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Investigation of Cold Start and Idling Emission Characteristics of Ethanol-Gasoline Blends in SI Engine

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Abstract
Increased emission levels are normally experienced in spark ignition (SI) engines at cold start and idling conditions. Carbon monoxide (CO) and unburned hydrocarbons (HC) are the main pollutants contained in the exhaust gas. This experimental work indicates a possible solution for reducing HC and CO emissions from a commercial spark ignition engine by blending ethanol with gasoline during the initial conditions. To the commercial available unleaded gasoline, in different percentage by volume varying between 0% (E0) and 30% (E30), ethanol was blended, for evaluating cold start and idling emissions. The pollutants measured were HC, CO, CO_2. The test results indicated that, the HC and CO emissions at cold start and idling reduced considerably compared to base gasoline as ethanol was blended with gasoline. Among the blends E5, E10, E15, E20, E25 and E30 which were tested, the E15 ethanol-gasoline blend showed the maximum reduction in CO and HC emissions at cold start and idling conditions.

Keywords: Cold start, Emissions, Ethanol-Gasoline blend.

Introduction
Cold start of the engine is defined as the starting of an engine after a stop time of not less than 6 hours and *i*dling indicates the continuous operation of an engine while the vehicle is not moving. The cold starts depend on engine design, fuel and coolant properties and use of starting aids and also on the condition of battery. During very low speeds the engine may not start due to losses to cold walls of the cylinder during compression and greater time available for leakage past the piston rings. At cold start there is a short time for vaporisation and preparation of mixture for ignition. The catalytic converters fitted to the exhaust manifold becomes efficient at the light-off temperature (250-300^{o}C) and hence catalytic convertors will not be effective during the cold start period. A major reduction is possible if pre-heating can be done to increase the temperature of the combustion mixture. But because of availability of time involved and amount of energy needed, it preheats only a small portion of converter volume. Moreover, it is challenging to implement a catalytic converter in larger engines due to its difficulty in implementation in larger engines. [1-3]. Rong-Horng Chen et.al [4], from a study found that as the quantity of ethanol in the blended fuel increases, the charge becomes leaner which in turn changes the Reid Vapour Pressure non linearly. The E5, E10, E20, and E30 blend could start the engine smoothly and stably. Due to an unstable mixture the E40 blend is too lean for starting the engine. A. Henein and M.K. Tagomori [5], investigated the sources of HC emissions during cold start of port-injected gasoline engines. Due to unstable combustion for few of the first cycles HC was the prime source of emission. The catalytic after-treatment devices has not become effective as warm up cannot be done efficiently, allowing these HC emissions to occur at the tail pipe. Fikret Yu¨ ksel, and Bedri Yu¨ksel [6], studied the performance of an SI engine for the usage of ethanol–gasoline blend as a fuel. The torque output of engine increased faintly and the HC and CO emissions reduced steeply. By using ethanol–gasoline blended fuel, the HC and CO emissions were found to reduce around 80% and 50%, while the CO_2 increased 20% for a newly developed injector for various loadings. Paolo Iodice and Adolfo Senatore [7], realised that with ethanol–gasoline blended fuels, cold start emissions reduced due to the leaning effect occurring due to ethanol addition which improves combustion and the higher volatility of blended fuels which in turn improves fuel vaporization during the transient time, for a four stroke motorcycle with fuel-injected SI engine. The E20 blend resulted in a significant reduction of cold emissions compared to the usage of gasoline. E30 gave in greater emissions than those of low ethanol content blends which can be due to both incomplete combustion during the transient time inside the combustion chamber, and to the lower volatility of G30 blend fuel that decreases at higher ethanol. Mustafa Koç et.al [8], studied the effect of ethanol–unleaded gasoline blends on the engine performance and exhaust emissions in a spark-ignition engine. The ethanol addition to gasoline increased the fuel consumption, engine torque and power and reduce hydrocarbon (HC) emissions, carbon monoxide (CO) and nitrogen oxides (NOx) emissions by varying the compression ratio (CR) without any knock. Jitendra kumar et.al [9], studied the use of ethanol blended gasoline fuel for the performance in spark ignition engines. Results revealed an increase in air fuel ratio, specific fuel consumption, and mechanical efficiency. 10% ethanol blend was indicated to found most effective. Yung-Chen Yao, Jiun-Horng Tsai, and I-Ting Wang [10], compared the gaseous

pollutant emissions from motorcycle with ethanol–gasoline blend for a carburetted and injector engine of same capacity. The results plotted revealed CO emission, compared with gasoline, from E15 it decreased by 32% (carburettor) and 10% (fuel-injection). THC emissions too reduced by 10% for fuel-injected engine, but not for carburetted engine. No considerable decrease in NO_X was noticed for E15 at all loads. From literature survey done, it was clear that, the exhaust gas emissions, particularly HC and CO from an SI engine were found to be high during a cold start of the engine. Various research works have been studied to reduce these emissions by methods. Majority of the studied had said that, fuel blend used for an SI engine during cold start is a mixture of gasoline and alcohols. Out of these alcohols, ethanol was used mostly as it was very compatible with fuel systems of an SI engine. It was also evident that the main reason causing the high HC emission during a cold start is due to less vaporization of fuel and improper mixing with air in a carburettor engine occurring because of rich mixture and low temperature. The insufficient availability of oxygen in gasoline was another reason found for increase in CO and HC emission during a cold start of an SI engine. During idling periods, an engine consumes power to keep engine itself running and also for its accessories thereby, no usable power is produced to run the drive train. So the idling emissions also contributed to a good percentage of total vehicle emissions particularly at no load conditions.

Experiments

The experiment was done on a Briggs and Stratton commercial SI engine. The engine was of carburettor type and 400cc displacement. The detailed engine specification are given below:

TABLE.1. Specifications of the engine

Make	Vanguard
Engine displacement	392cc
Engine configuration	Horizontal
Gross horse power	9.7kW(13HP)
Bore	89mm
Stroke	63mm
Compression ratio	8.6:1
Number of cylinders	One
Lubrication system	Splash lubrication
Carburettor	Single barrel float feed
Engine cooling	Air-cooled

The temperature was measured using a thermocouple just before the carburettor. The emission readings were noted for every 15 seconds. The engine was run totally for about 8 each time. A calibrated exhaust gas analyser (HORIBA MEXA 584L) has been used to measure the emission levels of HC, CO and CO_2 immediately on starting the engine.
The table given below define the properties of ethanol and gasoline used for this experimental study.

TABLE.2. Properties of ethanol and gasoline

Fuel Properties	Ethanol	Gasoline
Formula	C_2H_5OH	C_4 to C_{12}
Molecular Weight	46.07	102
Oxygen, weight %	34.7	3
Specific heat, kJ/kg-K	2.4	2
Latent heat of vaporization, kJ/kg	923	349
Flash point, ^{0}C	13	-43
Auto ignition Temperature, ^{0}C	423	257
Lower Flammability Limits, vol%	4.3	1.4
Higher Flammability Limits, vol%	19	7.6
Stoichiometric Air-Fuel Ratio, weight	9	14.7
Calorific Value, MJ/kg	29.7	47.3

Before conduct of each experiment, the engine was conditioned at 26 ± 1^{o}C for a minimum of not less than 8 hours. The emission tests were done initially with gasoline for every 15 seconds for a total of 8 minutes. The tests were again repeated with the different ethanol-gasoline blends and the results were noted. The following block diagram represents the setup for the experiment.

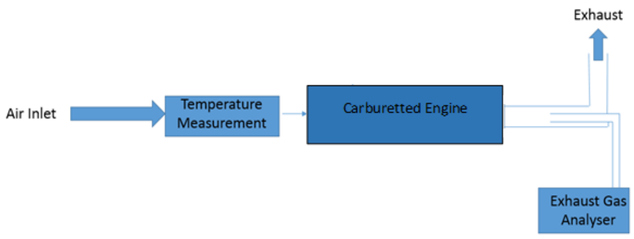

Fig.1. Block diagram of experimental setup

Results and Discussions

Based on the measurements from the exhaust gas analyser, the variation of CO, HC and CO_2 emissions were plotted. The graphs shown below were plotted for gasoline fuel and different ethanol-gasoline blends at 15 seconds time interval.

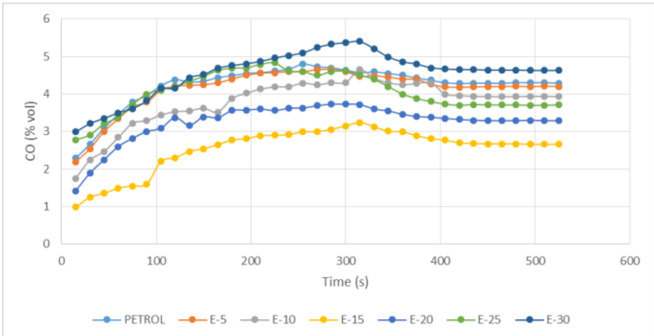

Fig.2. CO V/s Time

A rich mixture during cold start has insufficient oxygen and temperature arresting CO into CO_2 conversion. So high amount of CO emissions are found during the cold start as indicated in Figure 2. As the engine warmed up, the CO emissions showed a decreasing trend. This is due to reason that the engine operates in hot transition stage, enhancing the oxidation of CO. It then become constant when an equilibrium occurs for conversion of CO to CO_2. The least CO emission was found for E-15 blend.

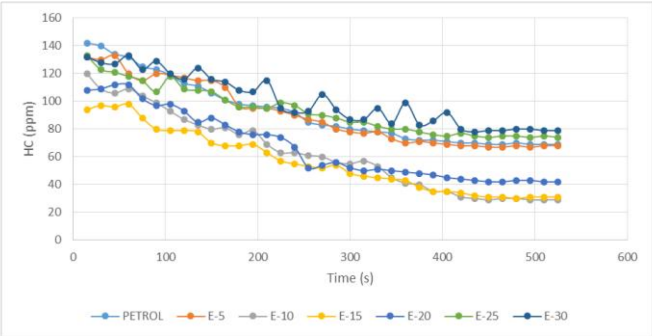

Fig.3. HC V/s Time

During cold start of the engine, the evaporation of gasoline was less and results in a richer fuel-air mixture. As a result a few amount of the charge escapes the first combustion cycles without undergoing any combustion. This leads to high unburned HC emission during the first few minutes as indicated in Figure. 3. When engine starts operating in transition stage, the HC emissions is lesser due to better mixture formation and combustion and remains almost constant afterwards. The least HC emission was found for E-15 blend.

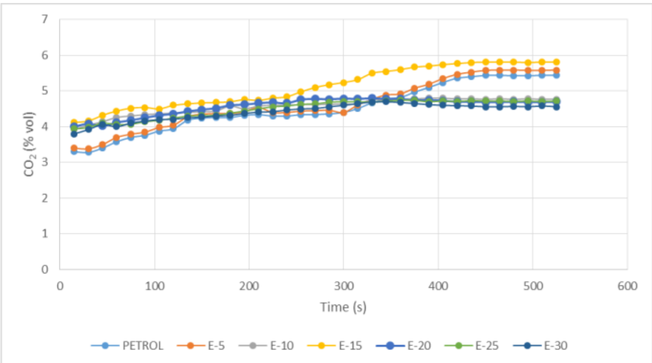

Fig.4. CO_2 V/s Time

Carbon dioxide shows an increasing trend as shown in Figure. 4 as time progresses. This may be due to better conversion of CO into CO_2 and conversion of hydrocarbons. The maximum CO_2 emission was found for E-15 blend.
The emission characteristics of gasoline, E5, E10, E15, E20, E25, E30 at ambient temperature of 26°C were taken. During cold start, the high oxygen content in the fuel blends favors oxidation of CO. This decreases the CO emission for ethanol blends when compared with CO emissions of gasoline. The higher oxygen content in the ethanol blends aids in improved combustion of the charge which in turn reduces HC emissions. E15 showed the maximum reduction in both CO and HC emissions. For E5 and E10 the emission reductions were less and was found to be similar to that of gasoline. For E25 and E30 the emissions were large because of over leaning of the fuel mixture and the excess oxygen cools the engine which curtails the conversion of CO to CO_2 and increases HC formation. The E15, when compared with gasoline, was found to have least emissions as the oxygen atoms promote sufficient combustion but the fuel mixture is not too over leaned and improved oxidation of and CO into CO_2 and oxidation of hydrocarbons at cold start and idling conditions.

Conclusions

- A single cylinder, 392 CC, air cooled, SI engine cold start and idling emission characteristics was studied using commercial gasoline and ethanol – gasoline blends varying between E5 and E30.
- For gasoline and all blends the CO increased first, reached maximum and then reduced after the transition, and finally became constant after almost stable combustion had attained.
- For gasoline and all blends the HC was found to have a decreasing trend initially, and finally became constant after the engine attained a stable temperature.
- For gasoline and all blends the CO_2 increased first, and finally became constant after equilibrium has attained.
- The E-5 and E-10 blends were having similar or slightly reduced emissions compared to petrol.
- The E-30 and above blends was not suited as chances of misfire were there, which may harm the engine in its long run.
- The E-15 blend was the blend having least emissions.

The E-15 had 40% reduction in CO emissions and 37% reduction in HC emissions.

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