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FLEXIBLE FUEL OR FLEXIBLE FUEL VEHICLE?

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FLEXIBLE FUEL OR FLEXIBLE FUEL VEHICLE ?

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ABSTRACT

Since 1990 the consumption of the methanol-ethanol-gasoline blend (MEG) in the State of São Paulo, Brazil, amounted more than seven billion liters. This blend, which was introduced into the market to overcome the ethanol shortage, showed excellent results as an ethanol substitute for the alcohol fueled vehicles. Its similarity with ethanol in terms of vehicle performance, emissions and fuel economy gives to this blend the status of a viable alternative whenever the use of straigth ethanol is not possible.
Based on the experience of the extensive use of the MEG blend, this paper discusses a new concept for an alternative fuel policy, the flexible fuel specifications, and analyses its characteristics in relation to the concept of the flexible fuel vehicle.

1 . INTRODUCTION

The possibilities of ethanol use as an automotive fuel have been known for more than a century. However, the discovery of large oil fields and the plenty availability of petroleum-based fuels, at low prices until the seventies, have not encouraged the use of other energy sources. Therefore, interest in ethanol use decreased substantially. After the first oil shock, strategic issues such as energy independence, political stability of the oil producing countries and oil price rise resulted in a renewed interest in alternative energy sources. As society has been gradually becoming environmentally-minded, question regarding the future of oil reserves, the environmental degradation and the role of energy as a source of wealth and well-being, gained a new dimension. The problems related to the greenhouse effect, to the stratospheric ozone layer depletion and to acid rain started to be widely debated and the need for clean and renewable energy has been recognised and considered of paramount importance.
Today, civilization faces a dilemma: if current fossil energy use growing trends are kept, the resulting environmental degradation could make life on Earth mean and uncertain.
As it is well known, nearly half of the current global oil demand is used to provide energy for the present 600 million vehicles world fleet. As a result of the present transport patterns, vehicle/fossil liquid fuel characteristics and fleet size, environment specialists admit that motor vehicles use generates more air pollution than any other human activity and, for that reason, contributes significantly to climate change (1). Considering that by the year 2.010, approximately, 1.1 billion vehicles will be around, it is estimated that carbon dioxide (CO_2) emissions will rise 65% over the 1990 level, due to the increased use of oil-derived liquid fuels(2).
Against the perspective of continuous dependence on fossil fuels, many countries have been carrying out research activities and pilot programs involving a number of clean alternative energy sources for motor vehicles such as ethanol, methanol, natural gas, vegetable oils, hydrogen, electricity and solar energy. The motor industry has also participated in this effort and developed commercially available vehicles for ethanol, methanol and natural gas. Furthermore, advances in the flexible fuel vehicle technology are also being made in order to make possible the use of a wide range of gasoline and oxygenated blends (alcohols and ethers).
In Brazil, which has the largest renewable alternative fuel program in the world, based on the extensive use of sugar cane ethanol, either as a neat fuel or as a blending component of gasoline, significant technological and conceptual developments have been made in the last years.
With regard to the automotive use of ethanol, brazilian vehicle manufacturers have put for sale state-of-the-art alcohol and gasohol vehicles, which are equiped with single or multipoint electronic fuel injection, mapped electronic ignition and three way catalytic converters. In addition, one manufacturer (General Motors) launched, recently, a dual-fuel version, ethanol-natural gas, for two of its regular models.
In 1990, with the introduction in the fuel market of the methanol-ethanol-gasoline blend (MEG), to overcome an episodic ethanol shortage(3), a new concept of fuel policy was put into effect: the FLEXIBLE FUEL SPECIFICATIONS.

This concept, which made possible the indistinct use of both neat ethanol and MEG blends, with highly similar vehicle performance, fuel consumption and emission results, is the focus of this paper. The authors believe that other countries or regions which do not have the conditions to have an alcohol program like Brazil, may take advantage of the concept in order to develop, within their limits, clean and alternative fuel formulations.

2.THEORETICAL BACKGROUND FOR OXIGENATES USE

For the correct engine operation and emission control, one of the most important fuel specifications is the stoichiometric air/fuel ratio - A/F_s, i.e. the ratio of air and fuel mass units necessary for complete combustion.

Small deviations in this parameter produce major variations on CO and HC emissions, as well as on NO_x emissions, which can also be affected.

Since A/F_s ratios of hydrocarbons are very similar, variations in their blend compositions do not alter the final fuel A/F_s ratio, significantly. However, alcohols and organic oxygenates have very different values of A/F_s ratio, when compared to each other or even to hydrocarbons. For instance, the stoichiometric air/fuel ratios for methanol, ethanol and gasoline are 6.4, 9.0 and 14.7, respectively. Thus, alcohols addition to gasoline reduces significantly engine air requirements and explains the CO reduction promoted by oxygenates addition to gasoline.

The equivalent ratio "A/F_r" (or relative air/fuel ratio) of an actual combustion process is defined according to the following formula:

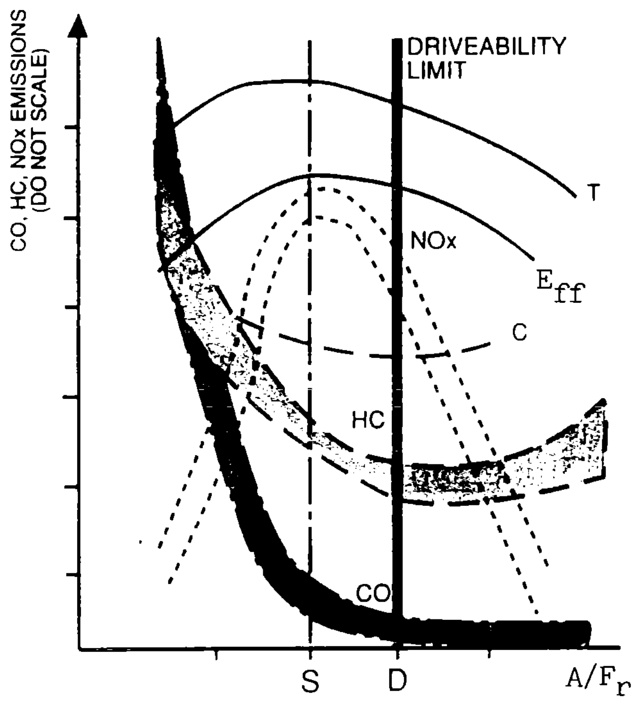
$$A/F_r = (A/F)_{actual} \div (A/F)_{stoich}$$

which corresponds to air in excess when $A/F_r > 1$ (lean combustion), or fuel in excess when $A/F_r < 1$ (rich combustion).

In fact, the engine behaviour, as shown in Figure 1, independs on the fuel type, but shows similar results when running with air-fuel mixtures of the same A/F_r, even with different fuels. The absolute values of the indicated parameters vary according to other variables (e.g. mixture mass flow and engine rpm), which define the different operating conditions.

As a result, the engine designer sets the engine specifications, looking for the best compromise of the various parameters, giving priority to one or other parameter depending on the desired engine operating characteristics. Thus, for the maximum available torque (wide open throttle) the mixture shall be prepared at A/F_r=0.97; for cruise situations (intermediate throttle positions), must be around 1.1 to assure the best fuel economy and, when a particular pollutant emission becomes critical, other values might be specified to solve this problem, at the expense of other parameters.

According to this analysis, the major alcohol advantage is its tolerance to burn leaner mixtures, under stable flames up to A/F_r = 1.35, whereas the limit for gasoline stands around 1.10. This characteristic, which corresponds to the vehicle driveability limit, allows the use of leaner mixtures and, therefore, results in important emission reductions for both alcohol and gasohol engines.



T = Torque
c = Specific Fuel Consumption
CO = Carbon monoxide
HC = Hydrocarbons
NOx= Nitrogen oxides
D = Driveability Limit
S = Stoichiometric mixture
Eff= Thermal efficiency

Fig. 1 - Air/Fuel Ratio Effects

3. THE CONCEPT OF OXIGENATES USE IN GASOLINE

The addition of oxygenates to gasoline is usually desired to reduce CO emission of in-use vehicles, without any engine modification.

Therefore, maintaining the engine air/fuel calibration corresponds to an increase of the

A/F on all engine operating conditions. This is possible due to the enhancement of the air excess tolerance limit, also originated by the alcohols, in proportion to their addition to gasoline.

In this case, Figure 1 could have its horizontal axis scale changed to percentage of alcohol addition, where point "S" would correspond to the nominal percentage considered in the original engine design.

Qualitatively, the influence on the actual air/fuel ratio (or even on A/F_r) depends on the additive being used or, more specifically, on its own stoichiometric air/fuel ratio. In this case, alcohols stand out compared to ethers, because their fuel oxigenation capabilities are higher.

Other fuel characteristics can limit the use of oxygenates, such as miscibility and phase separation when water is present. In terms of water tolerance, anhydrous ethanol is highly indicated as an additive, including as a methanol co-solvent.

It is also important to consider the gasoline vapor pressure increase due to the oxygenate addition, which can limit its percentage, depending on gasoline characteristics.

Experimental work shows that the maximum effects of oxygenates on blends vapor pressure occur at around 5% to 10% of oxygenate addition(4).

It should also be recognized that oxygenates, depending on their characteristics and proportion added, have the potential to reduce exhaust HC, particulates and sulfur compounds of in use vehicles and contribute to reduce emission control of new vehicles beyond legal requirements, as occurs in Brazil. With regard to aldehyde emissions, that increase with the presence of oxygenates, they can be properly controled by current emission control technology.

Another well known characteristic of oxygenates is their octane boosting capability.

Based on the number of advantages brought by the use of oxygenates, it can be inferred that their use should be stimulated as far as possible and preference should be given to those originated from renewable sources, as is the case of ethanol.

4. THE FLEXIBLE FUEL VEHICLE CONCEPT

This concept presumes that variable composition of fuels can be managed by the vehicle itself, and this makes possible the distribution and use of different fuel types.

To fuel a vehicle with methanol or ethanol (or even their blends, with 15% gasoline addition to improve driveability), different calibrations, compression ratios, intake ducts, etc, are required for each case.

Considering vehicle mobility and the difficulties to have each alternative fuel available all over a wide region, engine designers are looking for the development of an engine, capable to run with a variety of alternative fuels and any of their blends, in order to give to the vehicle the capability of being refueled with different fuels.

In this case, some important fuel parameters are highly variable, such as A/F_S, knocking resistance, heat of evaporation and flame speed, which lead to large variations on engine requirements for the optmization of A/F_r, compression ratio, intake manifold, fuel system and combustion chamber geometry, among other engine calibration characteristics.

Many prototypes are being developed by the motor industry, however, all of them have shown increased technology complexity. It is worth to comment some important points:

a) Fuel type identification: Many sensors are being studied, based on the optical refractive index, or dielectric and conductivity constants, or other physical parameter measurements. However, fuel oxidation, water contamination and other common field problems cause interferences in the measurement process and reduce sensors reliability. Thus, time and investments are still necessary for proper sensor development.

b) Air fuel ratio: The A/F_S variation from 6.4 for methanol up to 15:1 for gasoline became possible through the closed loop electronic injection systems application, but further development is needed to improve fuel nozzles performance in a wider flow range. Roughly, the A/F_r control also leads to power output control, since the energy content of a stoichiometric air-fuel mixture is around 3700 kJ/m^3 both for alcohols and hydrocarbons. However, different flame speeds, air excess tolerances and pre-ignition tendencies determine distinct A/F_r and spark advance requirements for engine optmization, for each kind of fuel and their blends. Additionaly, such requirements have non-linear relations with fuel blends(5). Such compensations are theoretically possible, but at least complex.

c) Compression ratio: Alcohols knocking resistance is the key factor to compensate the alcohols lower energy content on a mass basis, and make them viable when compared to gasoline. This leads to the use of compression ratios around 12:1 or more in optmized alcohol engines. However, in this case the spark timing map needs to be highly retarded (very far from the optmized advance) if such an engine runs with gasoline, which currently limitates the compression ratio of flexible fuel engines and its efficiency.

d) Heat transfer: The higher latent heat of evaporation of alcohols and combustion efficiency strongly influence heat rejection (cooling system size) and also the knocking limit and volumetric efficiency, through the air fuel charge temperature. Also, the spark plugs thermal range is affected by fuel changes, since fouling occurs whit gasoline at low speeds and pre-ignition occurs with methanol at high loads(5,6).

Overall engine or vehicle optimization must consider all these items and many others.

Technology development can already solve most of the problems involved and certainly will be viable in the future, at least for special and more expensive applications.

However some years and high investments are still necessary to transform the present multi-fuel capability to a fully optmized flexible fuel vehicle.

5. FLEXIBLE FUELS CONCEPT

This third concept is based on the implementation of a new fuel pump at the filling stations for the "alternative clean fuel", like occurs in Brazil with ethanol distribution. Its implementation requires just one type of engine to burn a standard alternative fuel and blends with equivalent specification as a second option, as it is the common practice for gasolines (aromatic, paraffinic, etc.) Based on the earlier analysis it is clear that the most important fuel characteristic is how the engine "senses" and "responds" to it. Looking at gasoline and diesel fuels, one can see that average parameters define engine behaviour rather than the characteristics of each chemical compound itself.

Therefore, considering an alternative fuels strategy, the clean fuels matrix should be established and a standard fuel (for blend) defined within the range of the matrix. The engines shall be developed for the standard fuel and commercially available fuels should closely match the overall standard fuel characteristics.

As mentioned earlier, this concept was adopted in 1990, when the MEG blend (33% methanol, 60% ethanol and 7% gasoline) became commercially available as an alternative fuel for the neat ethanol engines.

This blend formulation was developed to allow its operation on the hydrated ethanol engines, without any tunning or modification, and mantaining the same performance, fuel economy and emission levels(7). In addition, engine cold start was improved with MEG use, due to its higher volatility.

Also, it was not observed the presence of significant non regulated pollutants, like methanol and formaldehyde, both possible to occur according to theoretical predictions. Furthermore, MEG can be added to ethanol in any percentage, in case of alternated fuelling with either fuel.

About 7 billion liters of MEG have been used in the SÃo Paulo Metropolitan Area, since March 1990, without evidence of environmental, occupational and vehicle problems. It should be noted that the presence of gasoline denaturates the blend and therefore avoids accidental ingestion(3).

This use confirms and reinforces ethanol's role as an alternative fuel, because its specific heating value and stoichiometric air/fuel ratio are in between their correspondents of methanol and gasoline. These characteristics allow its substitution up to 40% (as is the MEG blend case) in order to balance production and demand differences (3). Therefore, one can see the advantages of an alternative fuel estrategy where the fuel specification is centered on the ethanol physical properties for the alcohol vehicle fleet, and methanol appears as the alcohol production/demand regulator.

The flexible fuel formulation, with proportions in between the hydrated ethanol and MEG, is the fundamental key of this concept. In Figure 2, the polygon "ABGOD" represents the various fuel alternative formulations for the "ethanol engine". The constancy of exhaust emission is kept provided the proper blending conditions are available to guarantee the same A/F_r, along with the line OA in Figure 2.

It is worth of note that current methanol prices are lower than those of ethanol, and this can improve the economic feasibility of the fuel. Also, this use of methanol may help to boost the use of natural gas resources, reducing its transportation and distribution costs (8).

In the brazilian case, this experience resulted from an emergency problem. However, it demonstrated a feasible, simple, reliable and less expensive alternative for alcohol use, which provides immediate application with current technologies and allows for some differences in fuel specifications for summer and winter. Furthermore, it makes possible the use of many compositions complying to the same basic fuel specification, required by only one type of "alternative engine", optmized for the standard fuel.

The adoption of this concept can make possible the use of alcohols in regions where, apparently, their use seems unlikely. Certainly a case-by-case feasibility evaluation has to be carried out but, as the brazilian experience has shown, it is possible to mantain a clean fuels matrix while, at the same time, switching fuels and, keeping air pollution under control.

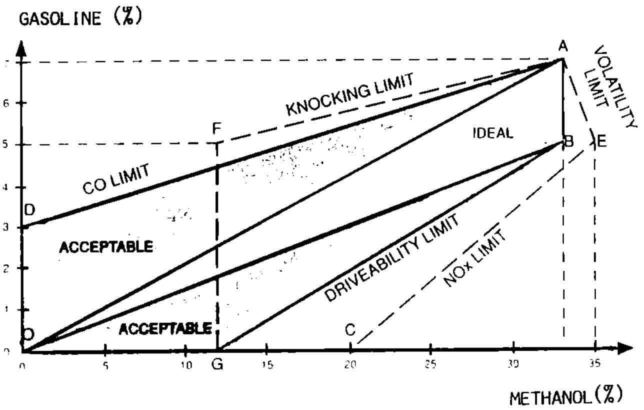


Figure 2 - Acceptable Tolerances for the MEG Ternary Blend (Ref.7)

6. NATURAL GAS DUAL FUEL ENGINES

The use of Compressed Natural Gas - CNG in non dedicated Otto engines requires a special conversion to make possible the best use of the fuel characteristics.

As it is known, the engine fuel economy and output power are very negatively affectted when the compression ratio is not increased within the range of 12:1 to 14:1.

Also in this case the ethanol engine characteristics are much closer to the CNG requirements than those of the gasoline engine.

The only brazilian CNG converted vehicles which comply with present federal emission standards are the GM cars equipped with ethanol EFI 1.8 and 2.0 liters engines, converted to the use of CNG through the application of a Koltec electronic gas injection system connected to the former control unit of the vehicle. The fuel consumption and driveability results are very good and the application of a three way catalist, for further emission improvements, is under development, since the original design doesn't include it yet.

7. CONCLUSIONS

Considering the increasing growth of vehicle fleets and the present engine state-of-the-art, it is safe to conclude:

a) The use of clean fuels is considered necessary to control environment degradation, especially in the metropolitan areas;

b) The use of renewable fuels is required both as a fossil fuels complement and to substitute them at the feasible extent, to refrein the green-house effect;

c) Gasoline-Oxygenates blends help to reduce vehicle emissions and should be required in the metropolitan areas;

d) Engines designed for ethanol are also adequate to run with "MEG blends" and should be considered for CNG/alcohol dual fuel operation;

e) Ethanol appears to have all necessary requirements to become the basis of a "FLEXIBLE FUEL" strategy and makes possible regional and seasonal fuel specifications;

f) Current engine technologies can easily comply with the strictest world exhaust emission regulations without any further requirements for ethanol and MEG use;

g) Methanol, ethanol and gasoline blends can play an important role to reduce fuel prices and stabilize fuel production/demand oscillations;

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