ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XVI, NR. 1, 2009, ISSN 1453 - 7397

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Full Load Performance of a Spark Ignition Engine Fueled with Gasoline-Isobutanol Blends

With fossil fuels reserves coming ever closer to depletion and the issue of air pollution caused by automotive transport becoming more and more important, mankind has looked for various solutions in the field of internal combustion engines. One of these solutions is using biofuels, and while the internal combustion engine will most likely disappear along with the last fossil fuel source, studying biofuels and their impact on automotive power-trains is a necessity even if only on a the short term basis. While engines built to run on alcohol-gasoline blends offer good performance levels even at high concentrations of alcohol, unmodified engines fueled with blends of biofuels and fossil fuels can exhibit a drop in power. The object of this study is evaluating such phenomena when a spark ignition engine is operated at full load.

Keywords: *spark ignition engine, biofules, isobutanol*

1. Introduction

Bioethanol is widely used in countries like Brazil, and most likely it will be the fuel of choice for most engine manufacturers as the source of alternative energy. Butanol is a higher alcohol, with the chemical formula C_4H_9OH. Given its much lower level of corrosion, as well as the higher calorific power, butanol is more compatible with fuel systems built to run on gasoline. Compared to n-butanol, isobutanol has a different structure that gives it a higher octane rating, close to the premium gasoline range. Lower oxygen content means that blends with a concentration higher than 10 % alcohol can be used. Very good results were obtained with 16 % butanol blended into gasoline [1], compared to a maximum 10 % limit for bioethanol that can be used in vehicles without any modifications. Another advantage of butanol is its lower heat of vaporization, as cold starts in winter time are known to be difficult when alcohol is used as a fuel. Also, compared to ethanol, butanol has a minor impact on the fuel blend distillation curve [1].

As with any alcohol, gasoline-isobutanol blends have a lower stoichiometric air-fuel ratio. Therefore, when using gasoline blended with isobutanol, fuel flow must be increased to ensure the same relative air-fuel ratio as with pure gasoline. During idle and part load operation, the engine runs with a close to stoichiometric mixture, with the fuel system adjusting the injection timing based upon the signals received from the sensors. Fuel pressure in the injector rail is maintained at a constant value above the air pressure in the intake manifold, therefore the quantity injected depends only on the time that the injectors stay open. Injection time is calculated based on engine load and the opening of the throttle, while adjustments to this injection time are made based on the signal received from the oxygen sensor. Under full load operation with gasoline, the fuel system delivers a predefined flow that ensures a relative air-fuel ratio in the rich mixture area ($\lambda \sim 0,8 - 0,9$), regardless of the reading from the oxygen sensor. As the isobutanol content in the fuel blend increases, the air-fuel mixture is leaned out (figure 1).

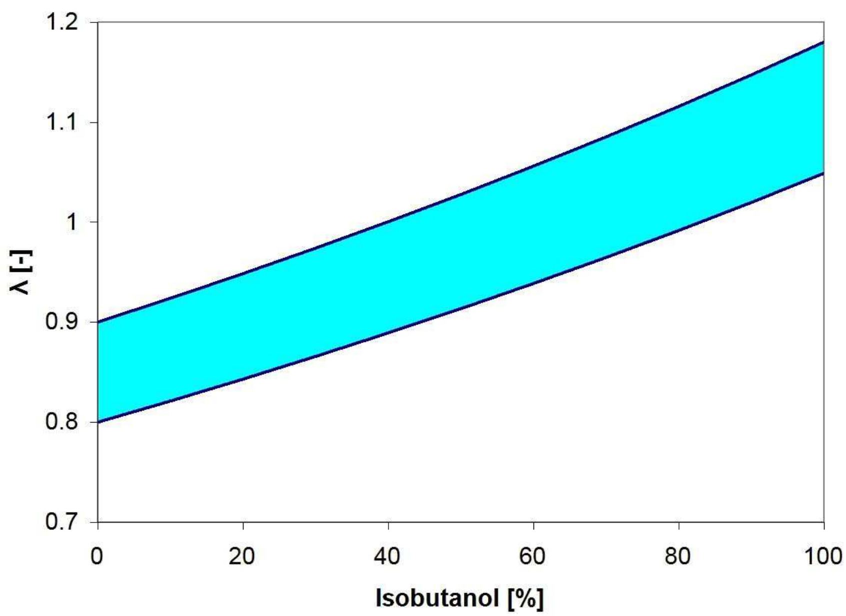

Figure 1. Full load relative air-fuel ratio for different gasoline-isobutanol blends

Lean operation is generally avoided with port-fuel injection spark ignition engines. The main reason is that lean mixtures do not ensure combustion stability and favor nitrous oxide (NO_x) formation. Also, leaning out the mixture slows down flame front propagation and increases the tendency to detonation, with a negative impact on engine performance and durability.

2. Experimental setup

The test vehicle, an Opel Omega A equipped with a 2 liter C20NE port injection spark ignition engine, was fueled with different gasoline-isobutanol blends, ranging from 0 % alcohol, namely pure gasoline, to 100 % isobutanol. Engine power was measured using a Maha LPS 3000 chassis dynamometer for passenger cars (figure 2). Maximum engine power of 85 kW at 5200 rev/min is well below the value of 260 kW that can be measured with the dyno [2].

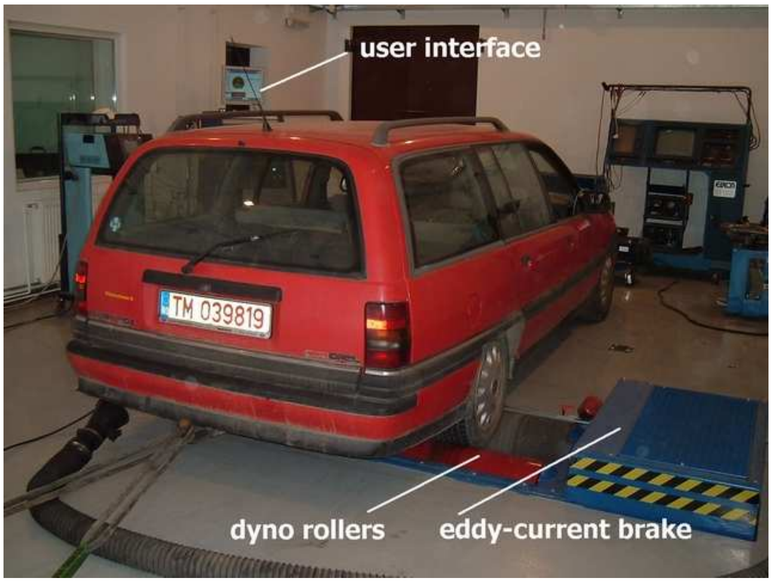

Figure 2. Test vehicle on a Maha LPS 3000 chassis dynamometer

Engine speed range was limited to a minimum of 1720 rev/min, and a maximum value of 6000 rev/min. The dynamometer starts recording engine power above 50 km/h and the lower value for engine speed corresponds to a vehicle speed of 50 km/h with the 4^{th} gear of the transmission gear box selected, while the maximum of 6000 rev/min was chosen to avoid excessive engine wear. A purpose fan was used to simulate air flow around the vehicle, thus ensuring proper engine air supply and power-train ventilation.

Even when correction factors are applied to quantify the influence of ambient pressure, temperature and relative humidity, measured power values can vary. These variations are the result of cyclic variations and other complex influences like engine components temperature. For this reason, numerous tests were conducted for every gasoline-isobutanol blend and only statistically meaningful values were chosen for comparison.

3. Analysis

Very good engine running characteristics were obtained for low isobutanol volumetric concentrations, of 10 % (IB10) and 30 % (IB30). When fueled with pure isobutanol (IB100), engine cold start proved very difficult even at high ambient temperatures of 25 °C. For a concentration of 70 % alcohol (IB70), cold start and idle running characteristics were greatly improved. At 50 % isobutanol concentration (IB50), good running characteristics were obtained at part load operation, however, at full load a large variation of measured power was observed (figure 3). Given that the measurements were conducted in the same conditions, the difference in measured power is most likely due to an increase of cycle to cycle variations. Mixture dilution by excess air or high exhaust gas recirculation (EGR) values lead to partial burning and even misfire [3]. Rich air-fuel mixtures ensure a fast flame front development speed and allows the use of optimum spark ignition for maximum engine power [4].

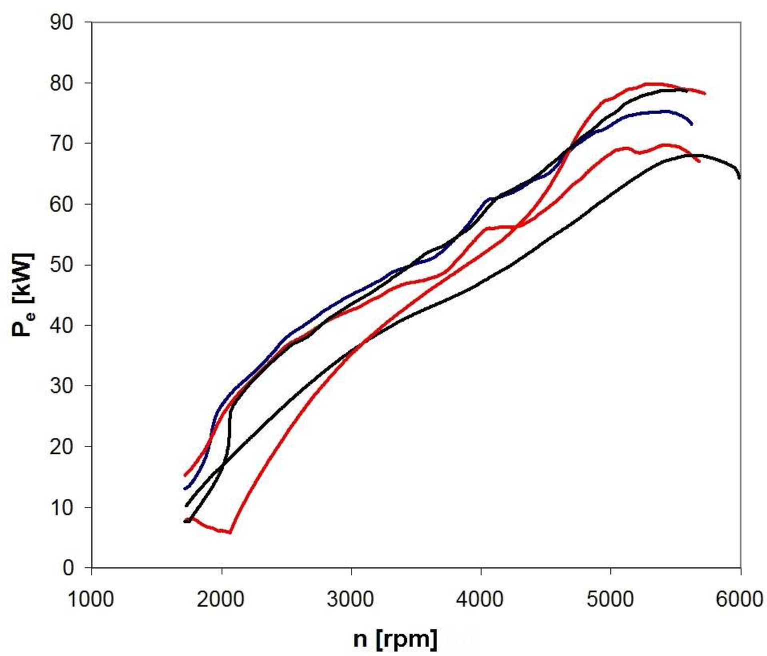

Figure 3. Full load engine power, IB50 fuel blend

Several studies [5], [6] performed on unmodified power-trains identified a drop in engine performance at concentrations of up 20 % isobutanol blended with gasoline. The results of this study are corrected values (with a coefficient k_a that quantifies the influence of ambient pressure and temperature) and show a significant loss of power only for high levels of isobutanol in the fuel blend (figure 4).

$$k_a = \left(\frac{990}{p_s}\right) \cdot \left(\frac{T}{298}\right)^{0,5}, \tag{1}$$

where k_a is the correction factor, p_s dry ambient air pressure measured in mbar and T the intake air temperature, in K.

Maximum engine power drops as much as 25 %, to ~ 62 kW when IB70 is used, from ~ 83 kW when fueled with gasoline. Fueling the engine with pure isobutanol (IB100) renders the power-train unusable for automotive traction. The fuel system electronic control unit (ECU) even recorded a fault code due to the low equivalence ratio during full load operation. The massive power loss for IB70 and IB100 is most likely explained by a slight detonation phenomena due to the lean mixture and high load.

For concentrations of up to 30 % isobutanol, engine performance remains within comparable limits to gasoline operation. Even for IB50, the power drops only ~ 10 %, however large variations of measured values from one test to another does not recommend the use of fuel blends with more than 30 % isobutanol.

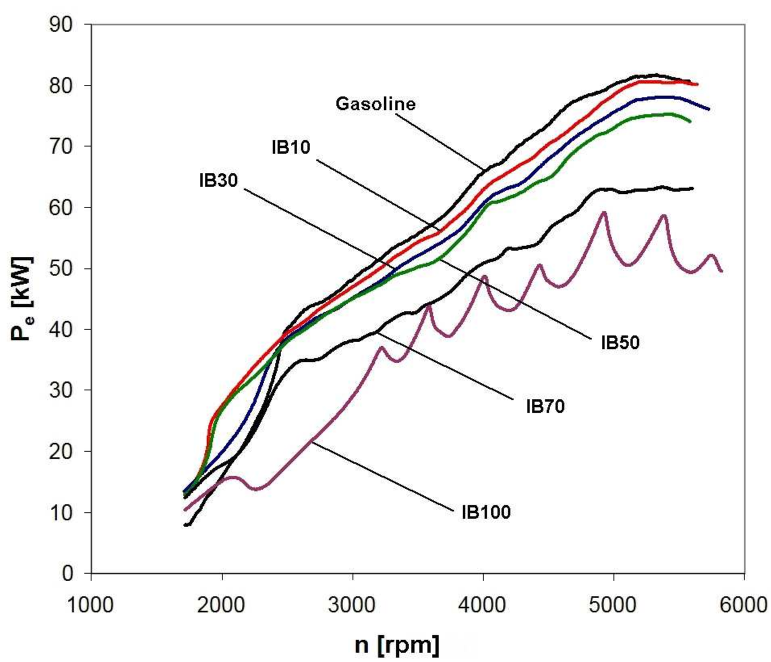

Figure 4. Full load engine power, different gasoline-isobutanol fuel blends

4. Conclusions

The use of biofuels can greatly reduce CO_2 emissions, with obvious environmental benefits. Compared to bioethanol, isobutanol is more suited as a fuel to be used in unmodified spark ignition engines. Its low corrosive nature and higher calorific power make isobutanol a better blending agent for replacing gasoline.

At full load, the power drop of unmodified engines is significant only for isobutanol concentrations higher than 30 %. While power loss is only ~ 10 % at 50 % alcohol mixed with gasoline, the engine exhibits an erratic behavior. For high concentrations of isobutanol, at 70 % and 100 %, maximum power drops significantly, and renders the engine unusable for automotive applications.

For gasoline-isobutanol blends with up to 30 % alcohol, engine performance at full load is maintained within acceptable limits, compared to the case of fueling the engine with gasoline.

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