust gas temperature was measured using J type (iron-constantan) thermocouple and digital temperature indicator. The exhaust gas temperature was measured for a constant load condition and different % of water injection.



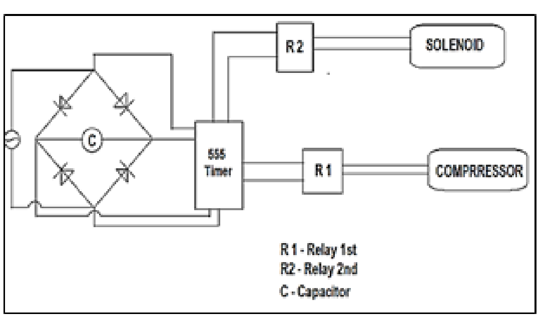
a)

b)

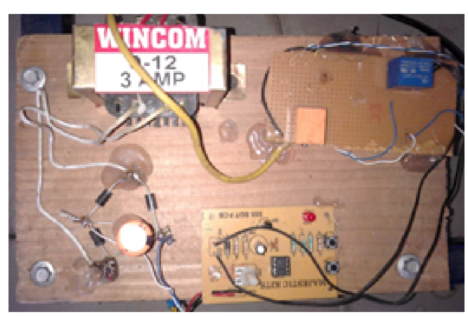
Figure 1. a) Experimental setup (schematic diagram) b) Experimental setup (photograph).

7. Solenoid valve
8. Stand
9. Water Tank
10. Carburettor
11. Water injector
12. T - junction

1. Fuel Tank
2. Water tube
3. Exhaust Gas
4. Engine
5. Spark plug
6. Compressor



a)



b)

Figure 2. a) Electrical circuit b)electrical circuit (photograph).

3. Experimentation

The SI engine was operated continuously under no load condition for the following different proportion of water injection. The exhaust temperature for the different proportion of water injection was measured using J type thermocouple connected to a digital temperature indicator. The thermocouple was initially calibrated with standard ice temperature and boiling point of water. The different proportions of water injection and the measured exhaust temperature is illustrated in the Table 2. The engine was operated until it stopped performing as the amount of water blended increased. There were 21 different proportions of water injection during the experimental study.

Table 2. Different proportions of water injection and corresponding exhaust temperature

Sl No	Volume flow rate of Water injected (ml/ min)	Mass % of water to mixture	Exhaust gas temperature (°C)
1	0	0	801
2	1.98	36.8	760
3	2.051	37.6	744
4	2.121	38.4	728
5	2.173	39	712
6	2.245	39.7	696
7	2.332	40.6	680
8	2.403	41.4	664
9	2.495	42.3	648
10	2.577	43.1	632
11	2.688	44.1	616
12	2.814	45.2	600
13	2.912	46.1	584
14	3.042	47.2	568
15	3.177	48.3	552
16	3.340	49.5	536
17	3.537	50.9	520
18	3.703	52.1	500
19	3.916	53.5	470
20	4.143	54.9	424
21	4.411	56.4	370

4. Results and Discussion

As the water along with compressed air was injected just after the carburettor, due to the high latent heat of vaporization of water reduction in overall temperature inside the cylinder was quite significant. As the temperature inside the cylinder reduced, the amount of harmful emissions from the cylinder such as NOx and CO were also should be reduced to a greater extent thus bringing down pollution to a considerable amount. If the temperature inside the cylinder due to combustion is higher, then it is always accompanied greater mean effective pressure. These conditions lead to detonation, referred to as engine knock, in this case the fuel-air mixture burns in an undesirable manner and it is undesirable. To combat the knock and the emissions from the engine, the solution is to reduce the temperature inside the cylinder. The exhaust temperature gas characteristics are plotted in Figures 3 and 4. From the exhaust gas characteristics curves, it is inferred that as the mass % of water injection was increased the exhaust gas temperature was decreasing continuously.

The slope of the curve was uniform until 52.1% of mass of water injection. Further increase in water injection indicates sharp increase in the slope of the characteristic curve indicating sudden fall in exhaust gas temperature. The engine was performing upto 56.4% of mass of water injection and beyond this limit the engine stopped working.

From Figure 4, the behaviour of the engine is found to decrease the exhaust temperature as the volume flow rate of water injection is increased. The drastic change in trend for the SI engine considered for analysis was from 3.7 ml/min, beyond this point the exhaust temperature of the engine fell sharply. It was also observed that the engine stopped working after 4.41 ml/min.

5. Conclusion

The exhaust temperature of the selected two wheeler engine (TVS Centra 100 cc) was found operating while water was injected. It was observed that, the engine was performing well with less detonation and exhaust temperature. The exhaust temperature of the engine without water injection was around 800°C, under no load condition. The exhaust temperature was found decreasing as the amount of water injected was increased. The slope of the characteristic curve corresponding to the exhaust temperature was decreasing with uniform slope until 3.7 ml/min (52.1% of mass) of water injection. The change in slope of the curve was found beyond this point. The SI engine taken for analysis was able to operate upto 4.41 ml/

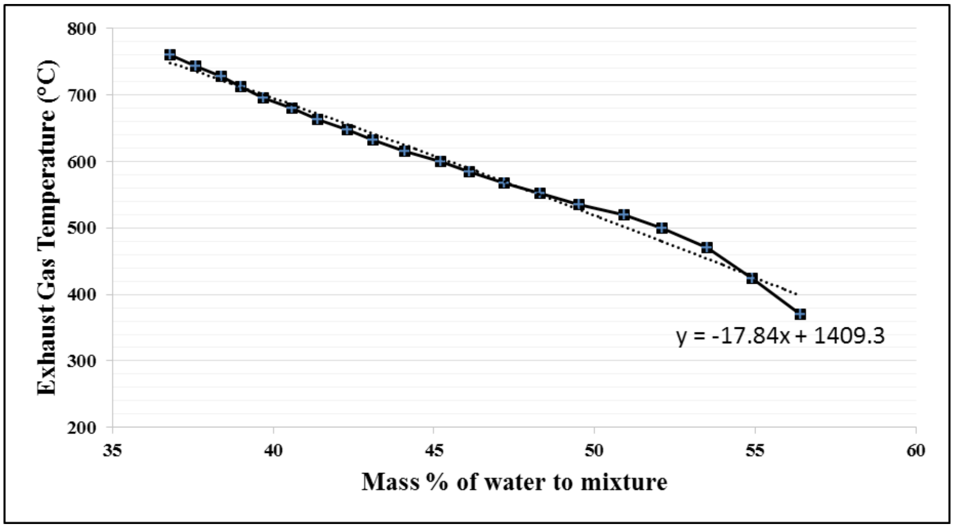


Figure 3. Exhaust temperature under different mass % of water injection.

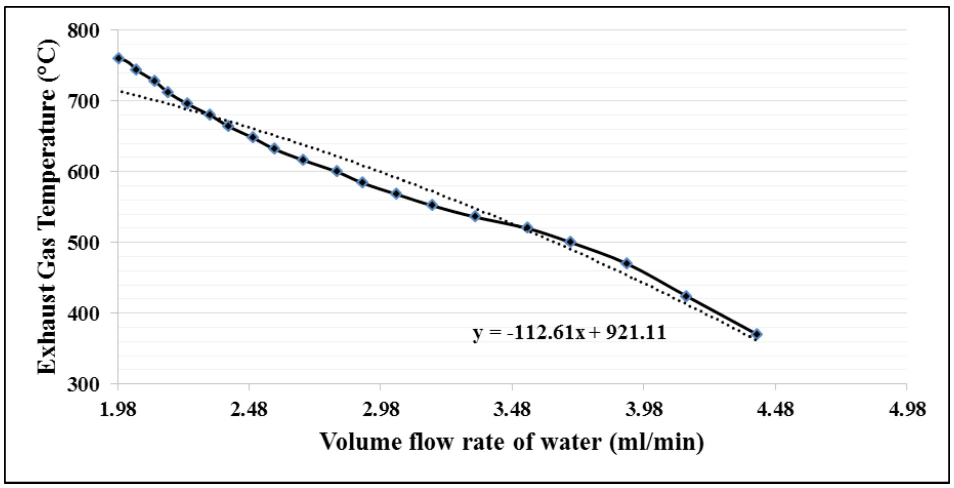


Figure 4. Exhaust temperature under different volume flow rate of water injection.

min of water injection. From the detailed literature survey carried out, it is obvious that the reduction in emission and knocking of the engine due to water injection will be there. The study can be extended to determine the amount of reduction in emissions from the engine considered for analysis. The provision for water injection in SI engine to combat the emissions can be implemented in the future.

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