Substitution of Petroleum Based Fuels by Biomass Fuels in Engines and Furnaces in Brazil

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1. Introduction

The energy crisis occured in 1973 affected the brazilian economy and demanded the substitution of fuels derived from petroleum by alternative fuels because at that time about 80% of the petroleum was imported.

Considering the extent of the brazilian territory, a good product for the intended substitution is obviously the biomass fuel.

Some alternatives were considered at that time: substitution of gasoline by ethyl alcohol, diesel oil by ethanol and vegetable oils, and fuel oil by ethanol or coal. In 1975 the brazilian government established a National Alcohol Program to produce ethanol for energetic purpose.

Whereas the substitution of gasoline by ethanol in Otto cycle engines was very successful, there were serious problems in the tentative of substitution of diesel oil by ethanol or vegetable oil in Diesel cycle engines and also in the substitution of fuel oil by ethanol in existing boilers and ordinary furnaces.

2. Fuel substitution in Otto cycle engines

Brazil is essentially a tropical country. Many agricultural products can be used to produce ethanol: sugar cane, manioc, sorghum, corn, wood, etc. At present, the ethanol is made from sugar cane.

For the production of 1 liter of ethanol, it is produced also about 12 liters of vinasse which is a residual liquid with a pH of 3.5. How to dispose this vinasse is a serious problem. One form to use this residual liquid is as a fertilizer.

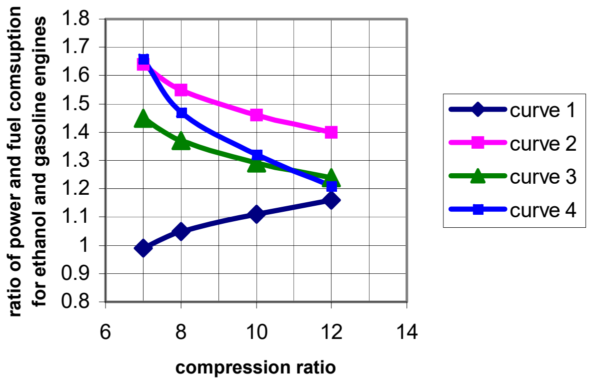

Fig. 1 Comparison of power and fuel consumption between ethanol and gasoline engines

The ethanol presents a smaller heating value when compared with gasoline. The lower heating value of ethanol is 26790 kJ/kg, which is only 60% of the value of gasoline. So, it is expected that the comsuption of ethanol shall be higher than gasoline. But the octane number of ethanol is higher than gasoline; then, it is possible to use higher compression ratio in ethanol engines, up to 12, without knocking problems. In this manner, the efficiency of alcohol engines is higher than ordinary gasoline engines.

From the data of reference [1], Figure 1 can be drawn. This Figure shows curves representing a comparison between Otto cycle alcohol engine and gasoline engine. The gasoline engine taken as reference has a compression ratio of 7 and same piston displacement as the alcohol engines. These curves are theoretical, following the model of Taylor [2] and the abscissa is the ethanol engine compression ratio. The curve 1 represents the ratio between the power of

Fig. 2 Photo of service station fuel nozzles for gasoline and alcohol, showing a densimeter, above the alcohol nozzle at right side, to guarantee the alcohol purity.

ethanol engines and the power of the gasoline engine; the curve 2 represents the ratio between the mass specific fuel comsuption of ethanol engines and the specific fuel comsuption of the gasoline engine; the curve 3 represents the ratio of volumetric specific fuel comsuption of ethanol engines and the correspondent comsuption of gasoline engine; the curve 4 represents the ratio of mass specific fuel comsuption of both engines for same power delivered.

Thus, using higher compression ratio, ethanol engines can have an increase of power of about 10% when compared with correspondent gasoline engine with same piston displacement. On the other hand, the fuel comsuption of ethanol engines can reach a figure of more 25%, in volume, when compared with gasoline engine. However, considering that the ethanol can be utilized in lean mixtures, as usually is done, a reduction in the increase of fuel comsuption can be obtained, but with a sacrifice of power increase in alcohol engines.

The ethanol has a high octane value; so, the alcohol engines do not need additives to the fuel for knocking supression. Additionally, considering also the alcohol combustion characteristics, these engines pollute less than gasoline engines. The production of carbon monoxide by ethanol engines is negligible when compares with gasoline engines.

In the 1980 decade the ethanol fuelled automobiles reached a peak of around 95% of the cars manufactured in Brazil (Fig. 2). But this figure decreased to about 5% in the 1990 decade due to problems related to alcohol availability, mainly because there was a competition with sugar, which is produced from the same sugar cane, with a price that was favourable in international market.

3. Fuel substitution in Diesel cycle engines.

There was also a brazilian tentative to substitute the diesel oil by ethanol in Diesel cycle engines.

But unfortunately this idea was proved to be unsuccessful. Considering the problem of ignition of the fuel-air mixture at the conditions existing in the engine cylinder, the cetane number of ethanol was increased adding some additives. However the researches involving this matter did not solve satisfactorily this problem.

Since the compression ratio in Diesel cycle engines is already high, the substitution of diesel oil by ethanol does not have the same effect obtained in Otto cycle engines concerning the increase of thermal efficiency of the cycle by raising the compression ratio.

Therefore, considering the small heating value of ethanol when compared with diesel oil and the above mentioned problem of ignition of the ethanol-air mixture in the cylinder, the tentative of substitution of diesel oil by ethanol in existing Diesel cycle engines was not successful.

4. Fuel substitution in steam generators and furnaces

At the time of the 1973 petroleum crisis, the steam generators and heating furnaces in the brazilian industry were using petroleum derived fuel oil.

For a given steam generator, or a heating furnace, designed and manufactured to use fuel oil, the tentative of substitution of this oil by ethanol also failed.

In the case of steam generators, for example, the mass flow rate of ethanol burned must be higher than the mass flow rate of oil because the heating value of ethanol is much lower than the value of the fuel oil, for the production of same heat generated in the boiler furnace.

For this condition, that is, for same heat generation in the furnace of the boiler, the comsuption of ethanol shall related to the ratio of the heating value of both fuels that is, in this case, 1.64 times the comsuption of fuel oil.

However, for the stoichiometric reaction, the air-fuel ratio in the case of ethanol is approximately 9 kg of air for each kg of ethanol and for the case of fuel oil (as bunker-C type) the ratio is around 14.5. Considering these figures, even burning 1.6 times, in weight, more ethanol, the mass flow rate of flue gas produced in both cases, differs less than about 7% for same value of heat generated in the furnace.

Thus, it seems that the fuel substitution does not change the heat transfered by convection to the fluid in the boiler.

But there is a great effect in the value of radiation heat transfer between the flame and the evaporation tubes of the boiler because the flame formed in the combustion process of ethanol, at the condition existing in the furnace, is a nonluminous bluish flame presenting a very low emissivity. This flame is well different from the yellowish luminous flame with high emissivity observed in the case of combustion of fuel oil. Thus, while in the case of combustion of fuel oil, the boiler section of the steam generator receives more radiative heat transfer from the flame than convective heat transfer for the vaporization process, in the case of combustion of ethanol the radiant heat transfer becomes very small.

Consequently the mass flow rate of saturated steam produced in the boiler decreases when it is used ethanol in substitution of fuel oil in existing boilers, for same heat generated by combustion in the furnace of the boiler.

When compared with the case of fuel oil, the ethanol flue gas then leaves the boiler section at higher temperature because it rejected less heat to the boiler tubes and reaches the superheater where the saturated steam entering this section has a smaller mass flow rate than before. The result is a significant increase of the temperature of the superheated steam leaving the superheater, when compared with oil fired boiler case, and introduces a serious problem in the superheated steam temperature control.

Summarizing, the overall effect that can be observed when it is used ethanol in substitution of fuel oil in existing steam generators, for same heat generated in the boiler furnace, is:

a- smaller mass flow rate of steam produced;

b- higher temperature of the superheated steam in the outlet of steam generator, not compatible with the requirement of the steam conditions in the inlet of steam turbines or in other thermal equipments.

Thus, the tentative of substitution of fuel oil by ethanol, in existing steam generators designed originally to use fuel oil, was not also well succeeded at that moment

5. Present situation regarding substitution by biomass fuel in engines and conclusion

Recently it was unveiled a new brazilian government plan to produce the so called biodiesel, following the examples of Germany and USA. According to this plan, it is programmed to use, as later as 2008, at least 2% in volume of biodiesel mixed with diesel oil for Diesel cycle engines. Four years later, the plan will impose a mixture of at least 5% biodiesel.

The biodiesel shall be made through a reaction of transesterification between ethanol and a vegetable oil using a catalyzer. Many vegetable oil can be produced in Brazil to obtain the biodiesel, as for example: palm oil, castor oil, soy bean oil, peanut oil, sun flower oil.

To fulfill the 2% target, it is needed to produce 800.10^3 m^3 per year of biodiesel. At present, the biodiesel is produced in a batch process but there are researches aiming to produce in a continuous process. At this moment, the production cost of biodiesel is up to 30% higher than the cost of diesel oil.

The use of biodiesel in Brazil has the objective of:

a- reduction of production of air pollutants;

b- reduction of the dependence of imported petroleum;
c- stimulate the production growth of vegetable for energetic use in different regions of the country. Concerning Otto cycle engines, recently manufactured automobiles are designed to use:
a- gashol: a mixture of gasoline and 25% in volume of anhydrous ethanol;
b- only hydrated ethanol;
c- compressed natural gas;
d- a mixture of different fuels.
In this last case **d**, the automobile is equipped with a Otto cycle multi-fuel, also called flex-fuel, engine which uses a mixed fuel in any proportion of gasoline and ethanol. At present, more than 50% of the automobiles manufactured in Brazil is equipped with this type of engine. The fuel tank of these automobiles is filled, in any proportion, with ethanol and gasoline.

Basically, a lambda sensor measures the oxygen content in exhaust gas and a electrical signal is delivered to the control system of the engine to adapt automatically to the conditions needed for the fuel mixture entering the cylinder.

Illustrativelly, according to actual tests, a car equipped with a multi-fuel engine that can use ethanol, gashol, or any mixture of these two fuels, attain, when it uses only ethanol,a power 5% higher and a comsuption of about 40% higher for same distance driven, compared with the same engine using only gashol.

Some multi-fuel engines can use other different fuels. Besides ethanol and gasoline, the tank can be filled with naphtha; and the same car can have a compressed natural gas tank. But for using the CNG the driver must activate a switch in the car panel.

Concluding, it can be observed that a effort is being taken in this country to substitute petroleum derived fuels by biomass fuel. The multi-fuel engine, mentioned above, offers a flexibility toward the use of different type of fuels in the same car. The driver can fill the fuel tank with any choice, and in any proportion, of fuels, according to the price (at present the price of ethanol is about half the price of gasoline) or the availability of the fuel at that moment.This is particularly a good alternative for a country as Brazil which is in a process of economic development and is preoccupied with ambient pollution and energy availability.

References

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Eitaro YAMANE completed his undergraduate course (1961) and received the doctorate degree (1970) in mechanical engineering, both at the Faculty of Engineering of University of Sao Paulo, Brazil. He was recipient of Mombusho Scholarship to study and engage in research at University of Tokyo. He is a Professor of Mechanical Engineering at University of Sao Paulo. His current interest includes energy alternatives and conversion".