International Conference on Renewable Energies and Power Quality (ICREPQ'14)
Cordoba (Spain), 8th to 10th April, 2014

Renewable Energy and Power Quality Journal (RE&PQJ)

ISSN 2172-038 X, No.12, April 2014

The Effect of using an Ethanol blended fuel on Emissions in an SI Engine

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Abstract

The economic impact of limited fossil fuel resources plus the mandatory limit for carbon dioxide (CO_2) emissions become important factors to developing alternative fuels for internal combustion engines. Ethanol (CH_3CH_2OH) blends are considered as alternative fuels due to their ability to reduce the greenhouse exhaust emissions.

This study highlights the effects of unleaded gasoline (E0) and ethanol- unleaded gasoline blend E30 (with 30% volume of ethanol) on engine performance and exhaust emissions experimentally using a 1.4 litre four cylinder four stroke SI engine with a compression ratio of 9:1, for a variety of load and engine speed conditions..

The results indicate that the blend E30 slightly increases the engine's torque and power after mid-engine speeds together with fuel consumption. However, exhaust emissions at 25% open throttle sees a reduction of carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbons (HC) whilst nitrogen oxide (NO_X) emissions increase at the lower speeds.

At full throttle, E30 reduces the CO considerably whilst CO_2 and NO_X increase. Similar quantities of HC are produced.

Key words

Internal combustion engines, power quality, emissions, alternative fuels.

1. Introduction

The demand for cheap, clean and efficient transport has been driven by both European emission directives [1] and the need for economy. These two factors have driven a global search for alternative fuels. It is considered important that the alternative fuels used should be:

(i) produced from renewable resources and
(ii) used without major modifications to the engine.

Alcohols, specifically ethanol, have been used as a replacement fuel for engines since the 19th century and ethanol is considered as one of the more suitable, renewable, bio-based and eco-friendly fuels available. It can be produced by fermentation of renewable energy sources, like cassava, sugar, cane and many types of waste biomass materials such as barley and corn. Additionally, ethanol has advantages in comparison to gasoline, e.g. a reduction in both CO and unburned HC particulates. Ethanol has a higher research octane number (RON) and motor octane number (MON) that is to say, better anti-knock characteristics, which enables higher compression ratios to be used. The reduction of carbon monoxide emission is due to the wide flammability and oxygenated characteristic of ethanol and thus efficiency and fuel economy are improved. The flash point and auto ignition temperatures are higher in comparison with gasoline and its low Reid evaporation pressure makes ethanol safer for storage and transportation. This causes lower evaporative losses. The latent heat of evaporation of ethanol is 3-5 times more than gasoline. This leads to lower temperatures in the intake manifold with result that volumetric efficiency (VE) is increased. Gasoline-ethanol blends used in SI engines with a low percentage volume of ethanol do not require the engine modifications necessary when pure ethanol is used.

The use of ethanol blends will achieve improvement in cold starting and anti-knock performance. Another advantage of ethanol is that the flame in the burning processes is colourless, thus creating cleaner combustion. More fuel is needed compared with gasoline to achieve the same distance or power output because of its lower calorific value (CV). Ethanol also has a higher oxygen content and for this reason it can be characterised as an oxygenated fuel. However ethanol does have very poor lubrication properties and chemically reacts with and degrades rubber components such as seals and also damages aluminium components. It is also easily miscible with water compared with gasoline.

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2. Emissions: their effects and legislation

2.1 Emissions and EU regulations

Table 2.1 shows the main emissions, their impacts and effects caused by vehicles. Due to these pollutants, the human health and environmental issues have forced many countries to create some regulations (emissions limits). Emissions damage both human health and the environment. Australia, Sweden, Japan and California in the USA were the first countries that applied regulations for decreasing pollutants. Nowadays, all countries aim to lower emissions and, since 1998 [2], manufacturers have achieved a decrease of 17 per cent regarding the CO_2 emission for today's cars.

	Cause	Symptoms
C (Carbon)	Partially burnt fuel	Smoke and odour (can be carcinogenic) .
CO (Carbon monoxide)	Incomplete combustion	Drastic poisoning to the point of death. Cardiovascular disease. Adverse effects on the development of the unborn child.
HC (Hydrocarbons)	Unburnt fuel (Fuel-rich mixture), vaporised fuel escaping from fuel system	Irritates eyes and nose. Carcinogenic.
NO_X (Oxides of nitrogen, mainly NO and NO_2)	Very high flame temperature	Toxic to human. NO_x combines with water to form nitrous acid which causes lung disorders. Irritates eye and nose, also affect nervous system. Asthma.
Pb (Lead)	Petrol additive to raise octane rating	Toxic to humans. Causes physical and mental disorders.

Table 2.1: Main emissions: their causes and symptoms [2].

2.1.1European-union regulations for SI engine

Table 2.2 indicates the emissions limits for petrol passenger vehicles for M1 category cars. Category M1 determines the vehicles design and construction for the carriage of passengers and comprising up to eight seats in addition to the driver's seat. More specifically the table shows emission regulations from EURO 1 (1992) up to EURO 6 in 2014 [3].

Stage	Date	CO (g/kg)	THC (g/kg)	$HC+NO_X$ (g/kg)	NO_X (g/kg)	PM (g/km)	PN (#/km)
Euro 1	07-1992	2.72	-	0.97	-	-	
Euro 2	01-1996	2.20	-	0.5	-	-	
Euro 3	01-2000	2.30	0.20	-	0.15	-	
Euro 4	01-2005	1.0	0.10	-	0.08	-	
Euro 5	09-2009	1.0	0.10	-	0.06	0.005*	
Euro 6	09-2014	1.0	0.10	-	0.06	0.0045*	6×10^{12}

Table 2.2: European emissions limits for gasoline fueled passenger cars (Cat M1) [3].

Gasoline is the main fuel for SI engines. This is produced from crude petroleum and is a mixture of many hydrocarbon components. Crude oil is a product of carbon and hydrogen with some traces of other species; 83% to 87% carbon and 11% to 14% hydrogen by weight. Cranking and /or distillation are two refinery processes where the crude oil mixture that is taken from the ground is separated into products components. The component mixture of the refining process can be used for several products, like:

- Alcohol
- Rubber
- Paint
- Plastics
- Explosives
- Diesel and jet fuel
- Home and industrial heating fuel
- Natural gas
- Lubrication oil
- Asphalt
- Automobile and aircraft gasoline

At cold starting conditions a small percentage of components that evaporate from low temperatures are required to ensure engine starting. Moreover, the fuel must evaporate prior to combustion. On the other hand it can cause problems if the fuel contains too much front-end volatility since it will evaporate too quickly. Equally, if fuel vapour replaces air too early in the intake system, not only will it cause reduction of volumetric efficiency but it can also cause vapour locks due to the evaporation of fuel in the fuel system at points at which the engine develops high temperatures and thus engine will stop its operation. It should be noted that a large percentage of the fuel should be vaporized at the normal temperature during of the intake process and, to ensure max volumetric efficiency, the fuel should have completed vaporization by late into the compression stroke and into the start of combustion. This is due to high molecular-weight components that are contained in gasoline mixture. In cases with high-end volatility, however, some of the fuel is not vaporized and ends up as exhaust emissions or it is condensed on the cylinder walls and dilutes the lubricating oil [4].

2.2 Ethanol

2.2.1 Introduction

Ethanol (CH_3CH_2OH) is more reactive than hydrocarbon fuels like gasoline. Ethanol is a liquid fuel and it can be produced by fermentation of the renewable energy sources, like cassava, sugar, cane, many types of waste biomass materials, barley and corn. Also, it can be used for human consumption, such as beers, wines and spirits. In Brazil, this renewable energy source is produced from sugar cane. Sugar cane molasses contains approximately 40% sucrose, which by hydrolysis by an enzyme called invertase produces glucose or fructose. Ethanol is formed by glucose ($C_6 H_{12} O_6$) fermentation in the presence of another enzyme called zymase [5]. Ethanol has been used as an alternative fuel in some major countries like USA, Germany, and France since 1950. It is an oxygenated fuel and it belongs to the alcohol family. It comprises a low content of hydrogen and carbon and high content of oxygen which explains why ethanol can be dissolved in both gasoline and in water. Thus ethanol blends produce a clean and more complete combustion than gasoline, so reducing emissions.

2.2.2 Ethanol properties

Factors such as blend stability, corrosion of engine parts and materials compatibility in the engine, are very important regarding the quality of ethanol as an alternative fuel in engines. The production of ethanol varies from country to country, because of the difference in quality of the product from sugar cane (in Brazil), cereals or corn (in U.S), sugar beet (in Europe) and molasses. Countries have defined their standards for ethanol/gasoline blended fuels differently as a result.

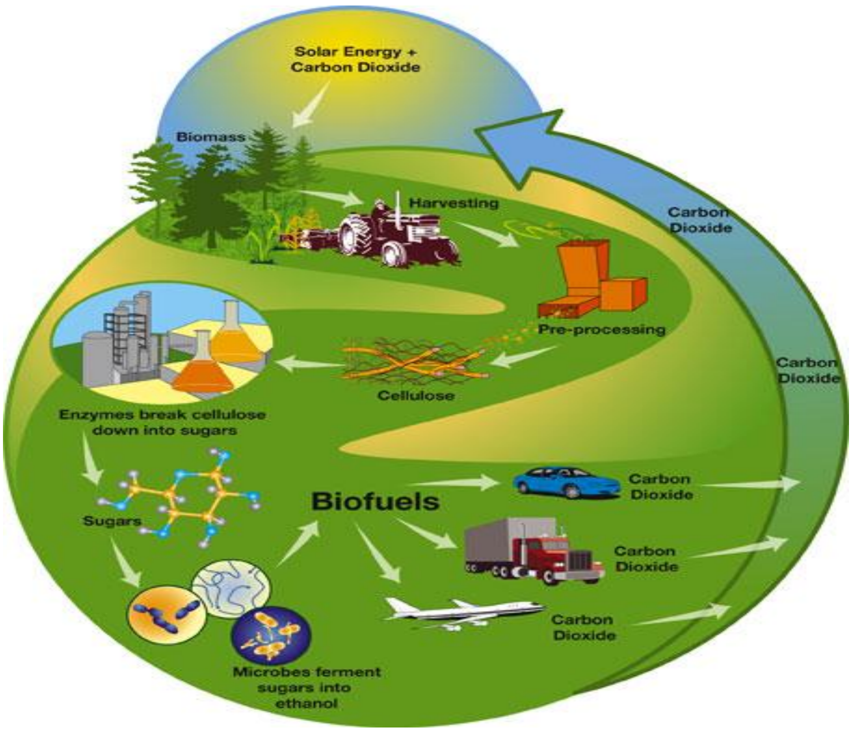

Figure 3.3: Production of ethanol [6].

The United States, which is the largest producer of fuel ethanol uses the ASTM D4806[7] fuel specification together with Canada and a number of African, Middle Eastern and Asian countries. The EN15376[8] fuel standard specification is used primarily in EU countries and has similar chemical properties to ASTM D4806 with the exception of water which is substantially lower. [9] Ethanol is a substance that contains oxygen atoms which, when blended with gasoline, can be viewed as an oxidized hydrocarbon due to the hydrocarbons that compose the gasoline. The chemical formula that characterizes ethanol is $C_2 H_5 OH$. The molecular weight of oxygen in ethanol fuel is 34.7%, which it is the main parameter which makes that made the combustion better and cleaner than gasoline.

Abdel-Rahman and Osman in 1997 [10] have used different ethanol/gasoline fuel blends to study the effect of variable compression ratio on SI engine performance. Their results showed improvement in the power with more ethanol in the gasoline blend. Blends of gasoline and ethanol have a high volatility which can cause problems with cold starting using high proportions of ethanol, due to the higher latent heat of vaporization of ethanol has compared to gasoline.
The Reid vapour pressure (RVP) of ethanol is lower than gasoline which can create difficulty in the cold starting conditions. Also ethanol is miscible with water while gasoline is not miscible. Other important properties, flash point and auto ignition temperature using ethanol are higher than gasoline. It is also safer for storage and transportation.

3 Experimental system

3.1 Introduction
An experimental investigation was undertaken at the University of Huddersfield using gasoline and gasoline-ethanol (E30) blends. Thus the engine, a Nissan Micra four cylinder, four stroke SI engine did not require any modification. The test bed used was designed to enable variable wheel loadings met in practice although this facility was not used in this investigation. Thus the experimental arrangement comprised the engine driving two AC dynamometers through its gearbox and differential unit. The engine test arrangement with the dynamometers either side of the engine /gearbox can be seen in Figure 3.1. Torque is measured at the hub flanges using a strain gauge bridge arrangement and engine speed measured using a 3600 tooth optical encoder and a pulse pick up on the crankshaft. A Coriolis type flow meter is used for instantaneous fuel flow measurement.

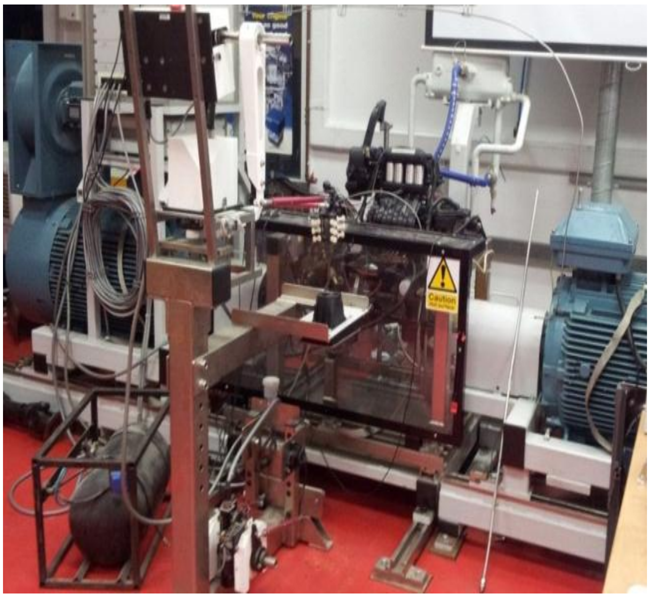

Figure 3.1 Engine Test Arrangement

Figure 3.2 Exhaust gas Analyser

A Horiba EXSA-1500L gas analyser (figure 3.2) was used to measure the CO, CO2, HC, NOX emissions and the lambda value.

3.2 Test procedure
Each fuel was tested between 1500 rev/min and 5000 rev/min at 25% and wide open throttle (100%).. Engine torque, power, and fuel consumption and exhaust emissions namely CO, CO_2, HC, NO_X and O_2 were recorded during the experiments. The stoichiometric air-fuel ratio (λ) was maintained at unity throughout the tests.

4.Results

4.1 Performance

Torque and power curves for petroleum and E30 (not shown here) were similar throughout the engine speed range tested although the E30 blend did show slightly higher values at the higher engine speeds. Predictably, specific fuel consumption, because of its lower CV was higher for the E30 fuel blend.

4.2 Emissions

4.2.1 Carbon monoxide
Figure 4.1 shows CO emissions for gasoline and E30 fuel for varying engine speeds at 25% throttle and WOT. The effect on CO emissions is startling with the E30 blend showing a reduction in CO greater than four for the speed range up to 4000rpm. This is judged to be caused by the oxygenated E30 blend enabling better combustion. This dramatic reduction tails off at the higher speeds, thought to be the result of a failing head gasket.

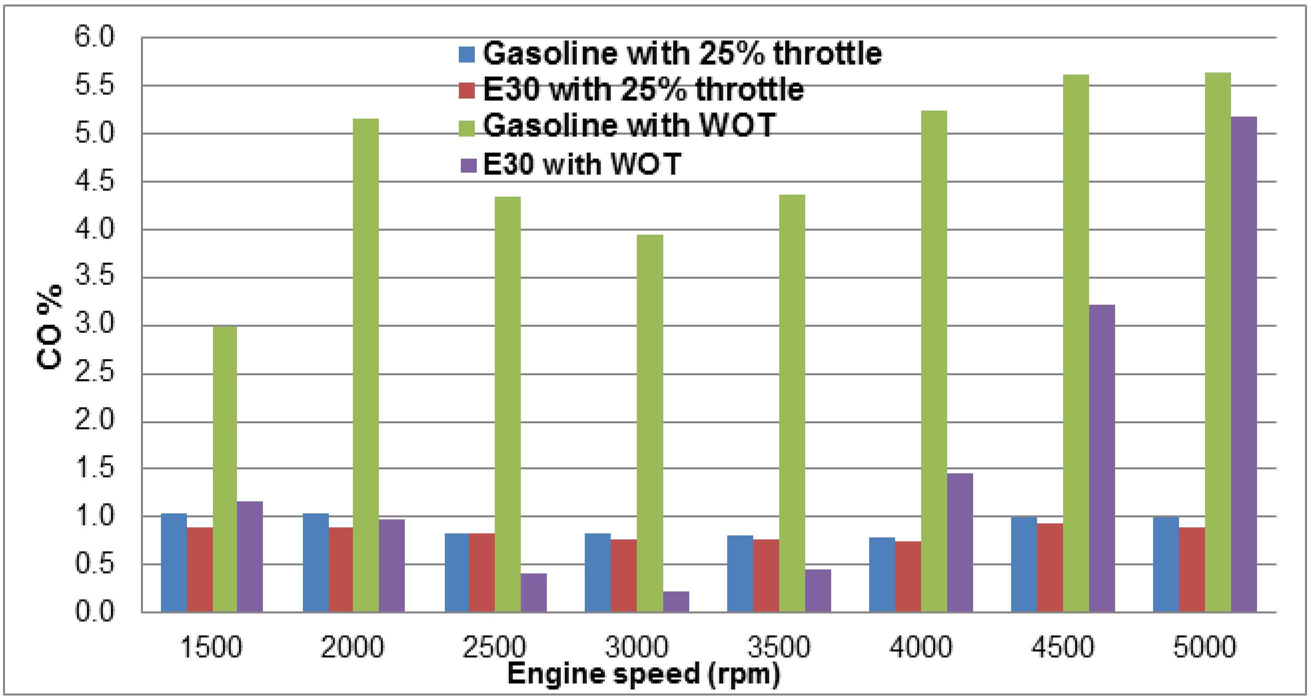

Figure 4.1: Fuel effects on CO emissions.

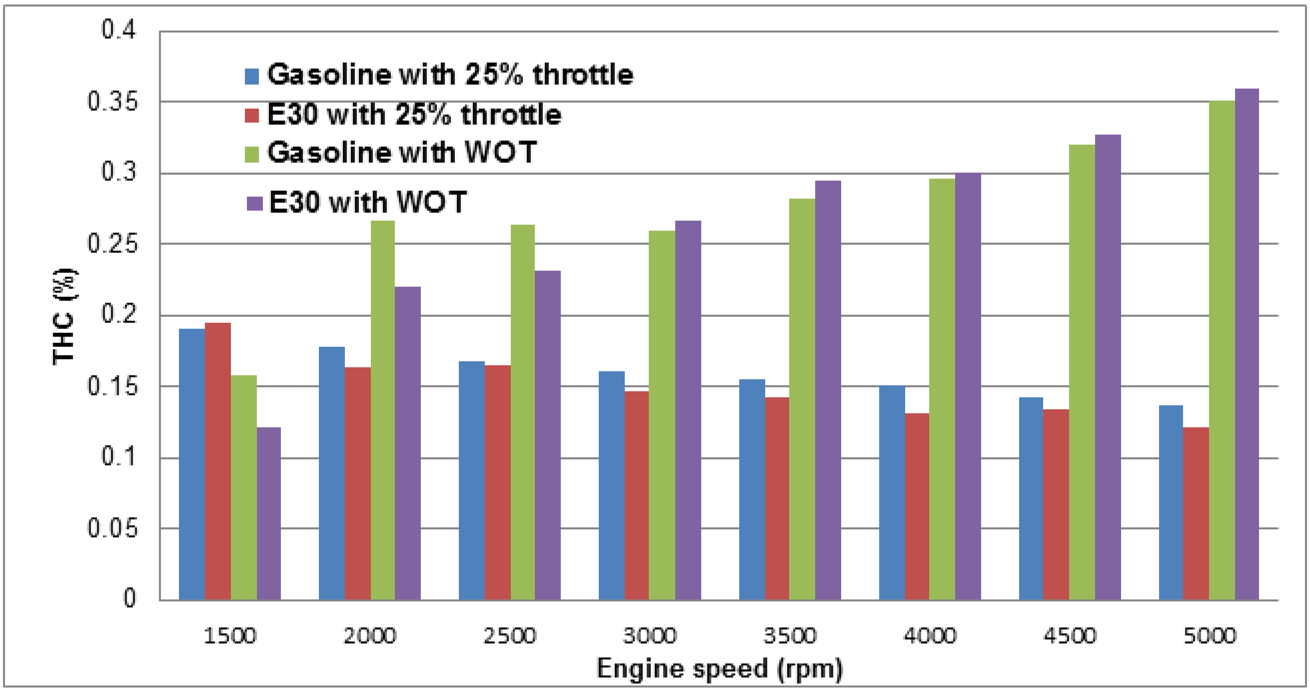

Figure 4.2 Fuel effects on HC emissions.

4.3.2 Hydrocarbons (HC)

HC emissions for the two fuels are illustrated in figure 4.2 and show a reduction in particulate emissions for E30 at the lower speeds thought to be caused by the more complete combustion enabled by the oxygen enriched characteristics of ethanol[1]

4.3.3 Nitrogen Oxide (NO_X)

Figure 4.3 illustrates the effect of the two fuels on NO_X emissions with the E30 blend showing a large increase, particularly at the higher speeds. The reasons for this are complex [11] but are thought to be due the higher oxygen content of ethanol having an adverse effect on fuel air mixture leading to an incomplete burn. This is more evident at the higher speeds because of the increased temperatures.

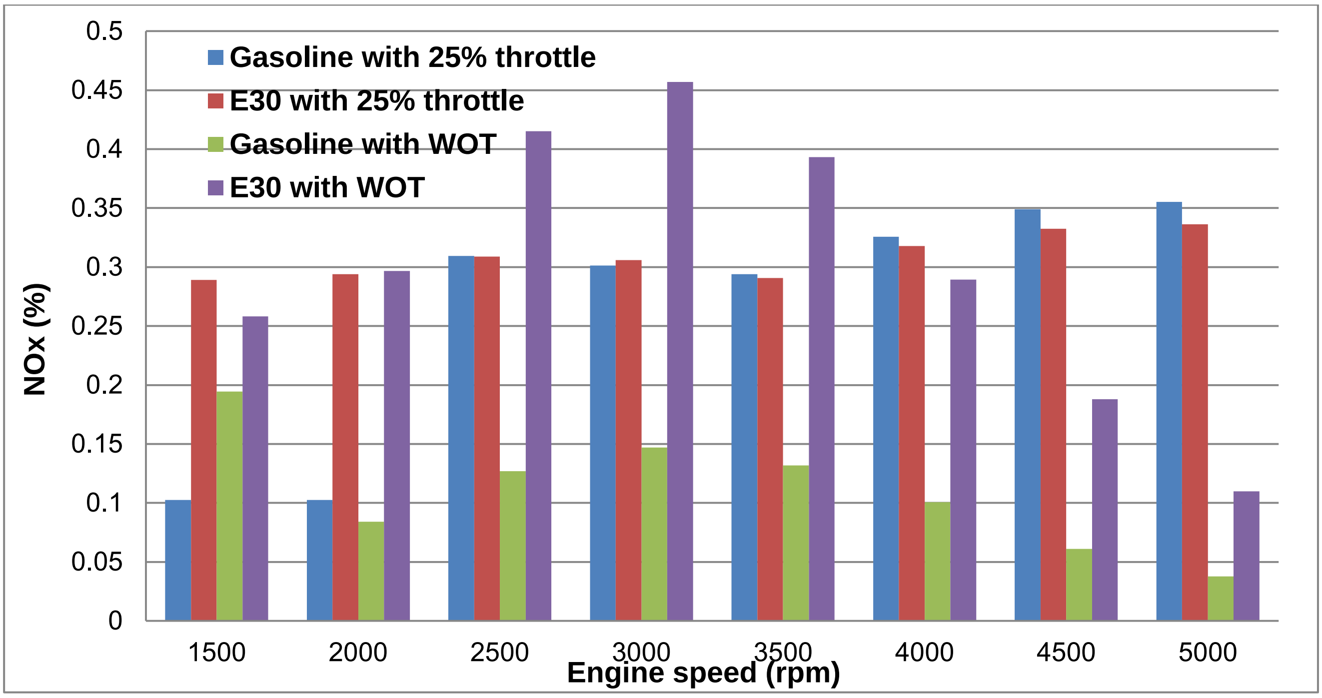

Figure 4.3 Fuel effects on NO_X emissions

5. Conclusions

Performance and emission measurements on a four cylinder SI engine demonstrate that using an E30 blend has clear advantages over the use of gasoline alone due to the increased oxygen carrying ability of ethanol. This yields significant advantages for the use of ethanol blended fuels in addition to its procurement from sustainable resources.

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