The impact of using pure ethanol additives on gasoline fuel with respect to SI engine emissions

H J Kurji¹, M S Imran¹ and A S Bded²

¹ Kerbala University, Engineering College, Mechanical Engineering Department, Kerbala, Iraq
² Kerbala University, Engineering College, Petroleum Engineering Department, Kerbala, Iraq
E-mail: hayder.j@uokerbala.edu.iq

Abstract. A major problem in the gasoline engine operation process under heavy-duty conditions is the knocking phenomenon, noises produced in the combustion chamber during the combustion procedure as a consequence of the pre-ignition process. These occur effect of the high temperature of the air, which causes fuel to ignite without additional activation energy (spark). The octane number for gasoline fuel measures the resistance of the fuel to such auto-ignition. Experimental work was done in this study to study the influence of adding pure ethanol to conventional Iraqi gasoline fuel at percentages varying from 10% to 90% in 10% increments by volume, with various fuel properties like density, octane number, viscosity, fuel vapour pressure, and flash point temperature, measured and compared. Ethanol additives were found to increase fuel density, flash point temperature, viscosity, and octane number while reducing fuel vapour pressure. The engine utilised in the trials was a single-cylinder, gasoline engine, naturally aspirated and air-cooled. The experimental outcomes for specific fuel consumption showed decreases of up to 29% at the 90% volumetric percentage of ethanol in conventional gasoline fuel, and emissions of engine NOX, CO, and HC decreased by 67.7%, 69%, and 61%, respectively. However, CO2 emissions increased.

Keywords: Ethanol, SI engine, Performance.

1. Introduction
Gasoline is the conventional fuel used in spark-ignition engines, yet it produces significant amounts of pollution in the form of harmful gases such as CO, HC, and NOX. These products of combustion have led to changes in temperature across the globe, known as global warming or climate change, that have increased the incidence of natural disasters that cause serious damage to property and risk lives. The simplest method to reduce the pollutant emissions from gasoline is to use a cheap additive, such as ethanol. Ethanol fuel (C₂H₅OH) is renewable, and it can be created from any sucrose-containing biomass, starchy biomass, or lignocellulosic biomass, such as sugarcane, sweet sorghum, sugar beet, wood, straw, grasses, or fruits [1,2].

Ethanol and gasoline mixtures reduce the emissions of NOX, CO, and HC; in addition, this combination decreases the level of engine knock, which can otherwise cause piston breakage, valve pitting, a decrease in output power, and excessive noise. Ethanol-gasoline mixtures are generally considered the best solution for engine knock reduction in most countries of the world [3], though ethanol is mixed with gasoline by varying volumetric percentage. Ethanol is a renewable fuel, and as such may be used to decrease petroleum imports, manage the stability of payments, and promote national energy safety by lessening dependence on petroleum from unstable regions of the world. Ethanol has a high latent heat of evaporation, octane number, and laminar flame propagation speed [4,5,6], as well as thus adding ethanol to gasoline increases output torque, power, and thermal efficiency [7,8,9]. Turner et al. [10] considered the influence of an ethanol-gasoline mixture used as fuel on a direct injection spark ignition.
engine. Their trial work was accomplished with a 1,500rpm engine with a mean effective pressure of 3.4 bar. The outcomes suggested that NO\textsubscript{X} emissions were decreased when the ethanol percentage in the fuel was raised to 85%, as the existence of oxygen in ethanol fuel reduced the heating value of the fuel, decreasing the flame and exhaust temperature. The experimental outcomes also suggested that the rise in volumetric ethanol percentage helped to reduce the effective pressure in the cylinder due to lowering the fuel blend heating value.

Oh, et al. [11] considered the influence employing a gasoline and ethanol blend on engine emissions. Ethanol was mixed with the gasoline fuel at volumetric percentages of 25%, 50%, and 85%. The results revealed that the increase in the volumetric ratio of ethanol led to a rise in unburned hydrocarbon emissions and a drop in NO\textsubscript{X} emissions due to a lowering of the combustion temperature.

Gravalos et al. [12] considered the influence employing an ethanol-gasoline mixture on SI engine emissions under wide-open throttle conditions at an engine speed of 2,000 rpm. Their experiments show that an increase in ethanol percentage reduced the NO\textsubscript{X} emissions but increased the unburned hydrocarbon emissions as a consequence of the high latent heat of vaporisation of ethanol. In addition, they observed that the best volumetric percentage of ethanol in fuel for unburned hydrocarbon reduction was 40%, but that that for nitrogen oxide reduction was 80%.

Canakci et al. [13] examined the special effects of using an ethanol-gasoline blend on SI engine emissions and performance experimentally and found that the growth in volumetric ethanol percentage produced a decline in combustion temperature and NO\textsubscript{X} emissions as a result of the low heating value of ethanol. Balki et al. [14] considered the influence of ethanol additives in gasoline fuel on SI engine emissions and performance. Their experimental work revealed that the ethanol blend reduced the emissions of HC, NO\textsubscript{X}, and CO consequently of the high latent heat of evaporation. The ethanol-gasoline combustion efficiency was better than pure gasoline due to the presence of oxygen atoms.

Schifter et al. [15] undertook experimental work in which ethanol was blended with gasoline fuel at a volumetric percentage of 20% to measure its outcome on various engine parameters and emissions. The trial work revealed that the ethanol and gasoline blend produced a reduction in NO\textsubscript{X} emissions because of the higher heat release of the blend’s combustion. Munsen et al. [16] considered the consequences of using ethanol with up to 40% water on the performance and emissions of an SI engine. The trial work revealed that growth in the volumetric percentage of water between 20% to 40% caused increases in emissions of HC and CO, while NO\textsubscript{X} emissions were reduced due to incomplete combustion. The combustion temperature was measured by measuring the spark plug temperature, and this was found to drop with the increase in the volumetric percentage of the ethanol due to a reduction in the thermal NO\textsubscript{X} formation due to combustion temperature reduction, where water atoms absorbed the heat from the combustion process and were converted from liquid to super-heated steam.

Al-Baghdadi [17] considered the consequence of using ethanol on a high compression ratio engine. The specification for this experimental work was a variable compression ratio engine which changed from 8 to 9.25. The volumetric percentage of ethanol which was mixed with gasoline was increased from 0 to 30%, and the experimental consequences appeared that the rise in ethanol percentage in fuel caused a reduction in NO\textsubscript{X} emissions. The experimental results suggested that the best outcomes for CO, UHC, power and thermal efficiency occurred when using a fuel mixture with 30% ethanol with an engine compression ratio of 8.

In the current research, the specification of the engine, used in the trial work differs from that of previous studies, and additional volumetric percentages of the ethanol were mixed with gasoline for investigation. The operational conditions of testing, such as the ambient temperature, load, and engine speed and the properties of the gasoline applied as base fuel, are also unique to this study.

2. Experimental setup
The test rig used in the experimental work was comprised of a four-stroke, air-cooled, SI engine over a square and naturally aspirated frame. The engine parameters were then measured using various devices. The test rig, as used, is presented in figure 1.

The engine was joined with a swing dynamometer to gauge the brake torque. The engine speed was measured by a speed sensor fitted on the end of the dynamometer shaft. The engine emissions were
measured with a gas analyser. Fuel samples were prepared by mixing a suitable amount of pure ethanol, measured by using a graduated cylinder, with Iraqi gasoline fuel. The mathematical equations by which engine power, specific fuel consumption, and fuel consumption were calculated were adopted from [18].

3. Mathematical Model of Engine Performance
The parameters of the engine were accomplished according to the functions below:

The mass flow rate of fuel was considered as:

\[
\dot{m}_f = \frac{V_F}{\text{time}} \times \rho_F \quad (\text{kg/sec}) \tag{1}
\]

and the brake power as:

\[
b_p = \frac{2\pi \cdot N \cdot T_b}{60 \times 1000} \quad (kW) \tag{2}
\]

The Brake specific fuel consumption was

\[
bsfc = \frac{\dot{m}_f}{b_p} \times 3600 \quad \text{kg/kW.hr} \tag{3}
\]

and the air consumption (S.I. engine) was

\[
\dot{m}_{a,act} = 2.056 \times 10^{-4} \times \sqrt{\rho} \quad \frac{\text{kg}}{\text{sec}} \tag{4}
\]

Finally, brake thermal efficiency was defined as

\[
\eta_{bth} = \frac{b_p}{\dot{m}_{f} \cdot \text{LHV}} \tag{5}
\]

4. Fuel Properties:
Fuel properties were measured via several devices, as illustrated below:
4.1. **Kinematic Viscosity testing**

The resistance to gravity flow of a fluid is its kinematic viscosity, and thus the pressure head is relative to the density. Kinematic viscosity is determined by a stable volume of trial fluid being permitted to flow over a viscometer at a carefully controlled temperature. The viscosity is then accomplished by multiplying the viscometer constant by the efflux time. The viscometer is presented in figure 2, and the results for ethanol-gasoline mixture kinematic viscosity are shown in figure 3.

4.2. **Density Testing with a Pycnometer**

Density is the mass per unit volume of fluid, and the method used in this study for density testing depends on the differences in the weight of the specimen under constant volume at various test temperatures. The device used for density testing is shown in figure 4, and the figures gathered revealed
that the density raised with an increase in the volumetric ratio of ethanol in the gasoline-ethanol blend, as shown in figure 5.

![Density measuring device.](image)

**Figure 4.** Density measuring device.

![Graph showing relationship between density and ethanol volumetric percentage in gasoline and ethanol blend.](image)

**Figure 5.** Relationship between the density and ethanol volumetric percentage in gasoline and ethanol blend.

4.3. **Gasoline and Ethanol Blend Vapour Pressure testing.**

The vapour pressure of fuel is the pressure applied by the vapour on the free surface of a liquid at a particular temperature, here taken as the absolute vapour pressure applied by a liquid at 37.8 °C as fixed by the investigation process outlined in ASTM-D-323. The device used to calculate the vapour pressure is shown in figure 6, and the vapour pressure was seen to decrease as the volumetric fraction of ethanol in the gasoline-ethanol combination increased, as shown in figure 7.
Figure 6. Fuel vapour pressure measuring device.

Figure 7. The relationship between ethanol percentages in gasoline fuel and fuel vapour pressure.

4.4. Flashpoint Temperature of Gasoline and Ethanol Blend

A hydrocarbon flashpoint is the lowest temperature of the vapour pressure of a hydrocarbon, which creates the vapour required for spontaneous ignition of the hydrocarbon in air, subject to the existence of an external source.

Walsh and Mortimer proposed the following equation for estimation of flash point of hydrocarbon mixtures based on vapour pressure:

$$T_F = 231.2 - 40 \log P_{vap}$$  \hspace{1cm} (6)

where $P_{vap}$ is the vapour pressure at 37.8°C.

The flashpoint temperature increased with increases in the volumetric ethanol percentage in the combined fuel, as presented in figure 8.
4.5. Octane Number Testing for Gasoline and Ethanol blend

The octane number of the prepared fuel mixture was ascertained with the octane number testing device shown in figure 9. The results for the octane number for the ethanol and gasoline blends are shown in figure 10.
5. Fuel Sample Preparation

The fuel samples were prepared by adding ethanol at different volumetric percentages of 10%, to 90%, in 10% increments by volume, to standard Iraqi gasoline fuel. A graduated cylinder was used to measure the required volumes of ethanol and gasoline. The prepared samples of ethanol and gasoline mixture were then submitted to various tests such as octane number, fuel vapour pressure, density, and viscosity, in the fuel lab.

6. Results

Each ethanol and gasoline mixture operated the spark-ignition engine in turn. The brake specific fuel consumption, engine speed, brake power, fuel consumption, and engine emissions were measured for all different volumetric ratios of ethanol, including zero. The experimental results were as follows:

1- The brake specific fuel consumption decreased as a result of the rise in the brake power and the reduction in fuel consumption caused by increasing the volumetric fraction of ethanol in gasoline fuel, as presented in figure 11. The maximum decrease was 29%, which occurred with a mixture of 90% ethanol and 10% gasoline. This reduction in brake specific fuel consumption is attributed to the fact that the flashpoint temperature of the ethanol and gasoline blend is greater than that of gasoline, which prevents the air and fuel mixture from self-igniting. The higher flash point temperature of fuel also prevents knock throughout the combustion operation, which highlights its essential role in power output reduction. The ethanol-gasoline blend also contains more oxygen atoms, with the combustion process within the combustion chamber improved due to the availability of these atoms, which participate in fuel oxidation to produce heat, light, and combustion products.

2- The carbon monoxide emissions were lessened with increases in the volumetric ratio of ethanol in the gasoline and ethanol fuel mixture. The maximum reduction of carbon monoxide emissions was 69%, which occurred with the mixture containing 90% ethanol, as shown in figure 12. The decrease in carbon monoxide emissions with the increase in volumetric ethanol percentage is attributed to the additional oxygen existing within the fuel blend, which leads to complete combustion inside the engine combustion chamber, allowing the conversion of all carbon monoxide to carbon dioxide, water, and heat.

3- The unburned hydrocarbon emissions reduced with increments to the volumetric percentage of ethanol in a conventional fuel. The maximum decrease in unburned hydrocarbon emissions was 61% which occurred while using the blend containing 90% ethanol, as shown in figure 13. This is attributed to the ethanol additive reducing the fuel vapour pressure, which leads a rise in the air mass flow rate at the intake manifold and the presence of oxidizers that allows all fuel atoms in the inside combustion chamber to burn throughout the power stroke. More oxygen is also present during the flame propagation
in the second stage of the gasoline fuel combustion operation in the spark-ignition engine, allowing the combustion of tiny droplets of gasoline throughout the power stroke.

4- The carbon dioxide emissions are increased with increases to the volumetric ratio of ethanol in the ethanol-gasoline mixture. The maximum increase in carbon dioxide emissions, 28%, occurred when the mixture contained 90% ethanol, as shown in figure 14. This was attributed to the additional oxidizer in this gasoline and ethanol blend increasing the combustion efficiency, allowing carbon dioxide to be created from carbon monoxide this merges with the available oxygen within the combustion chamber during the combustion process.

5- The nitrogen oxide emissions were reduced as the volumetric percentage of ethanol raised. The maximum decrease of 67.7% occurred at 90% ethanol, as shown in figure 15. The reduction in thermal nitrogen oxide emissions was attributed to the combustion temperature being minimised consequently of increasing the latent heat of evaporation of the ethanol and gasoline blend, causing the thermal nitrogen oxide process to be reduced.

![Figure 11. The relationship between engine speed and specific fuel consumption using ethanol-gasoline mixtures at altered volumetric percentages of ethanol.](image-url)
Figure 12. The relation between engine speed and carbon monoxide emissions using ethanol-gasoline mixtures at different volumetric percentages of ethanol.

Figure 13. The relationship between engine speed and unburned hydrocarbon emissions using ethanol-gasoline mixtures at different volumetric percentages of ethanol.
Figure 14. The relationship between engine speed and carbon dioxide emissions using ethanol-gasoline mixtures at different volumetric percentages of ethanol.

Figure 15. The relationship between engine speed and nitrogen oxide emissions using ethanol-gasoline mixtures at different volumetric percentages of ethanol.
7. Conclusion
A trial to examine the combustion effects of mixing ethanol with Iraqi gasoline in different concentrations was carried out. The results displayed that the brake specific fuel consumption reduced with increases in the volumetric ratio of ethanol in fuel and that carbon monoxide emissions, unburned hydrocarbon emissions, and emissions of nitrous oxides were reduced in proportion to the rise in the volumetric percentage of ethanol in the combination. However, carbon dioxide emissions augmented as the volumetric proportion of ethanol in the ethanol-gasoline combination increased.

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