

# NUMERICAL INVESTIGATION OF ETHANOL FUEL BLENDS ON ENGINE PERFORMANCE CHARACTERISTICS BY USING DIESEL-RK SOFTWARE

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**Abstract:** In this study the effects of adding ethanol to the unleaded gasoline on engine performance have been investigated numerically. The fuel blends have been obtained by adding ethanol to a base unleaded gasoline in different volumetric ratios (%5, %10, %15). Several parameters were calculated namely: engine torque, brake mean effective pressure, brake power, specific fuel consumption and the thermal efficiency, this was carried out using DIESEL-RK software. The results have indicated that adding into the base unleaded gasoline affected the engine performance positively at most of operating conditions.

**Keywords:** ALTERNATIVE FUELS, DIESEL-RK, ENGINE PERFORMANCE, ETHANOL FUEL BLENDS

## 1. Introduction

Alcohols and ethers (ethanol, methanol, MTBE, ETBE, TAME, DIPE etc.) are widely used as oxygenated gasoline additives in low blends. The use of this oxygenates have been preferred by the factors such as their enhancing effect on fuel octane number, tend to reduce of exhaust emissions; especially reducing of CO and HC emissions. In the literature, there are many experimental studies on oxygenated additives on engine performance, fuel characteristics and emission parameters.

Ethanol is an alcohol-based alternative fuel produced by fermenting and distilling starch crops that have been converted into simple sugars. Feedstocks for this fuel include corn, barley and wheat. Ethanol can be produced from cellulose feedstock such as corn stalks, rice straw, and sugar cane which are examples of feedstock that contain sugar [1]. As ethanol can be produced from agricultural crops, its cost can be lower in the states whose economy is largely based on agriculture and it can be used as alternative fuel. Thus, dependence for foreign oil is reduced in these states. The simplest approach to the use of alcohols in engines is to blend moderate amounts of alcohols with base fuel. The second and more technically challenging option is to use alcohols essentially neatly as engine fuel [2].

Furthermore, ethanol has some advantages over gasoline, such as the reduction of CO, and unburned HC emissions and better anti-knock characteristics, which allow for the use of higher compression ratio of engines [3]. The reduction of CO emission is apparently caused by the wide flammability and oxygenated characteristic of ethanol. Therefore, improvement in power output, efficiency and fuel economy. On the other hand, the auto-ignition temperature and flash point of ethanol are higher than those of gasoline, and the low Reid evaporation pressure which makes it safer for transportation and storage [4,5], and causing lower evaporative losses [6]. The latent heat of evaporation of ethanol is 3–5 times higher than that of gasoline; this provides lower temperature intake manifold and increases volumetric efficiency. Since ethanol is a liquid fuel, the storage and dispensing of ethanol is similar to that of gasoline [4,7–10].

Al-Hasan [11] investigated the effect of using unleaded gasoline–ethanol blends with different percentage on SI engine performance and exhaust emission. The results showed that the addition of ethanol to unleaded gasoline increased the brake power, torque, volumetric and brake thermal efficiencies and fuel consumption, while it decreased the brake specific fuel consumption and equivalence air–fuel ratio. The CO and HC emission concentrations decreased, while the CO<sub>2</sub> concentration increased. Yucesu et al. [12], and Topgul et al. [9], used unleaded gasoline (E0) and unleaded gasoline–ethanol blends (E10, E20, E40 and E60) in a single cylinder, four-stroke, spark-ignition engine with variable

compression ratio. They found that blending unleaded gasoline with ethanol slightly increased the brake torque and decreased CO and HC emissions. It was also found that blending with ethanol allows increasing the compression ratio without knock occurrence. Hsieh et al. [4] experimentally studied the engine performance and exhaust emission of a commercial SI engine using ethanol–gasoline blended fuels with various blended rates (0%, 5%, 10%, 20% and 30% by volume). Fuel properties of ethanol–gasoline blended fuels by the standard ASTM methods showed that with increasing the ethanol content, the heating value of the blended fuels is decreased, while the octane number of the blended fuels increases. In addition, with increasing the ethanol content, the Reid vapor pressure of the blended fuels initially increases to a maximum at 10% ethanol addition, and then decreases. Results of the engine test indicated that using ethanol–gasoline blended fuels, torque output and fuel consumption of the engine slightly increase; CO and HC emissions decrease dramatically as a result of the leaning effect caused by the ethanol addition; and CO<sub>2</sub> emission increases because of the improved combustion, and NOx emission depends on the engine operating condition rather than the ethanol content. Abdel et al. tested 10%, 20%, 30%, and 40% ethanol of blended fuels in a variable-compression-ratio engine. They found that the increase of ethanol content increases the octane number, but decreases the heating value. The 10% addition of ethanol had the most obvious effect on increasing the octane number. Under various compression ratios of the engine, the optimum blend rate was found to be 10% ethanol with 90% gasoline [13].

In the present study, engine performance using ethanol blended gasoline as the fuel, were simulated with Diesel-RK software which is full cycle thermodynamic simulation and optimization tool. These simulation results will be compared with the literature experimental data.

## 2. Simulation and Methodology

Diesel-RK is a software that is used multi-zone thermodynamic model with taking some important parameters into account: swirl intensity, piston shape, injection etc. The theoretical models used in ICE (internal combustion engine) can be classified in two main groups: *thermodynamic models* and *fluid dynamic models*. Thermodynamic models are based on the 1<sup>st</sup> law of thermodynamics and are used to analyze the performance characteristics of engines. Pressure, temperature and other required properties are evaluated with respect to crank angle. The engine friction and heat transfer are taken into account semi-empirically.

These models are further classified into two groups namely *single-zone* and *multi-zone* models. On the other hand, multi-zone models are also called CFD models. These are also applied for the simulation of combustion process in the internal combustion engines. They are based on the numerical calculation of mass,

momentum, energy and species conservation equations in either one, two or three dimensions to follow the flame propagation or combustion front within the cylinder. In the following, the equations for the cylinder pressure and temperature(s) are derived. This will show where additional information, in the form of sub-models, is necessary in order to close these equations. Before conservation of energy is written out for the cylinder volume, from inlet valve closing time to exhaust valve opening time, some assumptions are generally adopted to simplify the equations. During compression and expansion, pressure is invariably assumed uniform throughout the cylinder, with fixed unburned and burned gas regions in chemical equilibrium. During flame propagation, burned and unburned zones are assumed to be separated by an infinitely thin flame front, with no heat exchange between the two zones. All gases are considered ideal gases; possible invalidity of the ideal gas law at high pressures is countered by the associated high temperatures under engine combustion conditions.

The parameters, which were calculated to find the performance of the engine, are by the Diesel-RK: *brake power, brake mean effective pressure, brake torque, specific fuel consumption and volumetric efficiency*. These parameters were calculated for each blend ratio and at different engine speeds. The engine specifications used in this study has shown in Table 1 and the thermo-physical properties of the different fuel blends have shown in Table 2.

Table.1 Engine Specifications

Model of Engine	Ford 2264E
Number of Cylinders	4
Bore	81 mm
Stroke	77.6 mm
Type of Injection	Indirect Injection
Type of Cooling	Water Cooled
Swept Value	1599 cc
Compression Ratio	9:1
Inlet Valve Diameter	38.02-38.28
Exhaust Valve Diameter	31.35-31.60
Connected Rod Length	105 mm
Material of Piston or Piston Head	Aluminum Alloy
Material of Cylinder Head	Iron
Speed Range Continuous	1500-4000 rpm

Table.2 Thermo-physical Properties of fuels [9]

Property	Gasoline	E5	E10	E15
Research Octane Number (ASTM D 2699)	91.3	92.8	93	92.4
Motor Octane Number (ASTM D 2700)	84	84	83.8	82.8
Octane Index	87.6	88.4	88.4	87.6
Net Heating Value Mj/kg (ASTM D 240)	42.54	41.41	40.80	40.08
Relative Density (ASTM D 1298)	0.7454	0.754	0.7576	0.7586

Air/fuel mixture equivalence ratio,  $\lambda$ , is defined by the relationship between the actual air/fuel ratio and the stoichiometric air/ fuel ratio:

$$\lambda = \frac{(A/F)}{(A/F)_s} = \frac{(\dot{m}_a/\dot{m}_f)}{(\dot{m}_a/\dot{m}_f)_s} \tag{1}$$

where  $\dot{m}_a$  and  $\dot{m}_f$  are the engine intake air flow rate and fuel flow rate, respectively. The stoichiometric air/fuel mixture contains the necessary air amount to fully burn the fuel. Brake power ( $P_b$ ) is given by the product of engine torque (T) and rotational speed ( $\omega$ ):

$$P_b = T \cdot \omega \tag{2}$$

The torque is obtained by the vector product of the load applied and the dynamometer arm length. Brake mean effective pressure is a measure of the power produced per cycle as a function of engine size:

$$BMEP = \frac{T}{V_c} = \frac{P_b}{V_c \omega} \tag{3}$$

where is  $V_c$  the piston displaced volume per cycle. Specific fuel consumption, SFC, is the fuel amount consumed per unit of power produced, that is:

$$SFC = \frac{\dot{m}_f}{P_b} \tag{4}$$

where is  $\dot{m}_f$  the fuelmass flow rate into the engine. The engine volumetric efficiency  $\eta_v$  refers to the efficiency with which the engine can move the charge into and out of the cylinders. More specifically, volumetric efficiency is a ratio (or percentage) of what quantity of fuel and air actually enters the cylinder during induction to the actual capacity of the cylinder under static conditions. volumetric efficiency is defined as:

$$\eta_v = \frac{\eta m_a}{\rho_a V_c N} \tag{5}$$

where  $\rho_a$  and N are the air density and engine speed respectively.

### 3.Result and Discussions

At different engine speed, brake engine torque, piston engine power, specific fuel consumption, volumetric efficiency, brake mean effective pressure values were calculated by using Diesel-RK software. All numerical results were plot by using Sigma Plot Software. The effects of the ethanol addition (5%, 10% and 15% in volume) to gasoline on engine torque between 1200 and 3600 rpm engine speed are shown in Fig. 1 at compression ratios of 9:1.

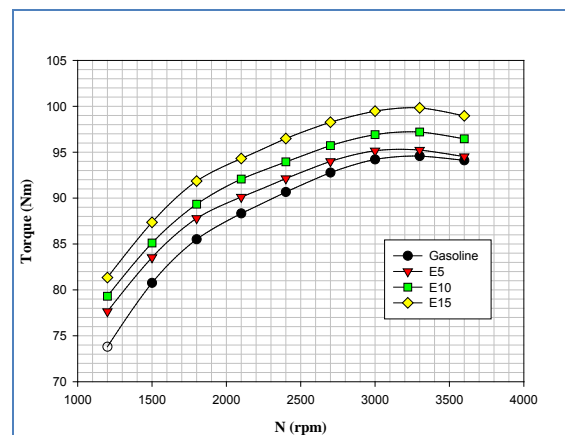
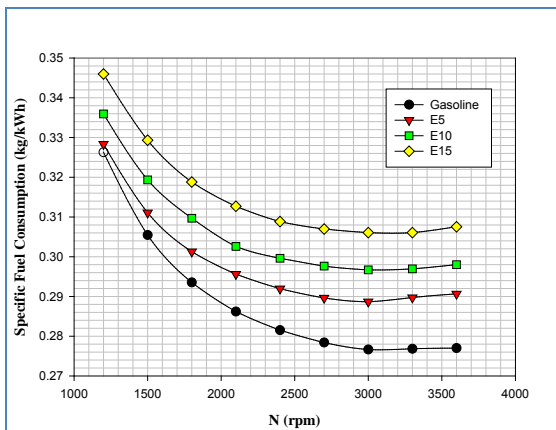


Fig.1 The effect of unleaded gasoline-ethanol fuel blends on engine torque.

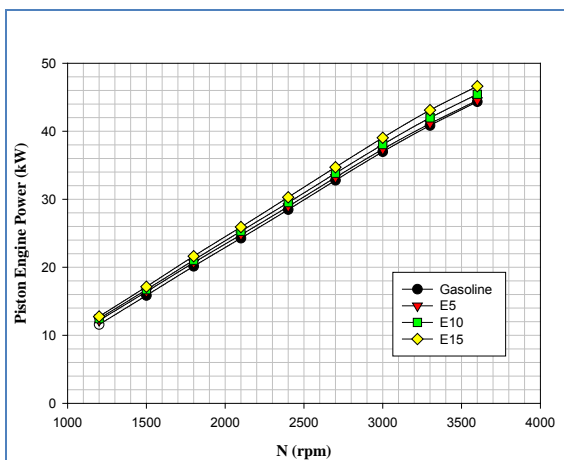
For the influence of different ethanol–gasoline blended fuels on engine output, it deserved to be noted that with increasing ethanol content, torque output slightly increases. In general, torque with blended fuels (E5, E10 and E15) are higher than that of base gasoline in the speed range. Even though the ethanol addition to the gasoline decreases its heating value, the increase in torque and power were obtained. This is explained with several reasons. Beneficial effect of ethanol as an oxygenated fuel is a possible reason for more complete combustion, thereby increasing the torque. In addition, a larger fuel for the same volume is injected to the cylinder due to higher density of ethanol. This results in increase

in torque and power. And finally, the latent heat of evaporation of blended fuels is higher than that of base gasoline; this provides lower temperature intake manifold and increases volumetric efficiency. The charge into the cylinder directly affects on torque and power. The average increment in engine torque compared with gasoline are about 1.06%, 2.65% and 4.25% with E5, E10 and E15 at engine speed of 3600 rpm respectively. The effects of the ethanol addition to gasoline on specific fuel consumption between 1200 and 3600 rpm engine speed are shown in Fig. 2 at compression ratios of 9:1.



**Fig.2** The effect of unleaded gasoline-ethanol fuel blends on specific fuel consumption.

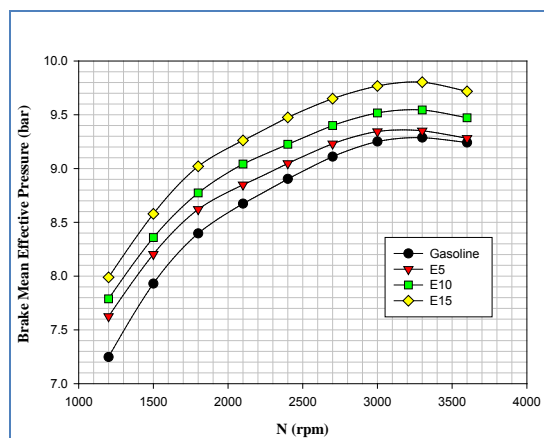
As it is shown in the figures, ethanol addition causes 4.3%, 7.19% and 11.6% average increments in brake specific fuel consumption (BSFC) with E5, E10 and E15, respectively at engine speed of 3600 rpm respectively. It is well known that heating value of fuel affects the BSFC of an engine. The lower energy content of ethanol-gasoline fuel causes some increment in BSFC of the engine when it is used without any modification. The increment mainly depends on the percentage of ethanol. The heating value of ethanol is approximately 35% less than the values of gasoline [15]. More blends are needed to produce the same power at the same operating conditions due to its lower heating value in comparison to base gasoline. As a result, BSFC increases. Increasing BSFC due to lower energy content of ethanol-unleaded gasoline blends may be improved by increasing compression ratio. The effects of the ethanol addition to gasoline on piston engine power between 1200 and 3600 rpm engine speed are shown in Fig. 3 at compression ratios of 9:1.



**Fig.3** The effect of unleaded gasoline-ethanol fuel blends on engine power.

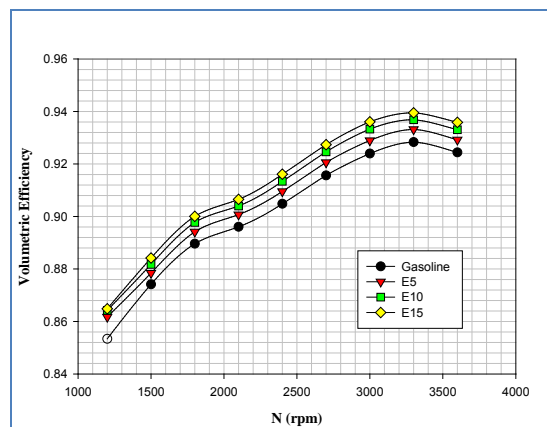
Fig.2 and Fig.3 show the effect of various fuel blends on power and specific fuel consumption (SFC). As the ethanol content in the blend fuel increases, power also slightly increases. When compared to base gasoline, the power increases of 0.4%, 1.8% and 5.2% are

obtained with E5, E10 and E15 fuels at engine speed of 3600 rpm, respectively. The heat of evaporation of ethanol is higher than that of gasoline. High heat of evaporation can provide fuel-air charge to cool and density to increase, thus higher power output is obtained to some extent. The effects of the ethanol addition to gasoline on Brake Mean Effective Pressure (BMEP) between 1200 and 3600 rpm engine speed are shown in Fig. 4 at compression ratios of 9:1.



**Fig.4** The effect of unleaded gasoline-ethanol fuel blends on brake mean effective pressure (BMEP)

As shown by Eq.(3), BMEP is directly proportional to the torque developed by the engine. Fig.1 shows slightly higher torque and Fig.4 shows slightly higher BMEP at all engine speeds when gasoline-ethanol blend was used as fuel. The effects of the ethanol addition to gasoline on engine volumetric efficiency between 1200 and 3600 rpm engine speed are shown in Fig. 5 at compression ratios of 9:1.



**Fig.5** The effect of unleaded gasoline-ethanol fuel blends on volumetric efficiency.

Volumetric efficiency is important process that governs how much power and performance can be obtained from an engine is getting the maximum amount of air into the cylinder during each cycle. More air means more fuel can be burned and more energy can be converted to output power. Volumetric efficiency is an indication of breathing ability of the engine. It depends on also the ambient conditions and operating conditions of the engine. Fig.6 illustrates the variation of volumetric efficiency with engine speed for the different ethanol-gasoline fuel blends. All ethanol-gasoline fuel blends in general indicate better breathing ability of the engine than the base gasoline fuel. The volumetric efficiency increase about 1.51% at the engine speed of 3600 rpm for E15 fuel blend. This increment in the volumetric efficiency can be explained by the lower cylinder temperature for all ethanol-gasoline fuel blends.

#### 4. Conclusions

Equivalence fuel–air ratio is one of the important parameters that effects engine performance parameters. Ethanol is an oxygenated fuel, and for this reason, adding ethanol to gasoline leads to leaner operation and improves combustion. Numerical calculation results show that equivalence fuel–air ratio was decreased as the percentage of ethanol (in volume) in the blended fuel was increased. Engine performance parameters such as brake power, torque, volumetric efficiency were increased when the ethanol amount in the blended fuel was increased. With the increase in ethanol percentage, the density of the mixture and the engine volumetric efficiency increases and this causes the increase of power. This is also due to the reduction in the Equivalence fuel–air ratio values. The gain of the engine power can be attributed to the increase of the brake mean effective pressure for higher ethanol content blends. at the end of the numerical calculations, the main findings were:

1. At the end of the calculations, torque with blended fuels (E5, E10 and E15) were generally found to be higher than base gasoline in all the speed range due to higher latent heat of evaporation of oxygenated fuel addition which also increase the octane number of the blended fuels.
2. The lower energy content of ethanol–gasoline fuel caused increment in brake specific fuel consumption of the engine depending on percentage of ethanol in the blend.
3. When air–fuel ratio is slightly smaller than one, higher volumetric efficiencies were seen at the all engine speed between 1200 and 3600 rpm.
4. A maximum change in volumetric efficiency occurred about 1.51% at the engine speed of 3600 rpm for ethanol–gasoline fuel blends which caused the increase of power.

The numerical results were compared with different experimental investigations. In these studies, ethanol addition caused positive effect on engine performance and exhaust emissions. It can be seen that the numerical results on engine performance characteristics are in good agreement with similar experimental studies [4,8,9,11,12].

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