USO EFICIENTE DO ETANOL VEICULAR NO BRASIL

Painel – Flex Otimizado para Etanol

Prof. Francisco E. B. Nigro
Departamento de Engenharia Mecânica
Escola Politécnica - USP
São Paulo, 21 de novembro de 2013
AGENDA:

- SPARK-IGNITION ENGINES AND ETHANOL
- PROPERTIES OF ETHANOL X GASOLINE
- POWERTRAIN EVOLUTION
- EVOLUTION OF STRAIGHT ETHANOL VEHICLES AND FFVs
- EMISSION AND MATERIALS STRENGTH CHALLENGES
- OPPORTUNITIES FOR FFVs DEVELOPMENT
- CONCLUSIONS AND RECOMMENDATIONS
FUNDAMENTAL CHARACTERISTICS OF OTTO ENGINES

• Air-fuel mixture homogenous and close to stoichiometric ratio for flame propagation (0.8< \( \lambda \)< ~1.4);
• Compression of air-fuel mixture;
• Load control → throttle valve reduces the mass density of the mixture in cylinder;
• Combustion angular position is determined by spark timing;
• Combustion process by flame propagation;
• Adequate fuels should have high volatility and resistance to auto-ignition to avoid “knock”, under high compression ratios.
### PROPERTIES OF ETHANOL X GASOLINE

<table>
<thead>
<tr>
<th>Property</th>
<th>Gasoline</th>
<th>Ethanol</th>
<th>E10</th>
<th>E85</th>
<th>E100 hydrous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Heat Value LHV (MJ/kg)</td>
<td>42-44</td>
<td>27</td>
<td>41</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>Mass Density (kg/dm³)</td>
<td>0.72-0.77</td>
<td>0.79</td>
<td>0.75</td>
<td>0.78</td>
<td>0.81</td>
</tr>
<tr>
<td>Heat of Vaporization h_{lv} (kJ/kg)</td>
<td>310</td>
<td>885</td>
<td>366</td>
<td>836</td>
<td>970</td>
</tr>
<tr>
<td>1000·h_{lv}/LHV</td>
<td>7</td>
<td>33</td>
<td>9</td>
<td>27</td>
<td>39</td>
</tr>
<tr>
<td>Air/Fuel Stoichiometric Ratio</td>
<td>14.7</td>
<td>9.0</td>
<td>14.1</td>
<td>9.8</td>
<td>8.4</td>
</tr>
<tr>
<td>LHV/CO₂ Exhaust Emission (MJ/kg)</td>
<td>13.5</td>
<td>14.1</td>
<td>13.6</td>
<td>14.0</td>
<td>14.1</td>
</tr>
<tr>
<td>Cooling Potential of Intake Air (°C)</td>
<td>19</td>
<td>81</td>
<td>23</td>
<td>71</td>
<td>93</td>
</tr>
<tr>
<td>Laminar Flame Velocity @ 1 bar, 20°C (m/s)</td>
<td>0.33</td>
<td>0.41</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Research Octane Number RON</td>
<td>86-98</td>
<td>110</td>
<td>+7- +3 a</td>
<td>105-109</td>
<td>111</td>
</tr>
<tr>
<td>Reid Vapor Pressure @ 37.8°C (bar)</td>
<td>~ 0.6</td>
<td>0.16</td>
<td>~ 0.7</td>
<td>~ 0.4</td>
<td>~ 0.15</td>
</tr>
</tbody>
</table>

a – Incremental values of research octane number over clear gasoline for splash blending

VOLATILITY – ETHANOL X GASOLINE

Difficult cold-start and cold-drivability, but less tendency of lub-oil contamination with warm engine
KNOCK RESISTANCE – ETHANOL X GASOLINE

Allows use of higher compression ratios (higher thermal efficiency), but is very sensitive to hot surfaces

Adapted from Taylor C.F. “The Internal-Combustion Engine in Theory and Practice”
Compromise between Performance and Fuel Efficiency

- F.E.Number = $\eta_{tot}/\mu_{mov}$ ~ thermo-mechanical total efficiency/moving resistance factor (tonne · km/MJ)
- Performance Index ($m/s^2$) · (m/s) ~ capacity to accelerate at a given velocity (kW/tonne)

Average improvement of 1.6% per year, each

RELATIVE ENERGY CONSUMPTION BY BRAZILIAN CARS

- 1979 – Total emphasis on fuel economy (Rc 7.5 → 11:1, full-load lean mixture, intake air heating, poor drivability)
- 1985 – Torque gain → engine down-speeding (Rc 8.5 → 12:1, materials compatibility, lean mixture, performance)
- 1997 – 3 way-catalyst (λ = 1, Rc 10 → 13:1, torque gain → performance bonus)

EXHAUST EMISSIONS OF GASOHOL & ETHANOL AUTOS

Average data on new sold cars after Cetesb (Report of Air Quality in State of Sao Paulo (in Portuguese) – 2007

• After the advent of 3 way-catalyst, ethanol lost lean-burn advantage (need of EGR)
• Cold phase of cycle dominates total emissions (R,D&I)
• Unburned ethanol is important for VOC emissions (ozone forming potential)
EVOLUTION OF FLEX FUEL TECHNOLOGY IN BRAZIL

<table>
<thead>
<tr>
<th>Generation</th>
<th>Market entry</th>
<th>Engine compression ratio</th>
<th>Power gain with ethanol</th>
<th>Torque gain with ethanol</th>
<th>Mileage loss with ethanol</th>
<th>Cold start with gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2003</td>
<td>10.1 – 10.8</td>
<td>2.1%</td>
<td>2.1%</td>
<td>25% - 35%</td>
<td>Yes</td>
</tr>
<tr>
<td>2nd</td>
<td>2006</td>
<td>10.8 – 13.0</td>
<td>4.4%</td>
<td>3.2%</td>
<td>25% - 35%</td>
<td>Yes</td>
</tr>
<tr>
<td>3rd</td>
<td>2008</td>
<td>11.0 – 13.0</td>
<td>5.6%</td>
<td>9.3%</td>
<td>25% - 30%</td>
<td>Yes</td>
</tr>
<tr>
<td>4th</td>
<td>2009</td>
<td>11.0 – 13.0</td>
<td>5.6%</td>
<td>9.3%</td>
<td>25% - 30%</td>
<td>No</td>
</tr>
</tbody>
</table>


- Cold start and heating with gasoline injection (small gasoline tank)
- 4th generation with heated injectors or fuel gallery (no gasoline tank)
ENERGY EFFICIENCY WITH ETHANOL IS POOR
At least on FTP combined cycle

Flex Fuel Consumption - combined cycle
(237 model-year submitted since 2009)

Average ethanol energy consumption 2.5% larger
• Branco, G.M., Nigro, F. et al “Emission control of organic compounds based on their ozone forming potential” (in Portuguese) XXI SIMEA – São Paulo – August 2013

TECHNOLOGICAL CHALLENGES

Increased Component Strength

A more recent version NA with compression ratio of ~13:1
Gasoline: 70 bar @ 20° ATDCF
Ethanol: 90 bar @ 12° ATDCF

Downsized turbocharged with compression ratio of 9.4:1
Gasoline: 85 bar
Ethanol: 130 bar

Maximum PCP
Gasoline: 51.5 bar @ 18° ATDCF
Ethanol: 70.2 bar @ 12° ATDCF

Neil Fraser – Simpósio SAE Brasil  Powertrain  ago/2009
FUTURE STEPS IN THE DEVELOPMENT OF FLEXIBLE-FUEL ENGINES

- Cost-effective solutions for cold-start and heating of ethanol
- Electronically (flexibly) controlled valve timing
- Variable compression ratio engines
- Engine downsizing and turbo-charging
- Direct injection of fuel in the combustion chamber (homogeneous and stratified charge)
- Hybrid-electric systems with special-cycle engines
TECHNOLOGICAL OPPORTUNITIES

Dilution Tolerance (2000rpm/4bar BMEP)

- MBT spark timing at every data point
- Fuel injection settings optimised for each fuel

EGR could imply in 2 – 3% efficiency advantage for ethanol

Tomanik, E “Ethanol as future fuel for optimized combustion engines” – BBEST, August 2011
Increased Number of Gears

MPI-NA AT 4

MPI-NA AT 9

Energy consumed (WLTC)

BSFC < 240 g/kWh

Explore larger torque and power with ethanol to down-speed engine and reduce fuel consumption (flexible gear change)


Fuel efficiency benefits of 5 to 20% on E85 operation
OPPORTUNITIES FOR ETHANOL USE ON FFVs

Variable Compression Ratio

Fuel efficiency benefits of 4 – 5% on E100 over E22

http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vcr.html
TECHNOLOGICAL OPPORTUNITIES

Downsizing and Turbo-charging (>25% of SI in 2020)

OPPORTUNITIES FOR ETHANOL USE ON FFVs

- Downsizing and Turbo-charging [>25% of SI engines in 2020 (IHS)]
- Advantage of Ethanol: Increasing Performance and Fuel Efficiency

OPPORTUNITIES FOR ETHANOL USE ON FFVs

- Ethanol Direct Injection with downsizing and turbo-charging (combustion pressure - 140 bar; injection pressure 250 bar)
- Increase of 17% and 22% in torque and power respectively
- CVT and same performance, 10 – 12% of energy economy on E85

Yilmaz, H. et al “Optimally Controlled Flexible Fuel Powertrain System” - Completion Report – Bosch, November 2010
With Downsizing & Turbo-charging, full load enrichment is necessary to control exhaust temperature. Fuel energy economy with E85 can reach 15-20% over regular gasoline.
When vehicle demands is out of engine efficiency island, load is increased for recharging or engine is turned-off. Atkinson or Miller cycles could be applied to complement ethanol fuel efficiency.
CONCLUSIONS

- It is necessary to use ethanol Total Octane Number and “pure substance” properties to get practical fuel efficiency advantage in FFVs or neat ethanol vehicles.

- Once fuel economy is becoming mandatory in global markets and DI engines are forecasted to represent more than 50% of SI powertrains in 2020, half of them turbocharged, ethanol has an excellent opportunity to regain its fuel energy efficiency (10 - 15%) over gasoline, exploring transmission ratios.

- Due to extreme peak combustion pressures possible to be used with ethanol without knocking (140 bar versus 90 for gasoline in DI engines) the demand for materials strength on future engines will drop on ethanol.

- If Brazil intends to make future good use of ethanol and to play some significant role in the automotive sector, the time is now.
THANK YOU FOR YOUR ATTENTION

fnigro@sp.gov.br