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Evaluation of gasoline–ethanol–water ternary mixtures used as a fuel for an Otto engine

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HIGHLIGHTS

- ETBE, TAME and palmitic acid promote water tolerance in ethanol–gasoline blends.
- Water quality produced no difference in water tolerance of ethanol–gasoline blends.
- NO and NO_x emissions were impressively reduced when burning E40h (10% hydrous).
- Some metal parts of the fuel pump are not fully compatible to ethanol fuels.

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ABSTRACT

In this study, gasoline–ethanol–water ternary mixtures were tested for stability, at three different temperatures, three water qualities, two gasoline compositions and three additives. Then, a specific mixture of 60:40 gasoline–ethanol-10% hydrous (E40h), was burned in a stationary automotive Otto engine. Measurements of exhaust emissions (NO_x, NO, HC, CO_2, CO, O_2), horsepower, fuel consumption and other parameters were taken through the λ scale and compared to those derived from the gasoline (E0) and 60:40(E40) gasoline–anhydrous ethanol fuels. The engine, a 997 cc VVTi Toyota gasoline engine without catalytic converter, had to be thoroughly retuned but not modified for these three different fuels. The experimental results show an impressive reduction of NO_x emissions for hydrous ethanol mixture and other less significant changes for the rest of the emissions. Also, the gravimetric fuel consumption is significantly higher for both anhydrous and hydrous ethanol mixtures due to the lower heating value of ethanol and zero heating value of water.

1. Introduction

Ethanol, was first used as an automotive fuel nearly a century ago, but was never widely spread until 50 years later. The first E100 production car was launched in 1979 in Brazil and had a lot of issues in comparison to classic gasoline burning vehicles. In the mid 80s those issues were nearly solved and ethanol burning vehicles were a success. After this period and because of ethanol's high cost comparing to fossil fuels the ethanol burning vehicle market was diminished even in Brazil until the start of the new century. Rising cost of petrol and anticipated future shortage persuaded governments worldwide to foster the use of ethanol in vehicles.

Nowadays, after decades of research [1–6] ethanol is used in many countries, pure or in a mixture with gasoline as a fuel. Flex fuel vehicles can burn mixtures from E20 up to E100.

Ethanol, as an alcohol, has some advantages over fossil fuels. It is renewable, sustainable and non-polluting, which means that it is not as harmful during production and usage for the environment. Also ethanol production can boost agriculture activities, such as corn, barley, and wheat, and reduce dependence on foreign oil. Another advantage is the higher octane value and higher heat of vaporization of ethanol, which both promote higher output from a given engine, due to higher compression used and better fuel–air charge. Finally ethanol produces less carbon emissions because extra oxygen content improves combustion, and lower molar C/H ratio gives less CO_2 per outputted KW.

However, ethanol has some disadvantages. Lower heating value, which means higher volumetric consumption and lower boiling point which leads to higher evaporative emissions. Also ethanol is highly hydrophilic and as a result, any existent moisture during the transportation procedure is captured, deteriorating the final product. Finally the cost of production is higher than gasoline especially for the pure 99.9% ethanol due to the energy needed during the distillation process.

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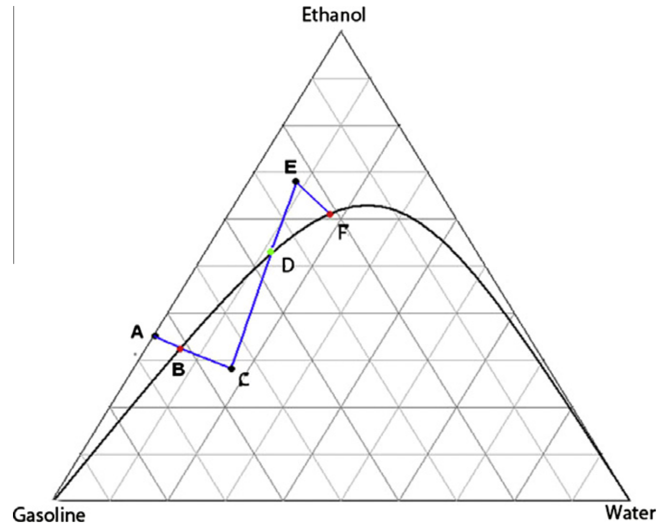

Fig. 1. Ternary plot for gasoline–ethanol–water mixtures.

Table 2
Technical specifications of the engine.

Manufacturer	Toyota
Type	1SZ-FE VVTi
Number of cylinders	4
Cycle	4-stroke
Displacement	997 cm^3
Compression ratio	10:1
Maximum horsepower	69 bhp
Maximum speed	6500 rpm
Ignition type	Electronically controlled four coil
Fuel system	Electronically controlled MPI
Cooling system	Water/water exchanger
Exhaust system	Custom w/o catalytic converter

Table 3
Technical specifications of the dynamometer.

Manufacturer	Go-power
Type	D-100
Type of absorption	Water brake
Maximum power	100 bhp
Maximum speed	14.000 rpm

So, anhydrous ethanol could may be replaced by hydrous ethanol if some basic issues were solved. Ethanol–water and ethanol–gasoline can mix homogeneously regardless mixture ratio, but ethanol–gasoline–water mixture is hazy or fully separated for most mixture ratios. The fact is, that every fuel has to be clear and homogeneous so ternary plot for this mixture was needed and there is limited research concerning gasoline–alcohol–water miscibility [7–13].

At the same time even a homogenous hydrous ethanol–gasoline mixture has different behavior as a fuel in an engine than an anhydrous ethanol–gasoline mixture. Again the research is limited concerning engine behavior (fuel consumption, exhaust emissions, output, etc.) [14–21] and material compatibility [22,23].

2. Experimental section

2.1. Ternary mixtures stability

For these tests the setup consisted of a 250 ml flask, two 50 ml burettes, a thermometer and a magnetic stirrer. The procedure followed, Fig. 1, was to start from a given ethanol binary mixture and add the third component, until the mixture becomes hazy or separates. Ethanol was then added until the mixture was clear again and so on. The mixture was being stirred the whole time and every change in the mixture homogenization was recorded. The above procedure was repeated for a set of three temperatures, i.e. 2 °C, 10 °C and 18 °C, so that we could examine the effect of different temperatures. The quality of the water used was also tested by using three different water sources (distilled, bottled and sea water), again following the same procedure. Another factor examined was gasoline composition. A special mixture of reformate, isomerate and FCC was prepared so that fuel specifications were in accordance with EN228:2009, but without adding MTBE or TAME which contain oxygen (formulated gasoline in Table 1). Finally, three stability additives, of analytical grade, were added in different ratios and examined whether they could improve the mixture's stability i.e. isopropanol, 2-butanol and palmitic acid.

Table 1
Properties of the fuels.

Property	Units	Formulated gasoline	E0	E40	E40h	
RON		95.0	95.4	107.5	110.3	EN ISO 5164
MON		84.4	85.6	88.2	91.0	EN ISO 5163
Molar C/H ratio		732.5	0.46	0.41	0.41	
Density	kg/m^3	42.0	736.9	760.6	772.3	EN ISO12185
Sulfur	mg/kg	0.0	8.0	4.7	4.6	EN ISO20846
EtOH	% (v/v)	0.0	0.0	40.0	36.0	EN 14517
MTBE	% (v/v)	0.0	6.5	3.9	3.9	EN 14517
ETBE	% (v/v)	0.0	0.0	0.0	0.0	EN 14517
TAME	% (v/v)	0.0	3.2	1.9	1.9	EN 14517
Oxygen	(% m/m)	14.1	1.72	13.56	13.60	EN 14517
Olefins	% (v/v)	34.8	15.4	9.2	9.2	EN 14517
Aromatics	% (v/v)	0.95	29.9	17.9	17.9	EN 14517
Benzene	% (v/v)	59.8	0.94	0.56	0.56	EN 14517
Vapor pressure	kPa	24.2	81.9	84.8	85.5	EN 13016-1
Distillation						EN ISO 3405
E70	% (v/v)	52.7	37.1	35.5	37.0	
E100	% (v/v)	86.5	63.6	85	86.7	
E150	% (v/v)	184.8	91.1	90.8	90.6	
FBP	°C	96.8	176.0	175.5	175.0	
Recovery	% (v/v)	0.8	95.4	95.1	95.9	
Residue	% (v/v)	2.4	1.0	1.1	0.7	
Loss	% (v/v)		3.6	3.8	4.1	