# Impact of Water Contents Blended with Ethanol on SI Engine Performance and Emissions

**Paras Gupta[1,2], Veeraphol Sae-wang[1], Pithayodom Kanbua[1] and Yossapong Laoonual[1,*]**

[1]Combustion and Engines Research Laboratory (CERL)
Department of Mechanical Engineering, Faculty of Engineering
King Mongkut's University Technology Thonburi (KMUTT), Bangkok, Thailand 10140
[2] Internship Student, Indian Institute of Technology, Kanpur, India 208016.

**Abstract**

Recently, the oil crisis and energy security have become the serious concern all over the world. Ethanol, one of the alternative fuels for SI engine seems to have the potential for replacing the conventional fuels such as gasoline. However, the process of removing water contents from hydrous ethanol to make it anhydrous is a very costly operation. In order to have the economical advantage, the use of ethanol with water content can be seen as an interesting choice as a fuel in SI engines. Therefore, this work aims to investigate the effects of water contents blended with ethanol on thermal efficiency and emissions of SI engine. The 125-cc SI engine is used for the experiments. Tests are run at constant engine speed and stoichiometric air fuel ratio. The results show an increase in the thermal efficiency for hydrous ethanol having more than 10% water content. The bsfc value is increased on increasing water content. The NOx produced by hydrous ethanol is very low. The total unburned hydrocarbons (THC) and the CO emissions are increased on water addition but even after the addition of 20% water by volume they are found lower than those of gasoline. So it proposes a solution for the fuel which satisfies the current environmental concerns and helps in improving the fuel economy.

**Keywords**: Water Content, Hydrous Ethanol, Thermal Efficiency, Emissions and Spark Ignition Engine.

## 1. Introduction

Today global warming has become a serious threat to the whole world. Political and public debates on this topic are continuously going on everywhere. Over the past two decades the research done in the field of internal combustion engines is highly dominated by the requirement of improving fuel economy, i.e. reducing the carbon emissions and fuel consumption without compromising the power output of the vehicle.

Current concerns over global warming and limited fossil fuel resources are motivating the researchers to use the alternative fuels. The change in global climate is posing a serious threat to our way of life. In1973 & 1979 oil crisis occurred in the Middle East and recently the oil spillage in the gulf of Mexico has emphasized the necessity of finding alternative fuel resources that could replace the petroleum-based fuels.

Ethanol is an eco-friendly fuel which can be seen as a renewable energy resource. It is produced by fermenting and distilling starch crops, such as corn or sugar cane which needs photosynthesis for growing.

Ethanol is widely used in Brazil and United States. In 2009 they were responsible for 89% of the world's ethanol production [1]. Their automobile industries got great success with the launch of flex-fuel vehicles which can be fuelled by gasoline, ethanol and blend of both. The reason why these engines are not widely used till now is the high cost of pure ethanol due to the low productivity of corps and inflation in international sugar market. At the end of 2009, Brazil had more than 9 million FFVs (Flexible Fuel Vehicles) regularly using pure ethanol fuel [2].

Now ethanol is seen as an alternative to gasoline. Higher octane rating gives this fuel a higher knock resistance which allows a higher compression ratio. Due to its high vaporisation rate, ethanol produces superior thermal efficiency at high temperatures. Ethanol has a faster combustion rate and its flame temperature is lower than gasoline which reduces the heat loss to combustion walls and ensures higher thermal efficiency [3]. Ethanol can burn rich air fuel mixture which generates higher engine power output when compared with gasoline. Ethanol-fed engines emit lower quantity of nitrogen oxides ($NO_x$) and unburned hydrocarbons. Because of the lower heating value, ethanol results in higher fuel consumption. In the case of ethanol engine, cold start is a problem due to its lower vapour pressure.

Ethanol is usually blended with gasoline to create more sustainable fuel for automotive industry. Recent research suggests that blending of ethanol with gasoline can be even more sustainable if hydrous ethanol is used for blending instead of anhydrous ethanol. Distillation of water from the hydrous ethanol for making pure ethanol requires additional cost and energy. A research carried out in an ethanol plant based in Minnesota suggested that 10-45% of energy can be saved by just removing the dehydration process from hydrous ethanol Eh95 (95% Ethanol, 5% water) [4]. In 2008 a study done by HE Blends BV in the Netherlands noted that Eh10-Eh26 hydrous ethanol blends are 10-20% less expensive than anhydrous ethanol [5].

Clemente et al. [6] concluded that the use of hydrous ethanol (water conc. 7%) improves the peak power and peak torque by 9% and 14% effectively with respect to ethanol gasoline blend (22% ethanol 78% gasoline). However, the specific fuel consumption is also increased by 35%. Olberding et al. [7] tested a transit van using 70% ethanol and 30% water fuel mixture. They noticed a significant increase in the thermal efficiency in comparison with gasoline. Li et al. [8] observed increase in torque and power when ethanol was used as fuel in a gasoline spark ignition engine. They also noticed a decrement in CO and THC emissions.

The work of Christensen and Johansson [9] showed that the use of water retards the ignition timing and slows down the rate of combustion, therefore, increases the emission of unburned hydrocarbons and CO. They have found that with increasing water concentration, ignition

*Corresponding Author: E-mail: yossapong.lao@kmutt.ac.th, Tel: 02 470 9123-4, Fax: 02 470 9111, Website: http://cerl.kmutt.ac.th

timing should be advanced to ensure the sufficient evaporation of water. They observed low $NO_x$ emissions with high water contents because higher latent heat of vaporization of water causes the reduction in peak cylinder temperature.

A number of research works have been carried out to investigate water tolerances of ethanol/gasoline blends and preventing the phase separation between gasoline and water(in low ethanol blends) to avoid the corrosion problem [10] but currently the researchers believe that they have overlooked the great possibility of using hydrous ethanol as fuel which is environment friendly as well as economical.

The aim of the present research is therefore to investigate the effects of water contents in ethanol on the performance of a spark ignition engine and compare them with the gasohol as a fuel. Emissions characteristics are also compared. Tests are conducted on a one cylinder, small SI engine with few modifications. This would determine the possibility of using hydrous ethanol as fuel in the near future.

## 2. Experimental Section

### 2.1 Experiment set up

The experimental work was carried on a Honda Model Wave-125i engine which was a one cylinder, four stroke SI engine whose technical specifications are mentioned in Table

1. The engine was originally designed for gasoline but it was modified for using hydrous ethanol. The injector size was increased and fuel injection and ignition timing were controlled by commercial electronic control unit (ECU). ECU optimizes the fuel injection period and spark timing to maintain a constant air fuel ratio and engine revolution speed. After these modifications, the engine was installed on an Eddy Current Dynamometer for measuring and controlling the torque produced by the engine.

Table1. Engine Specifications

| Model | HONDA WAVE 125i |
|---|---|
| Engine type | 4-stroke single cylinder |
| Displacement Volume | 124.8 $cm^3$ |
| Bore x Stroke | 52.4 x 57.9 mm |
| Compression ratio | 9.3:1 |
| Engine speed | 1,000-10,000 rpm |
| Cooling system | Forced air |
| Fuel supply | Electrical fuel injection |

For measuring the variation of cylinder pressure with crank angle, a pressure sensor with compatible charge amplifier and crank shaft angle encoder was used with a high speed data acquisition system designed on Indiwin software. The complete data of in-cylinder pressure will not be analysed here.

In the exhaust stream oxygen sensor was installed for measuring the equivalence ratio from the exhaust of the engine. Exhaust system (MRU Model SWG $200^{-1}$) measures and analyzes the exhaust temperature with the contribution of $O_2$, $CO_2$, CO, NO, $NO_2$, $NO_x$ and unburned hydrocarbons in the exhaust stream. Fuel consumption and laminar air flow was measured manually using a weight measuring machine and a U- tube manometer respectively. The equivalence ratio obtained from the oxygen sensor was compared with the value calculated from exhaust gas composition results and intake laminar flow. The schematic diagram of the experiment is shown in Fig. 1.

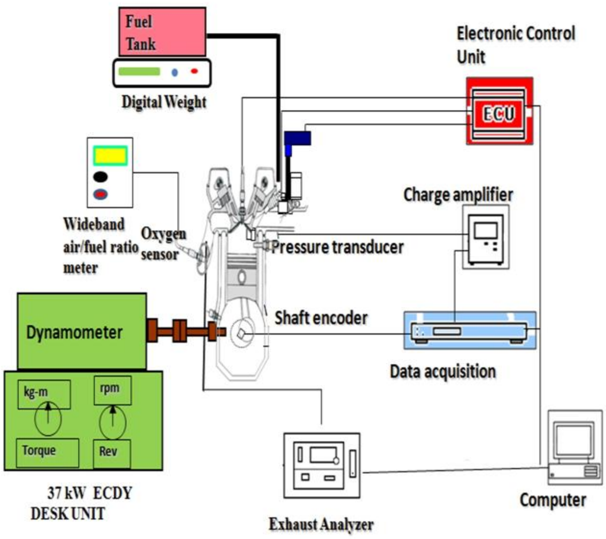


Fig. 1 Experimental set up

### 2.2. Experiment Procedure

Four fuels were considered for the analysis: Gasohol Octane 91 (E10), Pure Ethanol (E100), Ethanol with 10% water by volume (Eh90) and Ethanol with 20% water content (Eh80). The physical and chemical properties of these fuels are mentioned in Table 2. Ignition timing was optimized for the maximum torque in each condition. The test conditions are shown in Table 3.

Table 2. Physical – Chemical properties of the fuels experimented

| Parameter | Gasohol E10 | E100 | Eh90 | Eh80 |
|---|---|---|---|---|
| Composition(by volume) | 90% Gasoline<br>10% Ethanol | 100% Ethanol | 90% Ethanol<br>10% Water | 80% Ethanol<br>20% Water |
| Density (g/cc) | 0.7650 | 0.7921 | 0.8291 | 0.8492 |
| Lower Heating Value(MJ/kg) | 41.087 | 28.865 | 25.318 | 24.936 |
| Stoichiometric A/F | 14.421 | 8.953 | 7.853 | 7.734 |
| Chemical Structure* | $C_{6.66}H_{15.33}O_{0.22}$ | $C_2H_5OH$ | $C_{1.47}H_{4.94}O$ | $C_{1.42}H_{4.85}O$ |
| Carbon Mass(%) | 80.89 | 52.17 | 45.76 | 45.07 |
| Hydrogen mass(%) | 15.51 | 13.04 | 12.80 | 12.78 |
| Oxygen mass(%) | 3.60 | 34.79 | 41.44 | 42.14 |

*calculated for 1 mole of fuel from the given volume ratio of contents (using measured value of densities and standard value of molecular weight)

Table 3. Test Conditions

| No. | Fuel | Load (%) | Engine Speed (rpm) | λ |
|---|---|---|---|---|
| 1 | E10 | 25,50,100 | 5000 | 1 |
| 2 | E100 | | | |
| 3 | Eh90 | | | |
| 4 | Eh80 | | | |

Throughout the experiment, the air fuel ratio was kept constant at its stoichiometric value and engine crank shaft revolution was maintained at 5000 rpm. The engine load was varied by the position of throttle. For each test condition, brake power, indicated power, thermal efficiency, brake specific fuel consumption and regulated exhaust emissions were reported. Three load conditions were tested for each fuel to make the comparison more reliable. To enhance the accuracy of results and to avoid the fluctuations in the measured values every test was carried out until it reached its steady state and the final value was averaged out over this period.

## 3. Results and Discussion

The present motive is to observe the changes in brake power, thermal efficiency, bsfc and regulated emissions with increasing water content in ethanol and to compare it with the corresponding gasohol (E10).

### 3.1. Brake Power

As we can see in Fig. 2, when we switch the fuel from gasohol to pure ethanol, an increment in brake power of 12.53%, 4.30% and 4.95% is observed for 25%, 50% and 100% load respectively. The brake power is directly proportional to the torque output of crank shaft at constant engine speed. It is found that the laminar flame speed is higher in case of ethanol than gasoline [11]. As the engine speed increases, there is less time available for the complete combustion, so a higher flame speed is required. This makes hydrous ethanol produce more torque when compared with gasoline. This change is enhanced in case of higher engine speed and reversed in case of lower engine speed due to the high heating value of gasoline [3]. From Table 2, it can be observed that gasoline has a higher heating value than ethanol and it decreases with increasing water content. It causes a reduction in the brake power with increasing water contents. 20% water content by volume in ethanol reduces the brake power 21.74%, 2.55% and 6.42% from E100 for 25%, 50% and 100% load conditions respectively.

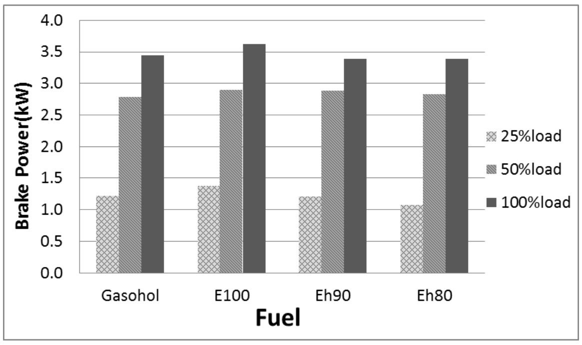


Fig. 2 Brake Power in case of Gasohol(E10) and ethanol with 0, 10 and 20% water contents at 5000 rpm and stoichiometric A/F(λ=1) for 25%, 50% and 100% load conditions

### 3.2 Brake specific fuel consumption ( bsfc )

The brake specific fuel consumption is increased with water content as it can be observed from Fig. 3. All the tests are operated on stoichiometric condition. The stoichiometric A/F for gasohol is 14.421 which is calculated by using the given volume ratio and measured density values. It is much higher than stoichiometric A/F for pure ethanol and found decreased as water is added in the fuel (see Table 2). Therefore, the bsfc value of ethanol is observed 11.76 %, 39.67 % and 41.90 % higher than that of gasohol for 25%, 50% and 100% load conditions respectively. Another reason supporting this trend is the lower heating value of ethanol with respect to gasoline. As we mix water in the alcohol, the lower heating value is decreased; therefore, bsfc value is increased. For Eh80 it reached 47.88 % of its E100 value at 25% throttle opening. Therefore hydrous ethanol can improve fuel economy when compared with gasoline only with proper engine hardware modifications. This result is consistent with the previous research done on the similar topics [6&12].

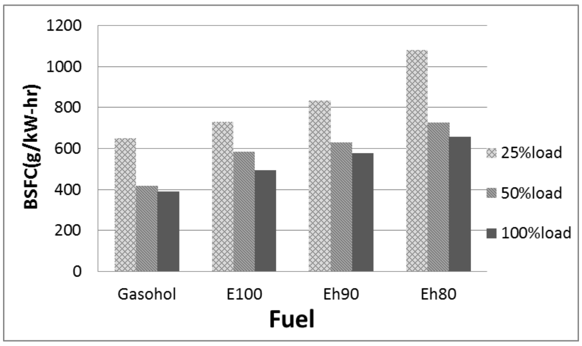


Fig. 3 BSFC in case of Gasohol(E10) and ethanol with 0, 10 and 20% water contents (E100-Eh80) at 5000 rpm and stoichiometric A/F(λ=1) for 25%, 50% and 100% load conditions

### 3.3 Thermal Efficiency

The thermal efficiency in case of ethanol is higher than that of gasoline. This could be explained by less heat loss through cylinder walls because of higher laminar flame speed in case of ethanol. For 25%, 50% and 100% load, thermal efficiency of E100 is 27.36%, 1.91% and 12.04% higher than that of gasoline respectively.

It is observed that the efficiency is decreased with increasing water contents after a small primary stage. It is expected that during the combustion process water takes the significant amount of energy, when it converts from liquid to vapour state which causes the thermal cooling of charge inside the cylinder. The efficiency in case of Eh80 is 21.75%, 7.22% and 12.82% lower than that in case of E100 for 25%, 50% and 100% load conditions respectively. The difference between the brake thermal efficiency obtained in case of gasohol and Eh80 is very low as it can be seen in Fig. 4. It favours the use of hydrous ethanol containing more than 10% water instead of gasohol without compromising the thermal efficiency of engine.

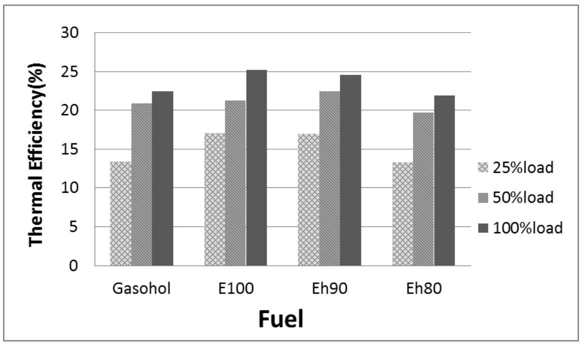


Fig. 4 Thermal Efficiency in case of Gasohol(E10) and ethanol with 0, 10 and 20% water contents at 5000 rpm and stoichiometric A/F(λ=1) for 25%, 50% and 100% load conditions

**3.4 Emissions**

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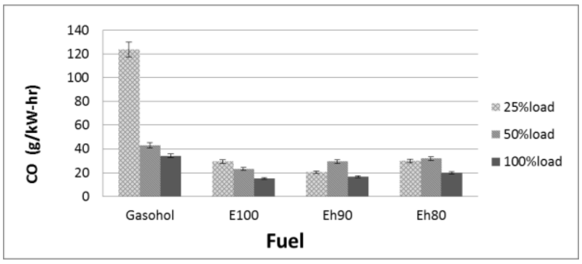
Ethanol shows a significant reduction in CO emissions when compared with gasoline. Due to the oxygen presence in ethanol, there is a noticeable conversion of CO into $CO_2$ which causes a decline of 76.24%, 46.09% and 56.20% in CO emissions for 25%, 50% and 100% load respectively when we switch the fuel from gasohol to pure ethanol. Water content in ethanol slows down the combustion rate. Therefore, as shown in Fig. 5(a), it increases the CO emissions from the pure ethanol values. The CO emission observed in case of Eh 80 is 2.06%, 36.78% and 30.81% higher than that of E100 for 25%, 50% and 100 % throttle opening respectively. From this result hydrous ethanol comes out as a better environment friendly fuel considering the adverse effects caused by CO as pollutants.

$NO_x$ emissions highly depend upon the in-cylinder temperature. These are found decreased linearly with water addition. The peak pressure inside the cylinder which is measured by pressure transducer is found to be decreased with increasing water contents. Because of that, a decrease in cylinder peak temperature is expected. NOx emissions in case of Eh80 are 79.18%, 65.25%, 49.04% lower than those in case of gasohol for 25%, 50% and 100% load conditions respectively. The linear slow down in NOx can be observed in Fig. 5(b).

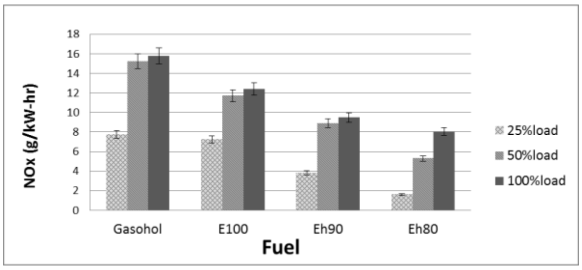
Hydrous ethanol seemed to be a better alternative as shown by Fig. 5(c) in terms of THC emissions. Using pure ethanol (E100) a decrement of 56.75%, 50.24% and 58.87% in THC emissions is observed from the gasohol values for 25%, 50% and 100% load conditions respectively. One reason is because of the polar character of ethanol which prevents it from bonding with non-polar engine oil at surface of cylinder wall [13]. Water content causes the incomplete combustion responsible for higher THC values. Eh80 produces higher hydrocarbons than pure ethanol for all loads.

**4. Conclusion**

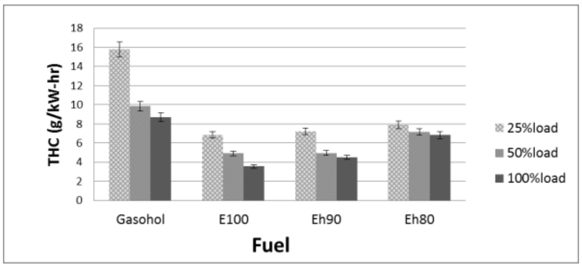
From the results, it can be concluded that the impact of water content blended with ethanol on the thermal efficiency of engine limits the amount of water which can be tolerated with ethanol. The addition of more than 20% water in ethanol might result in a major loss of efficiency. The bsfc in case of ethanol is 41.9% higher than that of gasohol at 100% load. The bsfc is also increased on increasing water content because of that it produces the brake power about the same range that can be achieved using gasohol. The measured brake power is always higher in case of ethanol when compared with gasohol. The CO emissions are reduced when ethanol is used in place of gasohol. CO emissions then increase with increasing water content at all loads (throttle positions). A significant reduction in NOx emissions is achieved by blending it with water. THC emissions increase with water content forcing a tolerance limit of water in ethanol. Therefore, we can conclude that using hydrous ethanol definitely has an economical advantage. The addition of water less than 20% by volume makes compromise with the engine efficiency and the emissions produced are still lower than those in case of gasohol, the commonly used motor fuel in Thailand.




(a) Carbonmonoxide (CO) emissions




(b) Nitric oxide ($NO_x$) emissions




(c) Total Unburned Hydrocarbon (THC) emissions

Fig. 5 CO, $NO_X$ and THC emissions from Gasohol (E10) and ethanol 0, 10 and 20% water contents at 5000 rpm and stoichiometric A/F for 25%, 50% and 100% load conditions.

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