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Towards 40% efficiency with BMEP exceeding 30 bar in directly injected, turbocharged, spark ignition ethanol engines

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ABSTRACT

Current flexi fuel gasoline and ethanol engines have efficiencies generally lower than dedicated gasoline engines. Considering ethanol has a few advantages with reference to gasoline, namely the higher octane number and the larger heat of vaporization, the paper explores the potentials of dedicated pure ethanol engines using the most advanced techniques available for gasoline engines, specifically direct injection, turbo charging and variable valve actuation. Computations are performed with state-of-the-art, well validated, engine and vehicle performance simulations packages, generally accepted to produce accurate results when targeting major trends in engine developments. The higher compression ratio and the higher boost permitted by ethanol allows larger than gasoline top engine brake thermal efficiencies and peak power and torque, while the variable valve actuation produces smaller penalties in efficiency changing the load than in conventional throttle controlled engines.

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1. Introduction

Bio ethanol is an alternative, renewable fuel resulting in less Green House Gas (*GHG*) emissions and nonrenewable energy depletion than fossil fuels, conventional gasoline and Diesel as well as alternatives including fossil ethanol (ethanol has indeed been available from processing fossil fuels long before the present biomass-based ethanol) [1–5].

The key environmental benefit of bio ethanol is that, unlike gasoline and Diesel, its consumption does not significantly raise the atmospheric levels of CO_2. This is because the CO_2 which is released during the burning of the fuel is counter-balanced by that which is removed from the environment by photosynthesis when growing crops and trees for ethanol production, with the processes of photosynthesis and combustion occurring almost simultaneously.

The fuel Life Cycle Analysis (*LCA*) shows significant reductions of carbon dioxide emissions and non renewable energy use per unit energy consumed on board of a vehicle with bio ethanol vs. fossil gasoline and Diesel, especially when the bio ethanol is produced from cellulosic biomass sources [1–4]. Therefore, replacement of fossil gasoline and Diesel fuels with bio ethanol is more sustainable because reduces the net amount of carbon dioxide emissions and post pone the depletion of non renewable energy sources.

On a fuel *LCA* basis, ethanol produced today roughly reduces 20% *GHG* emissions, and in terms of fossil energy, and it delivers one third or more energy than is used to produce it when accounting for the energy contained in the co-products. This *GHG* emission reduction could increase with improved efficiency of the production pathway, use of renewable energy sources and producing ethanol from more abundant, nonfood-based, cellulosic biomass sources rather than corn or sugar cane [1–4], with some uncertainties on the actual figures arising from the uncertainty of the *LCA* [5].

Ethanol is available in various blends, EX, where the E stands for ethanol and the X denotes the % of ethanol in the blend. Ethanol delivers less energy per litre than gasoline, but has an increased resistance to knock. Most modern gasoline vehicles may be fuelled with gasoline blended with small amounts of ethanol, with small effects on the fuel economy. Flex-fuel vehicles may be fuelled with both gasoline and ethanol in any proportions [6–8]. Flex-fuel engines require hardware and engine control modifications. Flex-fuel engines hardware modifications include more durable valves and valve seats, and the use of ethanol-compatible materials in the fuel system.

Today's flex-fuel vehicles can run on E85, gasoline or any mixture of the two, with automatic fuel adjustments of engine operation. E85 has a higher octane rating than gasoline, and turbocharged flex-fuel engines may use higher boost pressure and more advanced ignition timing with E85 vs. gasoline without risk of knocking or pre-detonation. The compression ratio of the flex-fuel engines is however fixed to the minim value needed when running gasoline and the further benefits that may be obtained running the higher compression ratio of E85 are therefore lost [6–8]. Significant improvement of the fuel energy conversion efficiency as well as the peak power and torque outputs may subsequently follow the development of engines specific for pure ethanol E100 [9–13].

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Pure ethanol engines are not a new idea. They have been very popular in Brazil in the 80 s. Brazil has been the pioneering country in the use of ethanol as a road transport fuel, starting its experience in between the two world wars. Sugar cane has been one of the main resources of Brazil since the 1500 s, and sugar cane crops are the basis for ethanol production in Brazil. In the 70 s, increased oil prices convinced the Brazilian government to launch the "*Proalcohol*" program to help reduce the country's dependence on oil replacing gasoline with ethanol made from sugar. In the early 80 s almost all cars sold in Brazil ran on ethanol. As oil prices dropped in the latest 80 s, the Brazilian government suddenly decreased support for ethanol production, and production volumes stagnated despite the fact that demand remained strong. A serious supply crisis occurred in 1989, when drivers where not able to find the pure ethanol fuel required to run their not flex-fuel cars. The supply crisis and the subsequent loss of consumer's confidence in pure ethanol fuelled cars plus the oil prices affordable over again plunged the popularity of pure ethanol-powered cars. When oil prices returned high, ethanol in Brazil rebounded, but this time car manufacturers designed flex-fuel cars powered by any mixture of gasoline and ethanol, allowing the driver to choose whichever fuel was cheaper or more easily available. The benefits in terms of reduction of CO_2 emissions and reduced use of non renewable fossil fuels and a more mature, environmentally friendly and sustainable ethanol industry may now renew the scope of pure ethanol engines.

High power density, stoichiometric engines for gasoline-like fuels are those where the most part of the research and development is now focused because of their very well established three way catalytic converter after treatment that makes easier to meet the future targets for pollutants emissions [14–16]. This paper therefore explores the advantages that direct injection and high turbo charging may give to pure ethanol engines fully exploiting the reduced knock tendency and the increased heat of vaporization of ethanol when compared to gasoline. Computations are performed with state-of-the-art, well validated, engine and vehicle performance simulations packages, generally accepted to produce accurate results targeting major trends in engine developments. The paper presents basic features of a dedicated E100 engine, plus details of engine and vehicle models, and results of simulations including engine Brake Specific Fuel Consumption (*BSFC*) map and full size, passenger car fuel economy covering the New European Driving Cycle (*NEDC*).

2. Turbo charging, direct injection and variable valve actuation

The most part of gasoline engines now in production are naturally aspirated, port fuel injected, throttle controlled stoichiometric engines with three ways catalytic after treatment having as a major advantage the low cost of production. The most important downfalls of these engines are not only the low top engine brake thermal efficiency, generally below 35%, but primarily the low part load efficiencies over driving cycles due to the large displacement and the large penalties in efficiency reducing the load throttling the intake, with efficiencies approaching 10% during operation at 1 bar Brake Mean Effective Pressure (*BMEP*).

As a reference, Figs. 1 and 2 present the engine brake thermal efficiency and the *BSFC* of a 4 l, naturally aspirated gasoline engine. The compression ratio is 10.5:1. These are computational results obtained with a validated engine efficiency model, with differences vs. experiments done on a properly operating and well maintained

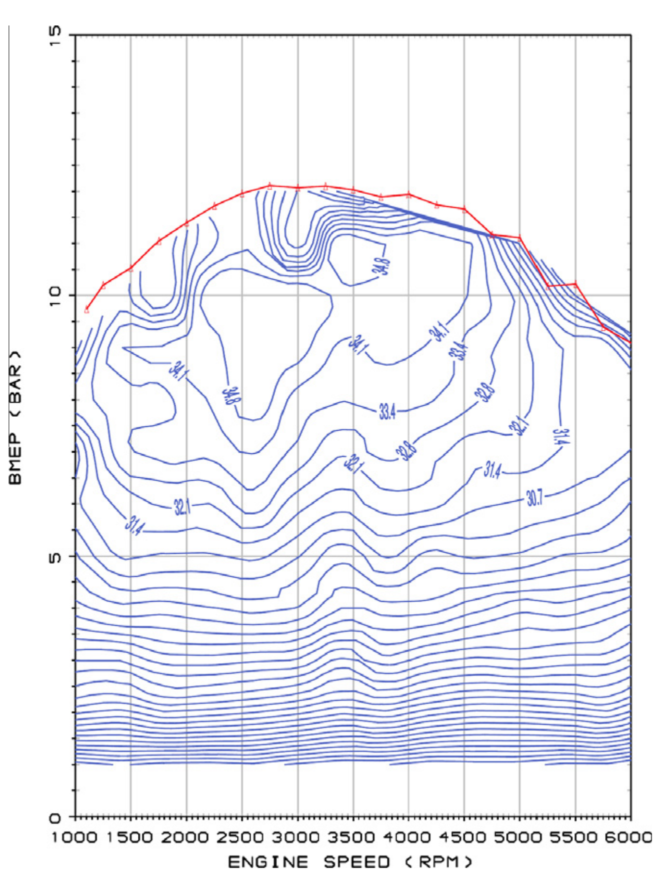

Fig. 1. Engine brake thermal efficiency of a naturally aspirated, 4 l gasoline engine (validated model results).

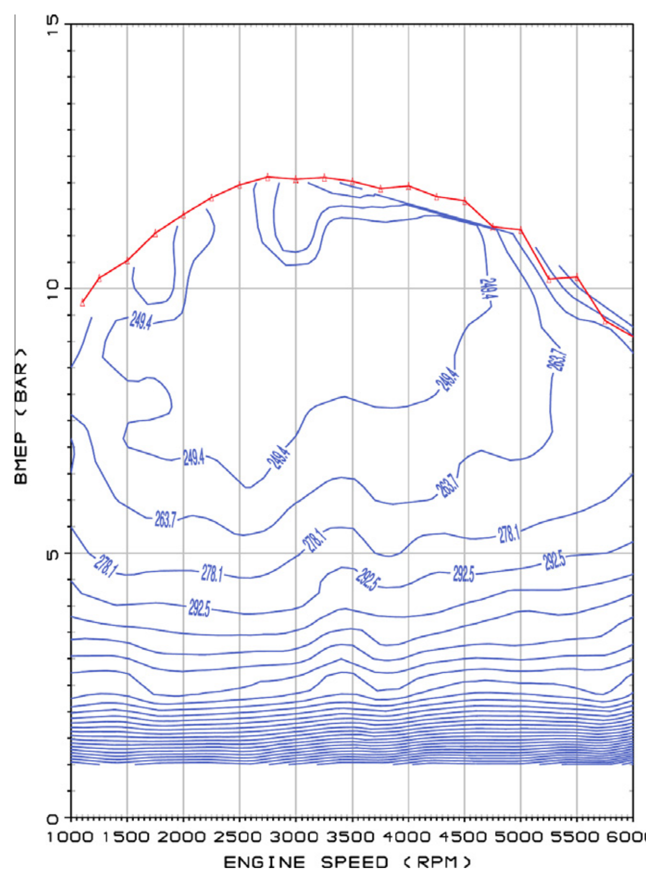

Fig. 2. *BSFC* (g/kW h) of a naturally aspirated, 4 l gasoline engine (validated model results).

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