UNIVERSITY OF IDAHO

# Combustion of Ethanol

## Effect of Ethanol on Internal Combustion Engines

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With increasing greenhouse gases in the atmosphere and depleting oil reserves, alternative energy sources have been considered to replace gasoline. A proven replacement that has been implemented in the previous decades has been Ethanol. It has good combustion and emission characteristics and also produces more torque and brake power than gasoline. Like every alternative energy source, it does have its downfalls, some of them being that it increases the brake specific fuel consumption (BSFC) of fuel and when used in current gasoline engines, has problems while cold starting. Also, the current world supply of Ethanol isn't enough to replace the world's energy needs, which means it cannot be used as a primary alternative energy source.

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# KEYWORDS

Bioethanol
Ethanol
Blends
Torque
Power
Emissions
Fuel consumption
Future

# NOMENCLATURE

| | |
|---|---|
| Wt% | Weight percent |
| E85 | 85% Bioethanol, 15% Regular Unleaded Fuel |
| HUCR | High Useful Compression Ratio |
| CR | Compression Ratio |
| Rpm | Rounds per minute |
| BSFC | Brake Specific Fuel Consumption |

# 1. Introduction

With increasing economic growth comes an increase in demand for energy resources. This was observed after the end of the Second World War, where a rapid world economic expansion was accompanied by a considerable increase in energy consumption (Raisman, 1984). With the current global based economies, most under-developed countries have seen a dramatic change in economic growth. Accompanied by this economic growth is going to be an increase in energy consumption. But, the problem lies therein. There is only so much oil reserves left in the world, most of the oil supply lies among the OPEC countries (Raisman, 1984). Figure 1 shows that even with Enhanced Oil-Recovery techniques, the oil reserves will only last us this century (Raisman, 1984), given that there are none other major oil reserves known to man.

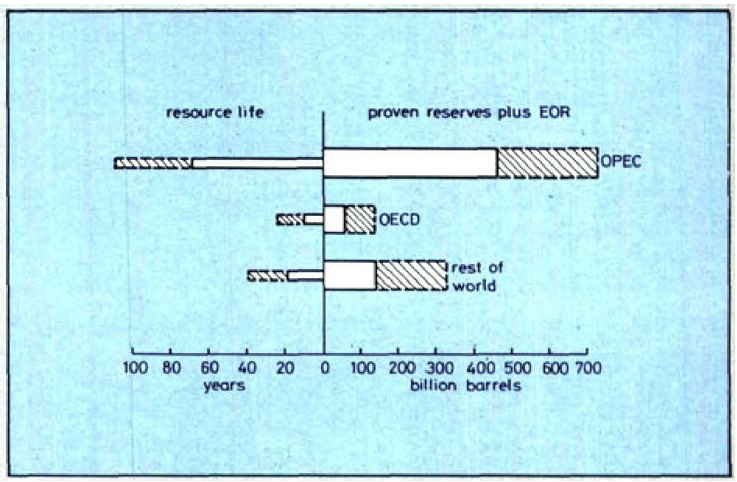


**FIGURE 1 EXPECTED LIFE OF OIL RESERVES (RAISMAN, 1984)**

Another growing concern is the increase in greenhouse gasses in the atmosphere. As of 2002, Power Plants in the US were required to reduce $NO_x$ emissions by 43%, and following this reduction the slope of ozone temperature relationship dropped from 3.2ppbv $O_3$/°C to 2.2ppbv $O_3$/°C. This change has helped improve the climate and temperatures in the United States, particularly in the Eastern region (Bloomer, Stehr, Piety, Slalawitch, & Dickerson, 2009). If a reduction in $NO_x$ emissions was required by automotives, this will further help reduce $NO_x$ levels in the atmosphere and lead to a better climate. One method that has proven to be effective and could easily be implemented with the current methods and technologies used in the automotive industry would be to use a combination of Bioethanol ($C_2H_5$) and fuel or even switch to a fully Bioethanol based automotive system.

# 2. Main Body

## 2.1 Advantages of Ethanol

### *2.1.1 Effect of Ethanol on Performance*

Figure 2 shows a plot of the ratio of the power the engine puts out when an ethanol blended fuel is used to the power when regular gasoline is used. The engine used in the study was a Ricardo E6/US Single Cylinder Four-Stroke Engine. As the Figure shows, the Torque output of the engine clearly increases with the Volume Percent of Ethanol in the mixture (Al-Baghdadi, 2008).

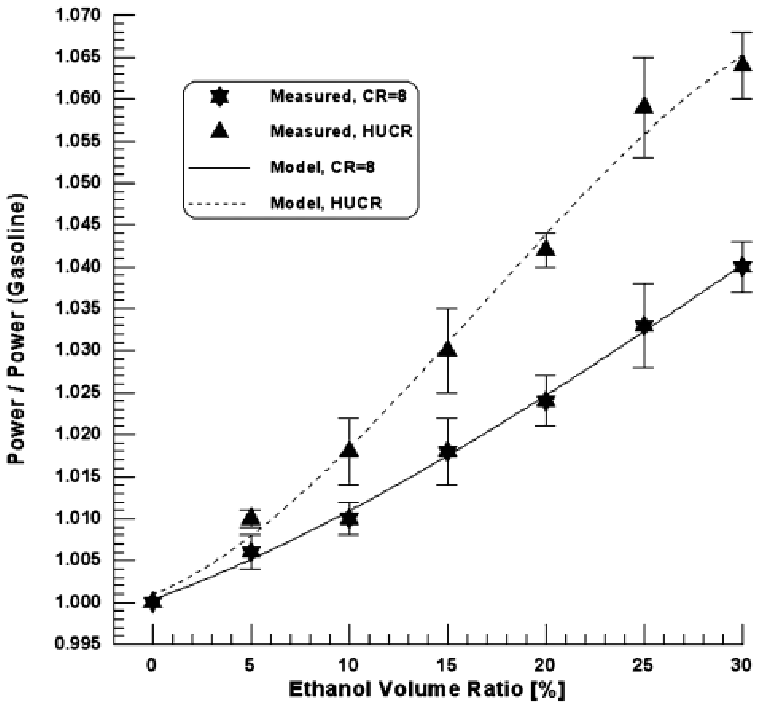


**FIGURE 2 EFFECT OF ETHANOL BLENDING ON THE ENGINE POWER (CR, COMPRESSION RATIO) (AL-BAGHDADI, 2008)**

The reason for this increase in Torque when using Ethanol can be accounted for with the increase in mixture density, volumetric efficiency, the additional oxygen content in Ethanol, faster laminar flame speeds and the higher Octane rating. Ethanol, having a higher latent heat of evaporation as shown in Table 1, causes a decrease in air-fuel mixture at higher engine speeds, and thus a greater air-fuel charge flow into the combustion chamber and increases the volumetric efficiency during the intake process. With the increased density of intake air, more Ethanol fuel needs to be injected to maintain the stoichiometric air-to-fuel ratio (Yoon, Ha, Roh, & Lee, 2009).

**TABLE 1 PROPERTIES OF ETHANOL AND GASOLINE (COONEY, YELIANA, WORM, & NABER, 2009)**

| property | gasoline | ethanol |
|---|---|---|
| chemical formula | C4−C12 | $C_2H_5OH$ |
| octane number (RON) | 91−99 | 107 |
| octane number (MON) | 82−89 | 89 |
| latent heat of vaporization (kJ/kg) | 350 | 840 |
| lower heating value (MJ/kg) | 44 | 26.9 |
| stoichiometric A/F | 14.6 | 9.0 |
| laminar flame speed (m/s)[b] | 0.333 | 0.388 |

Ethanol fuel also contains about 35 wt% oxygen which plays an important role at high engine speeds where insufficient time is available for the formation of a stabilized mixture and combustion (Yoon, Ha, Roh, & Lee, 2009).

Also, ignition delays were relatively reduced when using Ethanol fuel, because the initial combustion has a faster laminar flame speed (Figure 3) than when using regular fuel (Yoon, Ha, Roh, & Lee, 2009).

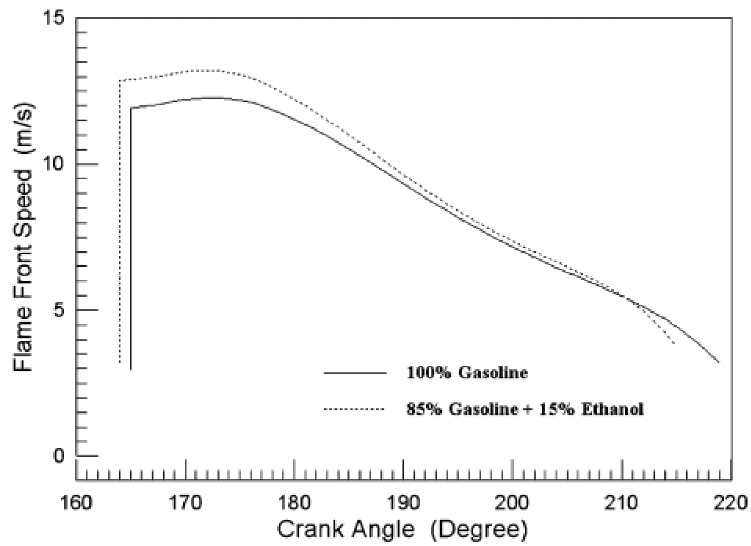


**FIGURE 3 FLAME SPEED OF GASOLINE VS ETHANOL BLENDS (AL-BAGHDADI, 2008)**

Ethanol fuel has a higher Octane rating (96-101) than regular gasoline (95), see Table 2, indicating greater anti-knock characteristics (Cooney, Yeliana, Worm, & Naber, 2009). Thus, higher compression ratios were possible (Figure 4) with the Ethanol fuel which leads to the engine being able to produce more power (Al-Baghdadi, 2008).

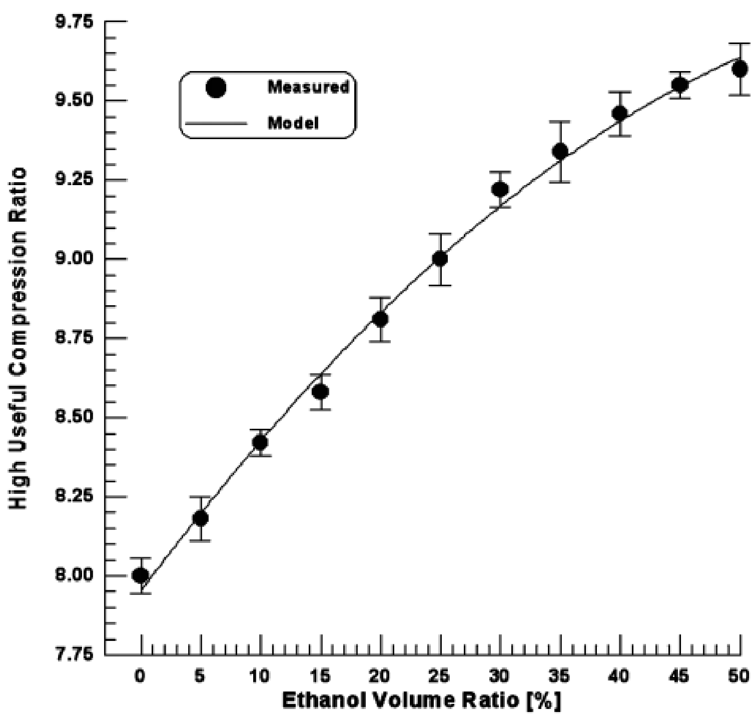


**FIGURE 4 HIGH USEFUL COMPRESSION RATIOS FOR VARIOUS ETHANOL BLENDS (AL-BAGHDADI, 2008)**

**TABLE 2 PROPERTIES OF DIFFERENT ETHANOL-GASOLINE BLENDED FUELS (AL-BAGHDADI, 2008)**

| Property | Value for the following fuels | | | | | | | Test method |
|---|---|---|---|---|---|---|---|---|
| | Gasoline | E5 | E10 | E15 | E20 | E25 | E30 | |
| Density (15.5 °C) (kg/l) | 0.772 | 0.773 | 0.775 | 0.776 | 0.777 | 0.778 | 0.780 | ASTM D1298 |
| Research octane number | 95 | 96.5 | 97.5 | 98.5 | 99.5 | 100 | 101 | ASTM D2699 |
| RVP (at 37.8 °C) (kPa) | 53.4 | 59.3 | 59.6 | 58.8 | 58.3 | 57.2 | 56.8 | ASTM D323 |
| Total sulphur (wt %) | 0.0074 | 0.0071 | 0.0068 | 0.0063 | 0.0059 | 0.0056 | 0.0052 | ASTM D4292 |
| Existent gum (mg/100 ml) | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 0.8 | ASTM D381 |
| Corrosivity (3 h at 50 °C) | 1a | 1a | 1a | 1a | 1a | 1a | 1a | ASTM D130 |
| Oxidation stability induction period (min) | > 360 | > 360 | > 360 | > 360 | > 360 | > 360 | > 360 | ASTM D525 |
| Distillation temperature (°C) | | | | | | | | ASTM D86 |
| Initial boiling point | 35.5 | 36.5 | 37.8 | 37.9 | 36.7 | 38.1 | 39.5 | |
| 10 vol % | 54.5 | 49.7 | 50.8 | 51.7 | 52.8 | 53.2 | 54.8 | |
| 50 vol % | 94.4 | 88.0 | 71.1 | 72.6 | 70.3 | 71.2 | 72.4 | |
| 90 vol % | 167.3 | 167.7 | 166.4 | 165.3 | 163.0 | 160.7 | 159.3 | |
| End point | 197.0 | 202.5 | 197.5 | 198.1 | 198.6 | 198.1 | 198.3 | |
| Heating value (kJ/kg) | 42 604.8 | 40 578.4 | 39 820.6 | 39 412.4 | 39 004.2 | 37 672.8 | 36 341.4 | |
| Carbon (wt %) | 86.6 | 87.7 | 86.7 | 87.6 | 87.6 | 86.7 | 86.0 | |
| Hydrogen (wt %) | 13.3 | 12.2 | 13.2 | 12.3 | 12.3 | 13.2 | 13.9 | |
| Residue (vol %) | 1.7 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | |
| Colour | Light green | | | Light green | | | | Visual |

## *2.1.2 Effect of Bioethanol on the Combustion and Emissions Reductions Characteristics*

An emissions test done on a multi-point port injected gasoline engine operating at stoichiometric air-fuel ratio showed that compared to E0 at full loads, at 2000 rpm, E10 and E30 decreased engine-out CO emissions by 4.7% and 5.8% respectively. At 3000 rpm, the engine-out CO emissions were decreased by 5.7% and 3.1% (He, Wang, Hao, Yan, & Xiao, 2003).

It is also known that introduction of bioethanol as an additive will help reduce $NO_x$ emissions. In a study done with the same Ricardo E6 engine, mentioned previously, the $NO_x$ concentrations decreased with increasing volume amount of ethanol in the fuel (Al-Baghdadi, 2008). This is shown in Figure 5.

The reduction in $NO_x$ emissions can be attributed to the increase in compression ratio which caused a higher peak temperature and higher pressure in addition to the reduction in time required to dissociate NO to $N_2$ and $O_2$.

HC, CO and $CO_2$ emissions also tend to decrease due to the reduction in the carbon atom concentration in the blended fuel (Al-Baghdadi, 2008).

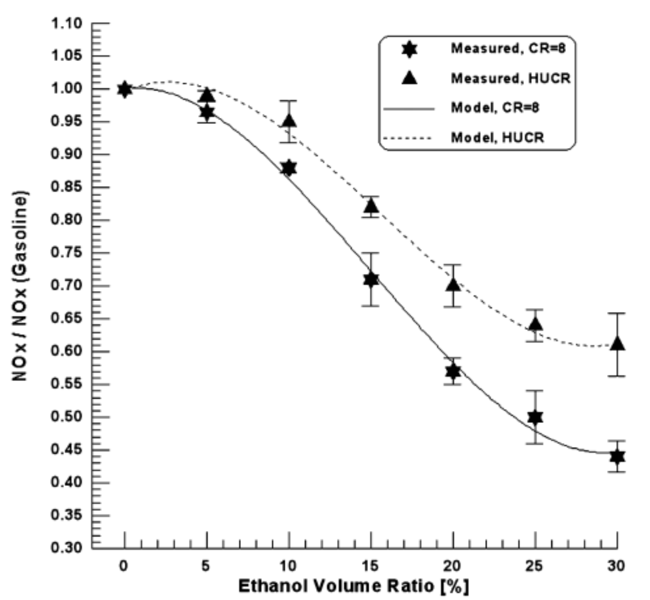


**FIGURE 5 EFFECT OF ETHANOL BLENDING ON NOX EMISSIONS (AL-BAGHDADI, 2008)**

CO and HC emissions also decrease due to the added weight percent of oxygen in the blended fuel due to the addition of ethanol (Celik, 2008).

## 2.2 Disadvantages of E85 as an Alternative Fuel

### *2.2.1 Ethanol Cold Start Problems*

Table 1 shows that Ethanol has a higher latent heat of vaporization. Thus, the addition of Ethanol to fuel increases the fuels net latent heat of vaporization. This causes cold-start problems in engines due to the lower in-cylinder temperatures (Liao, Jiang, Cheng, Huang, & Wei, 2005). Current methods to fix this problem are additives and preheating the fuel and/or engine block.

### *2.2.2 Increased Fuel Consumption*

The study done by Al-Baghdadi shows that the specific fuel consumption is increased as the volume percentage of ethanol is increased in the mixture, at a given fixed compression ratio. But, an increase in the compression ratio caused a decrease in the specific fuel consumption. The addition of 30% vol ethanol to the gasoline caused an increase in the speicific fuel consumption by 4.3% at a compression ratio of 8:1 (Al-Baghdadi, 2008)

But, since maximizing the efficiency of an engine using ethanol-blended fuel requires a higher than regular compression ratio, ideally the engine would be run at this higher specific fuel consumption.

This method of thinking could be better explained by considering the brake specific fuel consumption (BSFC) shown in Figure 6, which is the ratio of fuel consumption to brake power.

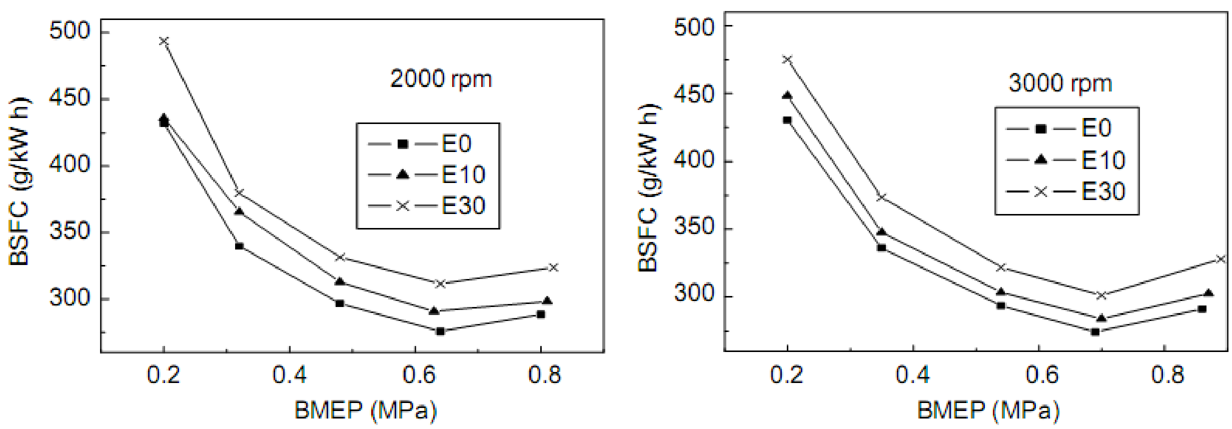


**FIGURE 6 BSFC OF ETHANOL BLENDED GASOLINE FUELS (HE, WANG, HAO, YAN, & XIAO, 2003)**

This can be explained by Ethanol's low heat value. In order to produce the same power at the same operating conditions, more fuel has to be burned as the proportion of ethanol increases.

This fact is also shown on Edmunds.com where vehicles that run on E85 show an increased fuel consumption, measured in miles per gallon (mpg).

# 3. Conclusion

Ethanol when added in small quantities of up to about 30 vol% has been proven to be the most efficient (Al-Baghdadi, 2008). It also has been proven that an increase in Ethanol vol% increases the fuels octane rating thus allowing higher operational compression ratio, which in turn increases brake power and torque and reduces emissions.

The addition of Ethanol helps decrease $NO_x$, CO, $CO_2$ and HC emissions also because of the increase in weight percent of oxygen and decrease in carbon atom concentration in the fuel.

One of the biggest downfalls of Ethanol addition to fuel is the decrease in BSFC and cold start problems with higher vol% of Ethanol since it has a higher latent heat of vaporization and a lower heat value.

As of right now most of the research and papers published have been on ethanol as an additive in fuel. And in the industry, the highest percentage of ethanol being added to the fuel has been 85% ethanol to 15% fuel (E85). If the fuel crisis is to be resolved, more research would have to be done on engines running solely on Ethanol without any fuel. More research should also be done on the current cold start problems when using Ethanol by the use of additives or pre-heaters for the engine to heat up the fuel prior to a cold start.

The current world supply of Ethanol is 2% that of gasoline (Walter, Rosillo-Calle, Dolzan, Piacente, & Cunha, 2008). The article also predicts that the world's Ethanol supply could get up to 20% of that of gasoline by 2030, which still isn't enough to replace the gasoline supply to the world. Thus, Ethanol shouldn't be considered a primary source of alternative energy and other alternative energy sources should be considered.

# 4. Acknowledgements

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