

Research on the Application of Hydrous-ethanol for Automobiles

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ABSTRACT: Amid growing concerns about unstable oil supplies and the impact of fossil fuels on global warming, biofuels are receiving increased attention. Ethanol biofuel could play an important role in reducing fossil fuels consumption and greenhouse gas emissions when applying to the transport facilities. At the present time, there is a variety of types from E100 to E5 ethanol fuels which are mature in the market, specially in Brazil and USA. But all need anhydrous ethanol (99.5%) which takes a lot of non-renewable energy and then results in CO₂ emissions during further distillation process from hydrous-ethanol. In this paper, a hydrous-ethanol boost engine approach, where hydrous-ethanol is reformed to hydrogen-rich mixture gas which is an excellent fuel for engines, is discussed. The advantages of this approach are that fossil fuel consumption and CO₂ emissions are reduced, and the waste heat from engine exhaust can be used as energy source for hydrous-ethanol evaporating and reforming. The experiment is carried out on a gasoline engine as primary engine with only modest changes. The results indicate that the hydrogen-rich mixture gas allows operation at much higher compression ratio due to its intrinsic octane number which could contribute to the power performance, and the NO_x, CO, THC emissions are reduced remarkably because of lean combustion realized in the cylinder.

Keywords: hydrous-ethanol, reform, hydrogen-rich gas, engine

1. INTRODUCTION

Increasing concerns about global climate change and energy security call for cost-effective new approaches to reduce use of fossil fuels in transport facilities. Recent legislations as well as the Kyoto protocol for greenhouse gas reduction set challenging goals for reduction of CO₂ emissions. The developed countries phase in requirements for reducing greenhouse gas generation by an average of five per cent against 1990 levels over the five-year period 2008-2012. Other developing countries may follow in setting this goal. Cost effective approaches using near term technology are needed to achieve the widespread use necessary to meet the goals for reduced fossil fuel consumption.

Ethanol biofuel could play an important role in meeting these goals when applying to the transport facilities which are responsible for two-thirds of total petroleum consumption and a third of carbon emissions. For ethanol as engine fuel, there is a variety of types from E100 to E5 which are mature in the market, specially in Brazil and USA. But all need anhydrous ethanol (99.5%) which takes a lot of non-renewable energy and then results in CO₂ emissions during further distillation process from hydrous-ethanol. And there are many structure modifications when ethanol is used to the existing engines in high rate. In this paper, a hydrous-ethanol boosted engine approach, where hydrous-ethanol is reformed to hydrogen-rich mixture gas which is an excellent fuel for engines, is discussed. The advantages of this approach are that fossil fuel consumption and CO₂ emissions are reduced, and the waste heat from engine

exhaust can be used as energy source for hydrous-ethanol evaporating and reforming. This approach involves only modest changes to the present gasoline engine systems and fueling infrastructure. The increase in vehicle cost could be modest (approximately \$800). This leveraged use of reformed hydrous-ethanol could remarkably reduce its energy consumption in ethanol production without rectifying process and help to alleviate concerns about a low energy output/input ratio (energy provided by the ethanol/energy need to produce the ethanol).

2. ETHANOL STEAM REFORMING

The reaction pathways and thermodynamics of ethanol steam reforming have been studied extensively [1-4]. The possible reaction pathways of ethanol steam reforming are summarized in Table I. It can be seen that hydrogen production varies significantly with different reaction pathways. In order to control the compositions in the reformat, it is crucial to ensure sufficient supply of steam and to minimize ethanol dehydration and decomposition. For fuel cell, it is important to minimize CO production and other poisonous compositions. But for engines, all compositions in the reformat are fuels. Otherwise, although the reaction of ethanol steam reforming is endothermic, the energy density of the reformat will be very low for engines if water is too much in hydrous-ethanol. In this paper, 75 percent (v/v) hydrous-ethanol, in which the mole ratio of water/ethanol is about 1.09, is selected.

Table I Reaction pathways of ethanol steam reforming

Reaction	Equation
Sufficient steam supply	$C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 6H_2$
Insufficient steam supply	$C_2H_5OH + H_2O \rightarrow 2CO + 4H_2$
	$C_2H_5OH + 2H_2 \rightarrow 2CH_4 + H_2O$
Dehydrogenation	$C_2H_5OH \rightarrow C_2H_4O + H_2$
Acetaldehyde decomposition	$C_2H_4O \rightarrow CH_4 + CO$
Acetaldehyde steam reforming	$C_2H_4O + H_2O \rightarrow 3H_2 + 2CO$
Dehydration	$C_2H_5OH \rightarrow C_2H_4 + H_2O$
Coke formation	$C_2H_4 \rightarrow \text{polymeric deposits (coke)}$
Decomposition	$C_2H_5OH \rightarrow CO + CH_4 + H_2$
	$2C_2H_5OH \rightarrow C_3H_6O + CO + 3H_2$
	$C_2H_5OH \rightarrow 0.5CO_2 + 1.5CH_4$
Reaction of decomposition products	
Methanation	$CO + 3H_2 \rightarrow CH_4 + H_2O$
	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
Methane decomposition	$CH_4 \rightarrow 2H_2 + C$
Boudouard reaction	$2CO \rightarrow CO_2 + C$
Water gas shift reaction (WGSR)	$CO + H_2O \rightarrow CO_2 + H_2$

In the above-mentioned reversible reactions, catalysts play a crucial role in the reactivity toward complete conversion of ethanol. However, each catalyst induces different pathways and, therefore, the selection of a suitable catalyst plays a vital role in ethanol steam reforming for the compositions in the reformat. Figure 1 and figure 2 show the recorded chromatogram of the compositions from 75 percent hydrous-ethanol reformed by the catalysts CB-7 and J106-2Q respectively. The main compositions of the catalyst are CuO, ZnO, and Al₂O₃ in CB-7 and NiO in J106-2Q. The reformat gas is analyzed by GC-TCD. The gas chromatography (GC) analysis indicates that the reforming yield is H₂, CO, CH₄ and CO₂ as the main products, and with little C₂* when reformed by CB-7. Table 2 has shown the volume concentration of the compositions

in the reformat gas.

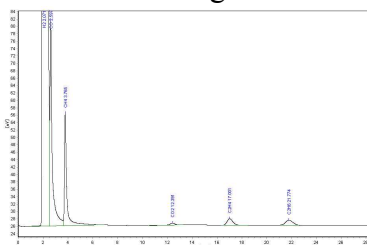


Figure 1 The Chromatogram of Ethanol Steam Reformat Gas with CB-7

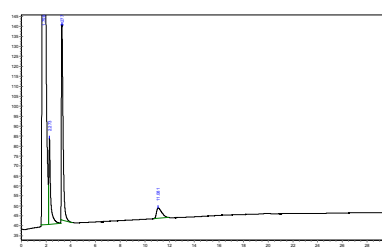


Figure 2 The Chromatogram of Ethanol Steam Reformat Gas with J106-2Q

Table II Concentration of the reformat gas composition (v/v%)

Composition	H ₂	CO	CH ₄	CO ₂	C ₂ H ₄	C ₂ H ₆
Concentration Reformed by CB-7	58.4	23.3	6.5	1.6	1.7	1.4
Concentration Reformed by JQ-106	45.2	15.7	21.3	17.8	-	-

The reformat from hydrous-ethanol is hydrogen-rich gas. Hydrogen has a relatively

high autoignition temperature due to its high fuel octane number. This has important implications when a hydrogen-air mixture is compressed. In fact, the autoignition temperature is an important factor in determining what compression ratio an engine can use, since the temperature rise during compression is related to the compression ratio. The temperature rise is shown by the equation:

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\gamma-1}$$

where:

- V_1/V_2 = the compression ratio
- T_1 = absolute initial temperature
- T_2 = absolute final temperature
- γ = ratio of specific heats

The temperature may not exceed hydrogen's autoignition temperature without causing premature ignition. Thus, the absolute final temperature limits the compression ratio. The high autoignition temperature of hydrogen allows larger compression ratios to be used in a hydrogen engine than in a hydrocarbon engine.

This higher compression ratio is important because it is related to the thermal efficiency of the system. The theoretical thermodynamic efficiency of engine is based on the compression ratio

of the engine and the specific-heat ratio of the fuel as shown in the equation:

$$\eta_{th} = 1 - \frac{1}{\left(\frac{V_1}{V_2} \right)^{\gamma-1}}$$

Where: η_{th} = theoretical thermodynamic efficiency

The higher the compression ratio, the higher the indicated thermodynamic efficiency of the engine. The compression

ratio limit of an engine is based on the fuel's resistance to knock. A lean hydrogen mixture is less susceptible to knock than conventional gasoline and therefore can tolerate higher compression ratios.

3. HYDROUS-ETHANOL REFORMING ENGINE

The hydrous-ethanol reforming engine is based on a direct injection spark ignition (SI) engine. The specifications of the SI engine are shown in table 3.

Table III Baseline SI engine specifications

Displacement	5.4 L
Number of Cylinders	6
Bore	100 mm
Stroke	115 mm
Compression Ratio	7
Max. Power	99kw
Max. Speed	300 r/min
Max. Operation Torq.	350 Nm

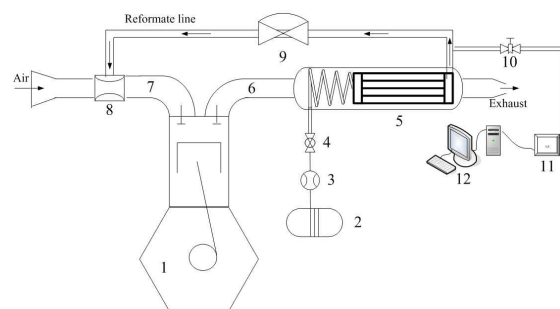


Figure 3 Schematic of the Hydrous-ethanol Reforming Engine System

- 1.SI engine 2.Ethanol tank 3.Flowmeter
- 4.Ball valve 5.Evaporator & Reactor
- 6.Exhaust outlet 7.Air/Fuel inlet
- 8.Venturi mixer 9.Pressure regulator
- 10.Sample valve 11.Gas chromatography
- 12.Computer

Figure 4 NOx Emissions and Lambda

Figure 3 shows the schematic of the hydrous-ethanol reforming engine, which consists of a baseline SI engine with the compression ratio changing to 8.5, and a set of hydrous-ethanol supply system with an evaporator and a reactor. In addition, there is a gas chromatography for analyzing the compositions of the reformat from ethanol steam.

The engine exhaust emission measurements were accomplished with an exhaust analyzing system from Horiba, Horiba MEXA-1500D Exhaust Analyzer. This system was used to measure oxygen(O₂), carbon dioxide(CO₂), carbon monoxide(CO), oxides of nitrogen(NO_x) and total hydrocarbons(THC), via a heat pipe from the engine.

3.1 Performance of the engine

The engine is still started by gasoline. When the temperature of the exhaust reaches about 300°C, the fuel is shifted from gasoline to hydrous-ethanol. From figure 4 to figure7 show at the same conditions of 2000rpm the emissions THC, CO, NO_x and energy consumption compared to the baseline. The plots illustrate that the emissions NO_x, CO, THC of the hydrous-ethanol reforming engine are lower than those of the baseline engine, and the energy consumption is reduced about 5% except in low loads.

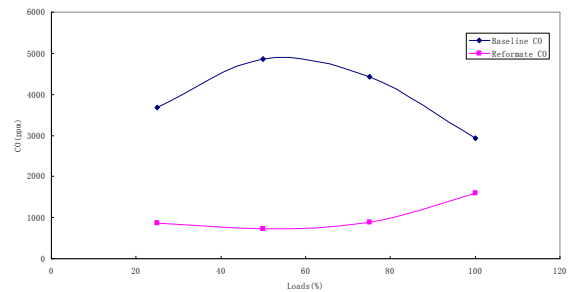
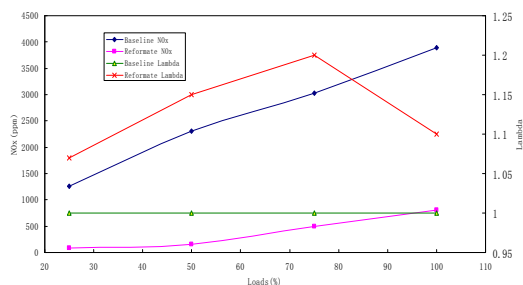


Figure 5 CO Emission

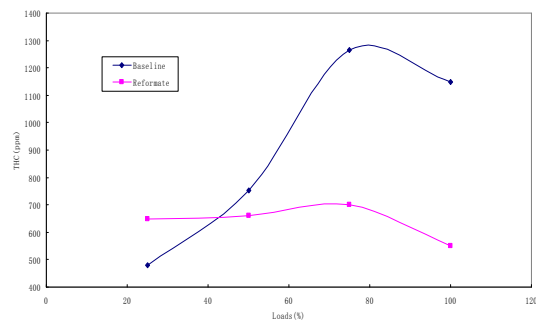


Figure 6 THC Emission

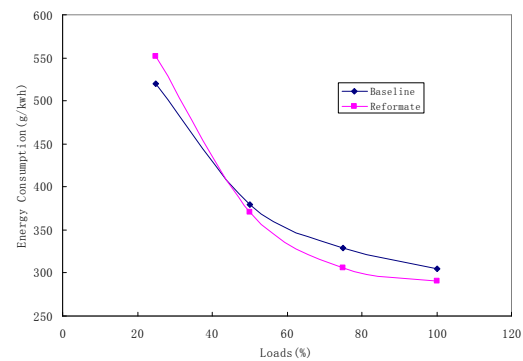


Figure 7 Energy Consumption

The different operating condition of the two engines is Lambda, which in all loads keeps constantly about 1 for the baseline engine and varies for the hydrous-ethanol reforming engine but greater than 1. Here Lambda is the ratio of air to fuel in relationship to the stoichiometry of combustion, denoted by λ . While a λ of 1.0, there is exactly as much air as required to react completely with the fuel in an air-fuel

mixture. While a λ less than 1.0, there is an excess amount of fuel in the mixture which is termed 'rich mixture'. While a λ greater than 1.0, there is an excess amount of air in the mixture which is termed 'lean mixture'. Obviously the hydrous-ethanol reforming engine can well run in lean condition which reduces pumping losses and provides a higher thermodynamic efficiency through a more favorable ratio of specific heats.

3.2 Appreciates hydrous-ethanol

Figure 8 and figure 9 show the 70, 75, 80 percent hydrous-ethanol impact to NO_x emissions and energy consumption of the engine respectively.

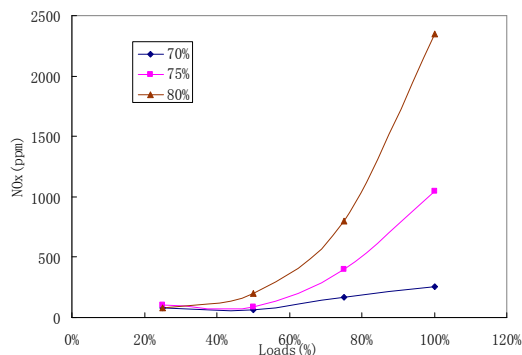


Figure 8 NO_x emissions Corresponding to Different Concentration Hydrous-ethanol

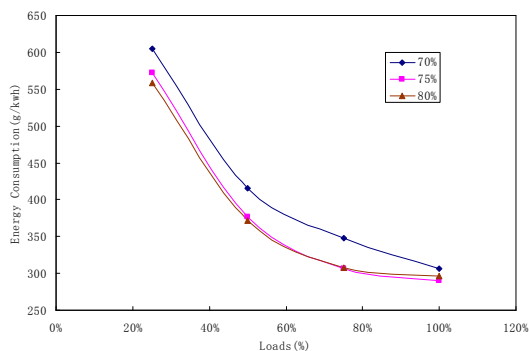


Figure9 Energy Consumption Corresponding to Different Concentration Hydrous-ethanol

Compared to 75 percent hydrous-ethanol, with 70 percent hydrous-ethanol NO_x emissions are lower but energy consumption is higher, and with 80 percent hydrous-ethanol energy consumption is close but NO_x emissions are so higher that are unacceptable. So 75 percent hydrous-ethanol is appreciated.

4. CONCLUSION

The hydrous-ethanol boost engine approach, where hydrous-ethanol is reformed to hydrogen-rich mixture gas which is an excellent fuel for engines, could provide a cost effective way to meet near term goals of reducing gasoline consumption and CO₂ emissions. The cost of fuel savings payback time for the increased vehicle cost of approximately \$800 could be about one year. The hydrous-ethanol boost engine approach could lead to a substantial increase in the use of ethanol and help to facilitate the market penetration of this renewable biofuel.

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