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Water Injection Effects on Performance Characteristics of a CI Engine

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Abstract:
All over the world, number of experiments are being carried out to reduce the emissions of the i.c engines. Among them, water injection in inlet manifold is one technique. Experiments will be conducted on four stroke single cylinder water cooled diesel engine with water injection system. Different water quantities will be supplied constantly with air in the intake manifold of the engine. The obtained results will be compared with diesel engine without water injection setup. As a result of the water injection in the form of fine spray droplets exerts positive effects on exhaust emission particularly on NOx emissions. Because of the water injection, combined effect of absorbing heat developed by fuel during combustion and increased partial pressure of oxygen puts down the combustion temperature and thus it helps to decrease formation of NOX

KEY WORDS: Performance, IC Engine, reduction of *NOx* Emissions, inlet manifold, water injection effect,

1. INTRODUCTION

In the present work, the effect of water injection into the intake air on performance characteristic and emissions of single cylinder CI engine are carried out at different loads and constant speed, with variable water to diesel ratio by mass. Different methods have been used to reduce the NOx emission successfully from compression-ignition engine;

1.1 NOx REDUCTION METHODS

a) Exhaust gas recirculation (EGR),
b) Catalytic converter (post combustion method)
c) Water injection.

1.1a Exhaust Gas Recirculation (EGR)

The main principle employed in EGR is re-circulation of a portion of an engine's exhaust gas back to the engine cylinders. The re-circulated exhaust gas decreases the local temperature in the combustion chamber. It is mostly effective in particular time/space zones during which the NOx emission is produced, specifically during the fuel injection and after the end of the injections. In the EGR system, the heat of combustion from the fuel is used to heat the exhaust gas. The exhaust gas is essentially inert and therefore does not react in the combustion chamber and only absorbs heat. Even though, the EGR has a potential of reducing NOx up to 50%, it has an inherent drawback of increasing the PM emissions. In addition, the heat absorption by exhaust inert gas in the cylinder chamber results in small amount of power loss from the engine as well

1.1b Post-composition Control Method

The other method to reduce NOx emissions is using post-composition control of the exhaust gas to remove the NOx emission. One such method being used for SI engines for reducing the NOx emissions is three-way catalytic converter. The catalytic-converter changes NOx to N2, CO to CO2 and unburned hydrocarbons (HC) into H_2O and CO_2.
However, the materials used in catalytic converters include platinum, palladium, and rhodium, which are expensive. In addition, the catalytic convertors work best at a stiochiometric air-fuel ratio about 14.1:1. Most of the diesel engines tend to run lean which makes the catalytic converter less effective in reducing NOx emission. Running lean also produces more over all NOx emission because of the increase in engine temperature. The other catalytic method of NOx reduction is selective catalytic reduction (SCR). This method is used for many years in stationery combustion installations to reduce NOx by injecting ammonia in the presence of catalyst. In the vehicles applications instead of ammonia an aqueous solution of urea (NH2CONH3) is used. The SCR can result in NOx reduction of up to 90%. However, the application of SCR finds most application in heavy vehicle application and has rarely been used in passenger cars. This is because exhaust gas temperature in diesel car is low which makes SCR less effective.

In addition, the urea/ammonia management is quite costly and requires modification of the exhaust system for

catalyst space and provisions for new Urea/ammonia infrastructure and maintenance of the system.

1.1c Water Injection/Emulsion

The third available method to reduce local combustion temperature and consequently the NOx emission is the injection of emulsion of water into an engine system. One of the advantages of the water injection as compared with the EGR and the catalytic converter is the enhanced possibility of reduction of NOx over the entire engine load range without affecting the PM emission negatively.

There are three main methods that are used to introduce water into a diesel engine. They are the following ways.

1. Emulsion,
2. Fumigation, and
2. Direct water injection

1.2 Formation of NO_x

Approximately 90% of the NO_x resulting from the fuel combustion process is NO. The NO is primarily formed by the oxidation of atmospheric nitrogen (N_2). In the atmospheric air, the nitrogen exists in the form of N_2 (Diatomic molecules) which is highly stable. During combustion a high temperature of around 800^0c to 1200^0c will occur inside the engine cylinder. At this high temperature the diatomic molecule of nitrogen, N_2 changes into monoatomic Nitrogen 2N which is highly reactive.

This monoatomic Nitrogen reacts with oxygen, which is already present inside the cylinder and forms oxides of Nitrogen. Oxides of Nitrogen generally occurs in the form of NO and NO_2.

About 90% of NO_x exists in the form of NO. Hence higher temperature and availability of free oxygen are the main two reasons for the formation of NO and NO_2. A high combustion temperature causes a reaction between the oxygen and nitrogen in the air flow and combustion products, forming NO_x.

2. EXPERIMENTAL SETUP

Figure 2.Model of an engine

The above figure shows the experimental setup, which is a four stroke single cylinder water cooled diesel engine with water injection setup in inlet manifold of a diesel engine.

2.1 ENGINE SPECIFICATIONS:

Engine	Single cylinder, 4 stroke, water cooled, stroke 110 mm, Bore 87.5 mm. Capacity 661 cc. Power 3.5 KW, Speed 1500 rpm, CR range 12:1-18:1.
Dynamometer Type	Eddy current, water cooled, with loading unit
Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 lit, Type: Duel compartment, with fuel metering pipe of glass
Piezo sensor	Combustion: Range 5000 PSI, with low noise cable Diesel line: Range 5000 PSI, with low noise cable.
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Engine control unit	PE3 series ECU, full build

	potted enclosure.
Sensors for ECU	Air temp, coolant temp, Throttle position and trigger.
Digital voltmeter	Range 0-20V, panel mounted
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature transmitter	Type two wire, Input RTD PT100, Range 0–100 Deg C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0–1200 Deg C, Output 4–20 mA
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Software	"Enginesoft" Engine performance analysis software
ECU software	PeMonitor & peViewer software.

2.2 Water (fuel) injector in the inlet manifold

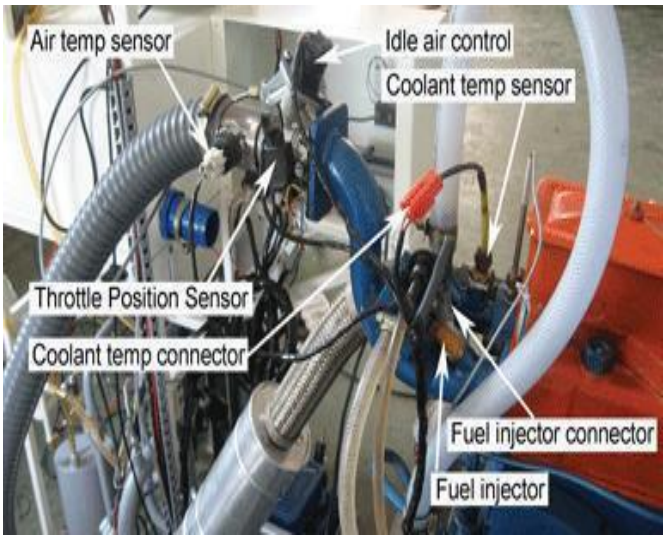

Fig.3 Water (fuel) injector setup in the inlet manifold

The arrangement of water injector in the inlet manifold is shown in the figure. By using this injector we can inject water or any other fuel, but in this experimental project we are injecting only the water. This injector is controlled by means of ECU (Electronic control unit). This ECU is operated by means of PE3 software, which is developed by the PERFORMANCE ELECTRONICS, Ltd., This injector is a programmable Fuel control system by means of this PeMonitor Tuning software. The PE3 system is a fully adjustable engine control unit for single and multi-cylinder engines requiring a standalone fuel injection and ignition Engine Control Unit (ECU). All setup and tuning Parameters can be adjusted with any PC running a Windows operating system and containing an Ethernet port. Below are some of the key features of The PE3 system:

2.3 Exhaust gas analyzer

Exhaust gas analyzer is used to measure the different quantities of emissions from the exhaust gas of an engine; here we are using AIRREX automotive emission analyzer. By using this Analyzer we can measure the emissions like CO, CO_2, HC, O_2, and NO_X.

Fig. 4 Automotive Emission Gas Analyzer

2.3 EXPERIMENTAL PROCEDURE:

Experiments were conducted in two different ways, they are

1. Experiments conducted on engine without any water injection in the inlet manifold, at 0%, 30%, 60%, 100%load and measured the exhaust gas emissions and performance characteristics are calculated at respected loads.
2. Experiments conducted on the engine with water injection in the inlet manifold, at 30%, 60%, 100%loads at different quantities of water like 30%, 60%, 90% of fuel consumed at respected loads, like as shown in below.

Load on the engine	Water quantity
At 30% load	30% of fuel consumed at 30% load 60% of fuel consumed at 30% load 90% of fuel consumed at 30% load
At 60% load	30% of fuel consumed at 60% load 60% of fuel consumed at 60% load 90% of fuel consumed at 60% load
At 100% load	30% of fuel consumed at 100% load 60% of fuel consumed at 100% load 90% of fuel consumed at 100% load

2.5 Experimental procedure [without water injection]

- Before starting the engine check all the water supply lines to the engine, and run the engine for 10min for stabilize the engine, Turn ON the computer connected to the engine and open the performance analysis software package "**Engine Soft**".
- The engine is now running at no load condition, as the engine is a computerized engine, we can see the engine performance characteristics on the computer by using the software,
- Save the performance characteristics of the engine and measure the exhaust emissions by using the Exhaust gas Analyzer at no load condition,
- Now increase the load on the engine to 30% of full load and wait for some time to stabilize the engine and save the performance characteristics and engine emissions by using gas analyzer.
- Like as said in the above manner save performance characteristics and measure the engine emissions at 60% & 100% load also.

2.6 Experimental procedure [with water injection]

- In this experiment i.e., with water injection, injector is going to inject water in the inlet manifold, this injector is operated by means of Electronic Control Unit and PE3 software which is installed in the computer.
- Here we measured the emissions and performance characteristics by injecting the water only at 30%, 60%, and 100%load, at no load condition there might be no significant

changes in the reduction of emissions, so that we not measured at no load condition.

- Start the engine and also open the "Engine Soft" software along with "PE3" software, increase the load on the engine up to 30% full load,
- Enter the water quantity to be injected in the PE3 software, allow the engine for some time to stabilize, now measure the exhaust gas emissions and engine performance characteristics.
- At the same 30% load only, change the water quantity in the PE3 software and allow the engine to run for some time, and measure the exhaust gas emissions and performance characteristics of the engine.
- As said in the above manner, measure the emissions and save the performance characteristics of the engine at 60% & 100%load at three different water quantities.

3. RESULTS AND DISCUSSION:

3.1 Brake thermal efficiency:

The complete combustion of fuel depends on the temperature in the combustion chamber. The water injection in the inlet manifold reduces the combustion temperatures. This result the decrease in break thermal efficiencies as the quantity of water injection is increasing. Fig. shows that the variation of brake thermal efficiency of the normal engine with the different quantities of water at various loads.

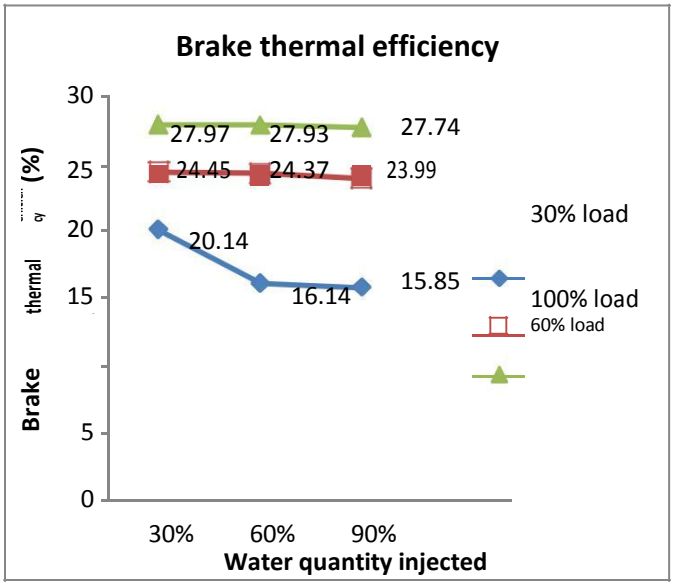

Chart -1: Brake thermal efficiency Vs water quantity injected.

In all cases, the efficiency is increasing with increase in loads. This is due to the reduction in heat loss. At 30% of load, there is a 21.3% decrease of efficiency, and at 60% of load there is 1.88% decrease in efficiency, and at 100% load there is only 0.82% decrease in efficiency. From the graph we can absorb that as the water quantity increasing there is slight decreasing in brake thermal efficiency at various different loads

3.2 Brake specific fuel consumption:

The result for the variations in the brake specific fuel consumption (BSFC) with load is presented in the fig. The variations of Brake specific fuel consumption with various loads on the engine at three different quantities of water injection.

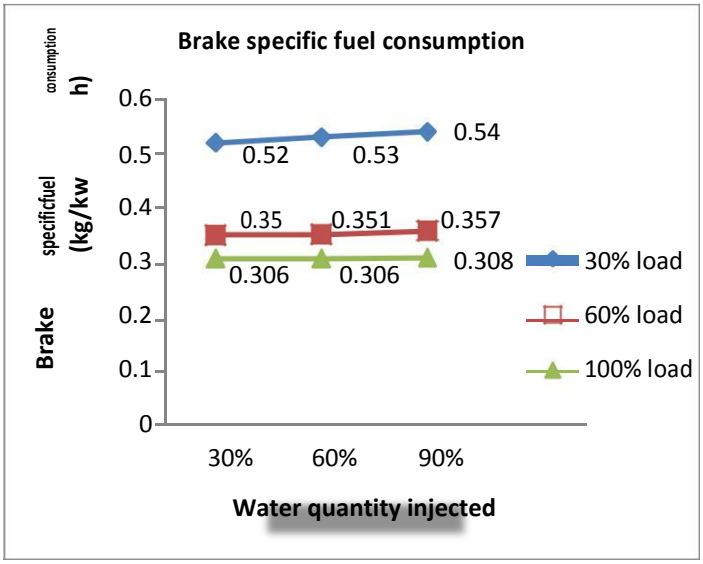

Chart -2: BSFC Vs water quantity injected.

We can observe from the above graph that the BSFC was increased as the load on the engine is increasing and also as the water quantity is increasing. The increase of BSFC is as follows at 30%, 60%, 100%loads are 0.65%, 1.96%, 3.7% respectively.

3.3 Nitrogen oxide emissions (NOx emissions):

The formation of nitrogen oxide emissions depends on the heat transfer rate and evaporation rate of the fuel. As the combustion temperatures are decreased, NO_x emissions are decreased.

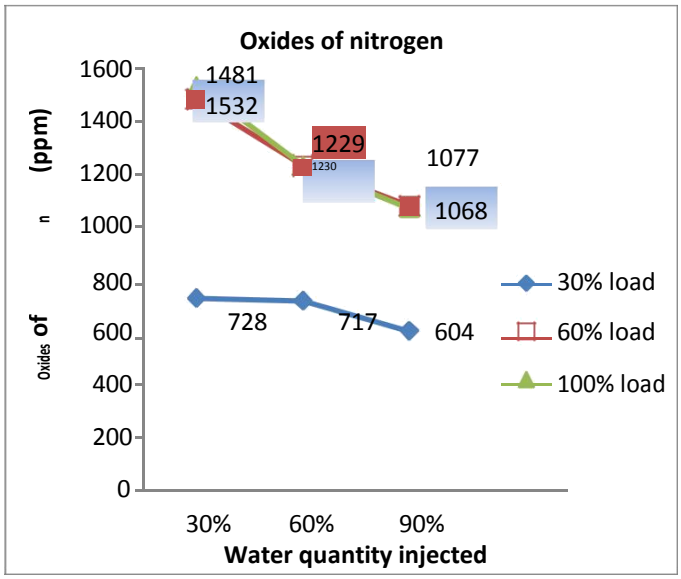

Chart -3: NO_x VS water quantity injected.

Fig. illustrates the variation of NOx emissions with different quantities of water injection at different loads on the engine. From the graph we can say that as the load on the engine is increasing, NOx emissions increasing. But as the water quantity in the inlet manifold is increasing, there is a decrease of NOx emissions at various loads on the engine.

3.4 Hydrocarbon emissions (HC emissions):

The amount of unburn hydrocarbons present in the exhaust as a function of load for different quantities of water injected in the inlet manifold is illustrated in Fig. The main sources of these emissions in diesel engine are lean mixing, burning of lubricating oil and wall quenching. The HC emissions are reduced considerably due to the completion of combustion of the fuel with hot combustion chamber

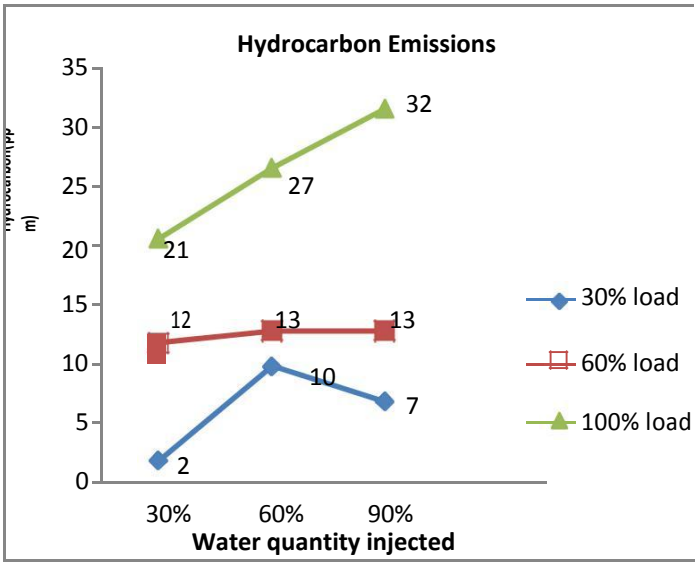

Chart -4: HC emission VS water quantity injected

As the load is increased, it would increase the temperature and this could increase oxygen content, reduce the density, leading to improved spray and atomization, better combustion and lower HC emissions. From the graph it is observed that as the load on the increasing HC emissions are increased. And also observed that as the water quantity injected is increased also the HC emissions are increases. Because of water injection, combustion will not takes place completely, so as water quantity increases HC emissions also increases.

3.5 Carbon monoxide (co):

From Fig. shows the emissions of CO with respect to different loads at three different quantities of water injected in the inlet manifold. It clearly shows that CO is increased as the load on the engine as well as water injection quantity increases. At high temperature carbon easily combines with oxygen and reduces CO emission. But, here we are injecting water, so the temperature in the combustion chamber reduces. As the temperatures are reduced, carbon does not react with oxygen. So that carbon monoxide emissions are increased.

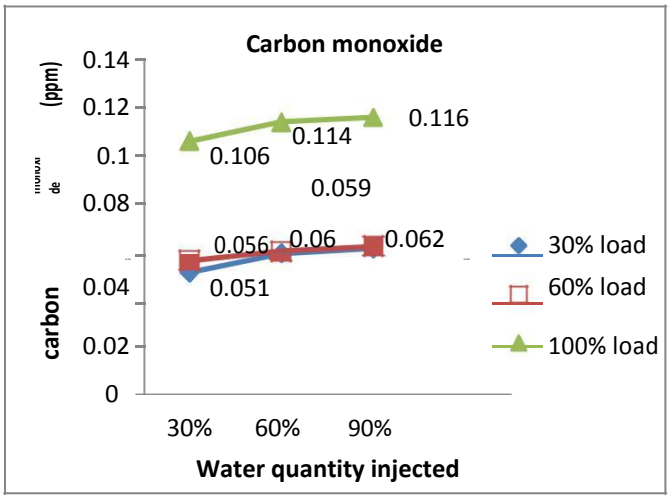

Chart -5: CO emission VS water quantity injected

The graph clearly shows that as the water quantities injected is increasing, the co emissions also increasing along with the increase of load on the engine.

4. CONCLUSION:

From this experimental test of water injection in the inlet manifold, emissions significantly and brake thermal efficiency were slightly reduced. In this conclusion at higher loads and at less quantity of water injection there was a supreme reduce of NOx emission. HC and CO emission were goes on increasing as the water injection

quantity was increasing. The brake thermal efficiency reduces at all outputs below diesel values with ingestion due to poor combustion as a result of reduction in the charge temperature. The brake specific fuel consumption of engine is also slightly increased as the water injection quantity was increased when compared to conventional engine.

The present of water vapour increase ignition delay as aforementioned. Increase of ignition delay period which tend increase the lean flame out region (LFOR). In this region of mixture does not participate the combustion or partially burned these are reason for hydro carbon emission and reduction of cylinder temperature was increase carbon monoxide emission. Aforementioned both HC and CO emissions were increased proportional to water injection quantity increased.

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