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Emission Experiment of Intake air Humidification of a Port Fuel Injected Spark Ignition engine

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Abstract— In this study, experimental analysis was carried out to investigate the effect of humidified air induction on emissions of a single cylinder, four stroke, air cooled, Royal Enfield Bullet engine 350cc, with modifications made to assist port fuel injection. Tests have been performed on test engine fuelled with gasoline over a range of engine loads and at rated speed for 75 % and 95 % relative humidity with water injection. The outcomes of the experimental analysis reveal that increasing the intake air humidity from 75 % to 95 % decreased the exhaust emissions of NOx, CO, HC and CO_2 at 95% rated load of the engine without much or less impact on the thermal brake efficiency.

Keywords: SI engine; Humidified air induction; Exhaust Emissions

I. INTRODUCTION

Road transport is probably the largest world purchaser of petroleum based fuels (~25 %), making it the principal air pollutant emitter of urban centers (> 75 %). Because of growing demand for energy, rising fuel prices, severe air pollution issues in city centers, and more restrictive environmental standards in the road transport sector, nations around the world are aggressively working to develop and finding new renewable energy sources and emerging technologies to reduce air pollutant of vehicle emissions.

Since the development of petrol (SI) engine, they are being used in vehicles such as cars, motorbikes and to power several different devices. Generally, petroleum-based fuels burned in petrol (SI) engines within the cylinders produces exhaust gases that are the main sources to atmosphere pollution [1]. NOx, HC, CO and CO_2 constitute the primary pollutants caused by the spark ignition engine exhaust [2]. As these gases have a significant effect on public hygiene as well as the ambiance [3, 4], strictest emissions laws are mandatory to scale back exhaust emissions [5, 6].

Because of growing demand for energy, rising fuel prices, severe air pollution issues in urban centers, and perhaps more stringent environmental standards for the road transport sector, nations around the world are aggressively working to develop and finding new renewable energy sources and emerging technologies to reduce air pollutant vehicle emissions.

One of the spark ignition engine's most dangerous emissions is NOx emissions since it reacts with the atmospheric oxygen resulting in petrol chemical smog and acid rain in the atmosphere [8].

Catalytic converters are intended to concurrently decrease NOx, CO and HC pollution with modern spark ignition engines. To obtain elevated transformation effectiveness, the engine needs to be operated at the stoichiometric air-fuel ratio. When the engine runs with a Lean air-fuel Mixture, a three-way catalytic converter has become very ineffective for decreasing NOx [8]. However, the minimisation of NOx emissions may include other techniques including exhaust gas recirculation (EGR) and water introductory technology such as direct water injection with a high-pressure injector into the cylinder, water spray in the intake multiple, water fuel emulsions[9], and steam injector[10]. The use of EGR, which reduces the concentration of oxygen in the combustion chamber that lowers the cylinder temperature but increases the emissions of HC and CO [11], can reduce NOx. The advantages of water entering the combustion chamber are to reduce the temperature of peak flames and thus reduce the formation of NOx emissions [9–13]. The three effects of introducing water into the cylinder that can be explained as: (1). A chemical effect resulting due to water dissociation in active radicals at high temperatures [14]; (2). A thermal effect due to the higher water heat than gasoline that results in greater volumetric efficiency; (3). This replaces air with water vapor in the inlet manifold of the engine with a dilution effect.

All of the above - listed effects result in a significant decrease in in - cylinder temperature and NOxemissions[14] without any deterioration in engine performance[15, 16].

Recently, a great deal of attention has been paid to minimizing NOx emissions through various water supplementation techniques and has been suited by many researchers [10–14]. However, there is still a lack of humidified air effects on SI engine emissions in existing literature. The primary goal of this study is therefore to investigate the impact of humidified intake air on the exhaust emission of a port fuel injected spark ignition engine. In this research paper, apart from most water introduction methods, the relative humidity of the intake air is increased by the adiabatic humidifying process.

In fact, adiabatic humidification is commonly used in air conditioning applications, especially in the areas of hot climates and in various industries. Water is atomized into the air during adiabatic humidification through the use of nozzles, and the water droplets in the air are evaporated and a gaseous state is attained. The energy required for evaporation is drawn in the form of heat from the

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surrounding air. Due to adiabatic cooling effect the air temperature drops up to 10°C [17]. The evaporated water also enhances air moisture content and thus increases air moisture.

II. EXPERIMENTAL SETUP AND TEST PROCEDURE

An experimental setup was developed to conduct tests on a spark ignition, single cylinder, four stroke, air cooled, petrol engine with the necessary instruments to evaluate the exhaust emissions namely NOx, HC, CO2 and CO at different operating conditions. The schematic diagram of the experimental setup is presented in Figure 1.

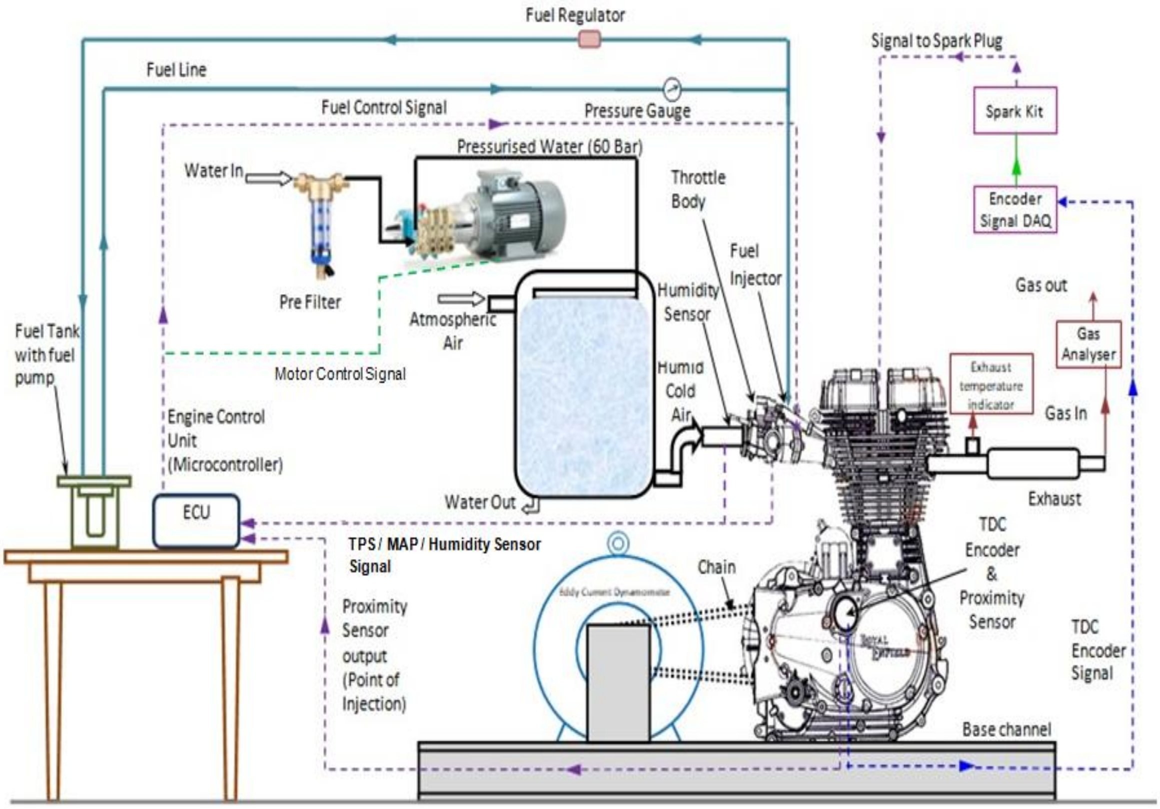

Figure 1 Schematic diagram of the experimental setup

A spark ignition, single cylinder, four stroke, air cooled, Royal Enfield Bullet engine, with modifications made to assist port fuel injection, was used in the present investigation, the technical specification of which is given below.

Make	: Royal Enfield
Type	: Four stroke, Single cylinder, Air cooled
Displacement	: 346 cc
Bore X stroke	: 70 mm X 90 mm
Compression ratio	: 6.5 : 1
Connecting rod length	: 175 mm
Fuel	: Gasoline
Rated Brake power	: 13.42 kW at 5625 rpm
Maximum Torque	: 31.98Nm at 3000 rpm
Fuel supply	: Port Fuel Injection (PFI)
Dry weight	: 163 kg
Starting	: Self motor / Kicker

The carburetor of a conventional Royal Enfield 350cc bullet engine was removed and a throttle body, consisting of a butterfly value, TPS and MAP which control the quantity of air that gets into the engine cylinder was retrofitted in the inlet manifold of the engine to assist the port fuel injection system which is coupled with an eddy-current dynamometer.

The constituents of exhaust emissions of the engine like NOx, HC, CO, CO_2 and O_2 were measured using an AVL Di-gas analyzer. The measurement was made by positioning the sensing probe near the outlet of the silencer in the tail pipe.

A humidification unit comprising of a pump for water with a highest possible mass flow rate of 2 lpm, a filter for water, a large-air insulation box, a relative humidity sensor and a temperature sensor has been installed. On the air box head, the water nozzle (high-pressure) was installed. Based on the input signal from the humidity sensor a control signal is given as output from the microcontroller to the motor control unit, which controls the operation of the water pump. By adjusting the amount of water injected into an air stream, the relative humidity of the air was adjusted.

Initially, the engine was running at a constant crank speed of 3000 rpm (rated speed) using the gasoline fuel until the stable condition was achieved at normal temperature and pressure at no load. At steady state conditions, the fuel consumption and the concentrations of NOx, HC, CO_2 and O_2 in engine emissions were measured using an AVL DI-Gas analyzer and the experiments were repeated for four loads in the range of 20 % to 95% in steps of 25% of the rated load. After completing the experiments with normal temperature and pressure, the experiment was then repeated for 75 % and 95 % humid air and the observations were made and recorded.

III. RESULTS AND DISCUSSION

Figure 2 shows meteorological information (temperature and relative humidity) of the study area received from the Meteorological Observatory, Faculty of Agriculture, Annamalai University.

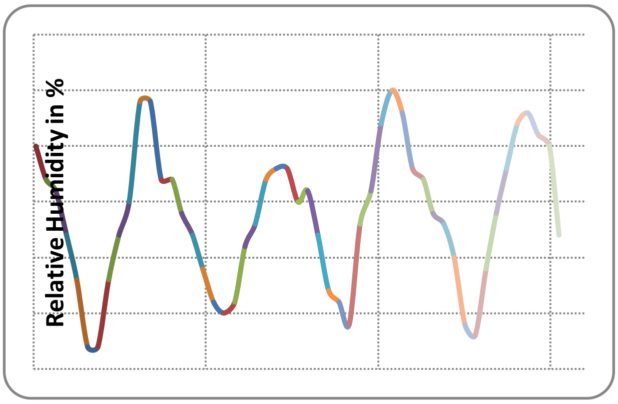

Figure 2 Meteorological information of Relative humidity

In the year 2017, the average maximum temperature of 31.25°C with relative humidity of 70% was observed during the winter season. The average maximum temperature is 35°C and relative humidity is 63% during rainy season. During summer the temperature ranged between 25.5°C and 30°C with relative humidity of 77%. In the year 2018, the average maximum temperature of 30.75°C with relative humidity of 71% was observed during the winter season. The average maximum temperature is 34.75°C and relative humidity is 62% during rainy season. During summer the temperature ranged between 25.5°C and 31°C with relative humidity of 74%.

The effect of intake air humidification on the experimental engine NOx, CO, CO_2 and HC emissions is presented and discussed graphically in this segment.

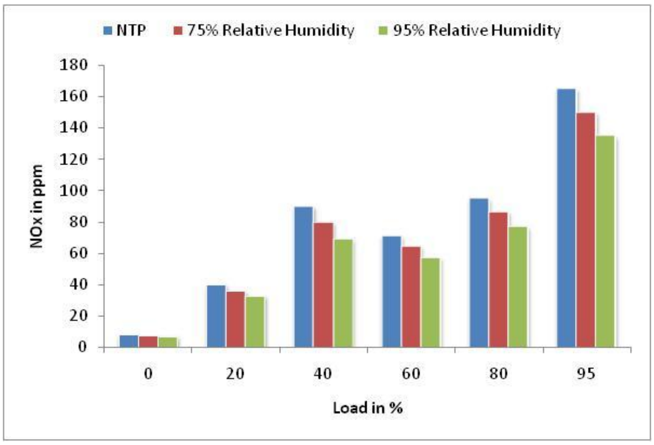

Figure 3 Effect of intake air humidity on NOx emissions

Fig. 3 represents the effect of humidified air on NOx emissions at a rated speed of 3000 rpm for engine loads from No load to 95% of the rated load. When the relative inlet air humidity for all engine loads is increased from 75% to 95% a notable reduction in NOx emissions take place. By raising the intake air relative humidity from 75% to 95%, NOx emissions are reduced by 18% for 95% of the rated load. Numerous factors influence NOx formation in the cylinder, but it is highly dependent on the in-cylinder temperature of the engine, the concentration of oxygen and the duration of combustion [2]. With increasing the humidity of inlet air, its moisture content also increases. As well-known, water vaporization heat is about 7.6 higher than gasoline heat. Thus, the evaporation of the water droplet in the inlet air decreases the intake charge temperature, causing the temperature to fall at each stage of the cycle. Moreover, the peak in-cylinder temperature is decreased due to the high heat capacity of the water and consequently the NOx emissions are reduced[18].

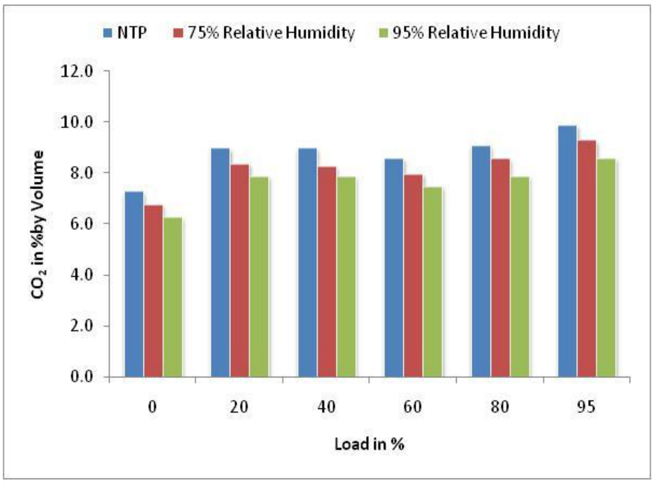

Figure 4 Effect of intake air humidity on CO_2

The effect of humidified intake air on the test engine CO_2 emissions was shown in the Fig.4. With 95% relative humidity, an appreciable reduction in CO_2 emissions was achieved at 95% of the rated load. This is a favorable outcome, as CO_2 emissions are a greenhouse gas, and so many nations have committed themselves to reducing CO_2 emission levels [20, 21]. With

95% relative humidity, CO_2 emissions were reduced at 95% of the rated load by about 13%.

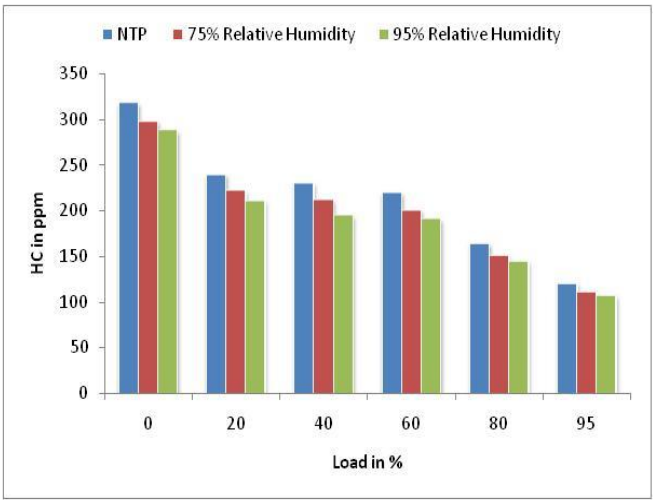

Figure 5 Effect of intake air humidity on HC

Fig.5 illustrates the effect of intake air humidity on HC emissions. The figure clearly shows that increasing the intake air humidity results in a considerable reduction in HC emissions at 95% of the rated load. From here it can be concluded that the engine loads affect HC emissions more than the inlet air relative humidity. Due to the high load mass flow rate in the cylinder, fuel burning is improved at full engine load, resulting in lower HC emissions compared to half engine load for the same relative humidity. It is concluded that with 95 % of the rated load, HC emissions have been reduced by about 11.5 % for 95 % relative humidity.

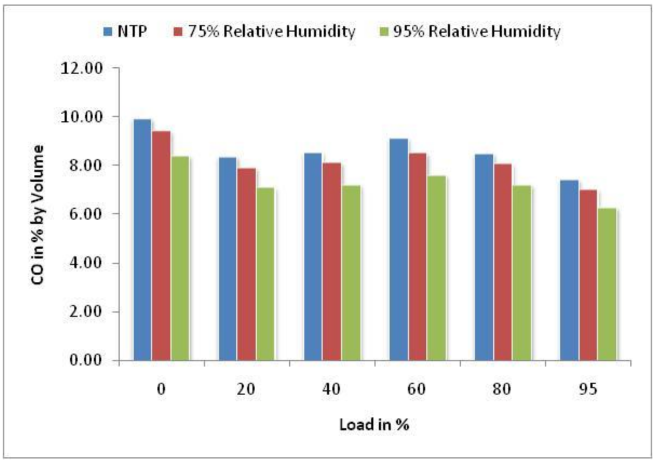

Figure 6 Effect of intake air humidity on CO

Fig. 6 Exhibits the effect of inlet air humidity on CO emissions. At 95% relative humidity, CO emissions were reduced by about 10% at 95% of the rated load. Therefore, it would be mentioned above the possible reasons for the lowest CO emissions with a relative humidity of 95 percent at full engine load. The lower combustion temperature with 95 percent relative air humidity reduces the dissociation rate of CO2 to CO and O2 resulting in lower CO emissions. In addition, the lowest CO emissions can be linked to the water-gas shift reaction which influences emissions by transforming CO to CO2 and generating H2 from water vapor.

IV. CONCLUSION

The purpose of the whole experimental work is to examine the impact of natural action of intake air humidification on hazardous emission components of engine exhaust of a modified Royal Enfield single cylinder 350cc SI engine for port fuel injection system. The result reveals that an increase of 75 % to 95 % intake air relative humidity showed significant benefits in terms of exhaust emissions. With 95% humidified intake air at 95% rated load, the maximum decrease in $CO_{2,}$ CO and HC emissions was achieved. The lowest NOx emission was observed at 60% of rated engine load with 95 % intake air humidity. Therefore, it is concluded that adiabatic humidification of intake air to a port fuel injected spark ignition engine is a successful method of reducing exhaust emissions without much or less impact on the engine performance.

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