GASOLINE "A" AND HYDRATED ETHANOL BLENDS: EXPERIMENTAL ANALYSIS ON THE VIABILILITY OF UTILIZATION IN A CYCLE OTTO ENGINE

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Abstract. This article presents the procedure and results of experimental tests performed with a cycle Otto Engine operating with different blends of gasoline A (Gas. A) and hydrated ethanol (AH). The measurements were made by using a chassis dynamometer and a vehicle projected for the use of gasoline C (75% gasoline A (Gas. A) and 25% anhydride ethanol (AA) in %v/v – volumes) as fuel. The vehicle's engine had a total displacement volume of 1800 cm^3 and maximum power of 115 HP. A comparison of the results obtained with the engine operating with the following blends is presented: (1) Gasoline C – (75% Gas. A + 25% AA); (2) Gasoline C25 – (75% Gas. A + 25% AH, 93^o INPM); (3) Gasoline C30 – (70% Gas. A + 30% AH, 93^o INPM); (4) Gasoline C35 – (65% Gas. A + 35% AH, 93^o INPM); e (5) Gasoline C40 – (60% Gas. A + 40% AH, 93^o INPM). The experimental results, obtained with the vehicle running through an established cycle, show the viability of the addition of hydrated ethanol (~ 93^o INPM) in gasoline A, alternatively to 25% of anhydride ethanol, used in Brazil at present.

Keywords: *gasoline and ethanol blends, hydrated ethanol, anhydride ethanol, Cycle Otto engines, chassis dynamometer*

1. Introduction

The low prices of crude oil until the 1970s made the world have a high consumption of this fuel. Galbraith, mentioned by Lima (1981), said this fact characterized the "abundant society". It is important to mention that the war tensions initiated in 1973 in the Middle East caused a total modification of this picture.

The world energy crisis caused negative impacts to all countries of the world. In the case of Brazil, a developing country, with a transportation system based on roads, thus dependent on oil, this crisis caused serious problems. At that time, the Country produced only about 20% of its oil consumption. Those facts caused a great disequilibrium of the Brazilian external payments balance.

It was necessary to change the energy profile of Brazil. The most important action in this sense was the start up of the National Program of Alcohol (PROÁLCOOL) at the end of the 1970s. The ethanol is a renewable energy source and can substitute partial or totally the gasoline used in Cycle Otto engines. This kind of engine is used in small and medium vehicles (cars for personal/family use) in Brazil.

Considering that the Country already had some ethanol production capacity installed, the then existing National Oil Council (CNP) specified the alcoholic content for the hydrated ethanol for use in vehicles run exclusively by this fuel: from 91.2° to 93.8° INPM (or 92.5±0.7º INPM). In other words, this fuel can be seen as a blend of anhydride ethanol (absolute – without any water) and water, with this second component varying between 6.2 and 8.8%, in mass base.

The main advantage in the utilization hydrated ethanol inferior to 94° INPM is that this alcohol can be produced by simple distillation. To obtain an alcohol with less water, an assisted distillation is necessary. This fact increases its production costs comparatively to an alcohol that contains more water. The limitation for the use of those blends containing more water as fuel is that solutions with more than 50% (of water) are not inflammable.

There are reports on the use of alcohol as fuel for engines in Germany and France in 1894 (Almeida, 1952). In Brazil, the engineers Ernesto Costa e Souza Mattos used alcohol containing 30 and 50% of water as fuel for engines in 1925 (Braga, 1983). At that time, the Country did not have installations capacitated to produce ethanol with less water. Experiments performed at PUC/Rio in the first years of the 1980s (Braga et al., 1983 and Braga, 1985) show that the maximum thermal efficiency of a Cycle Otto engine was obtained using a blend with 12% of water and 88% of anhydride alcohol, without any power decrease.

On the other hand, the same CNP at this same time also established the addition of anhydride ethanol to gasoline A used in the Country. With this procedure, it was possible to cancel the addition of tetraethyl lead (cancerous product) in the gasoline. At present, the level of addition of anhydride ethanol to gasoline A is 25% in volume. This blend (75% of gasoline A and 25% of anhydride alcohol) is named gasoline C.

The recent event – apparent success – of vehicles named flex-fuel (operate with any blend of gasoline C and hydrated alcohol - 92.5±0.7º INPM), mostly popular cars with small Cycle Otto engines (total displacement volume of 1000 cm^3), shows the chemical stability of these blends. Experimental tests performed at PUC/Rio, including 12 blends from 0.0% of hydrated ethanol and 100% of gasoline C to 100% of hydrated ethanol and 0.0% of gasoline C confirm this stability.

Considering the above, three questions can be made:

1- Why is hydrated ethanol (92.5±0.7º INPM) utilized in vehicles that are run exclusively with this fuel?
2- Why is anhydride ethanol utilized in gasoline A to obtain the gasoline C?
3- Would it be possible to use hydrated ethanol (92.5±0.7º INPM) added to gasoline A to obtain a "new gasoline C"?

The answer to the last question may be favorable to hydrated ethanol. In that case, the "new gasoline C" would have a low price and the excess of anhydride ethanol could be exported. It is important to mention that the anhydride ethanol has better prices in the international market than the hydrated alcohol.

This is the main focus of the present work. In other words, in this paper it is preliminary demonstrated that it is possible to operate a vehicle, projected to consume gasoline C, with a fuel containing up to 40% of hydrated alcohol and 60% of gasoline A.

For this purpose, the performance of a serial vehicle on a chassis dynamometer was observed, using different blends of gasoline A and hydrated alcohol (92.5±0.7º INPM). Its consumption and power did not change significantly for the different blends with the vehicle running through the same cycle (idle, accelerations – increasing or decreasing velocities, various levels of constant speed up to 113 km/h). The car was driven by a pilot-robot.

2. Experimental procedure

In this section the experimental procedures adopted in the work are presented. First, tests were performed to check the blend's (gasoline A and hydrated ethanol) stability in terms of homogeneity. Next, measurements obtained with the vehicle utilizing five different blends as fuel were made on the chassis dynamometer to demonstrate the possibility.

2.1. Stability tests of the blends

Initially, experiments were performed to verify the chemical stability of blends containing different volumes of gasoline C and hydrated alcohol (ethanol - 92.5±0.7º INPM). Gasoline C was bought at a reliable gas station in Rio de Janeiro city and alcohol in a pharmacy (ethanol sold in pharmacies has the same specification than the one for use as fuel). This gasoline was tested to determine its percentage of anhydride ethanol content, following the procedure established in the rule ABNT NBR 13992 (1997). Hydrated alcohol from the pharmacy had its water content measured according to specific rules (INPM, 1967). This basic procedure can guarantee that both fuels were in accordance to Brazilian specifications.

Eleven samples were prepared in 100ml Pyrex test tubes. The first contained only gasoline C; the second, 90% of gasoline C and 10% of hydrated alcohol, in volume base; the third, 80% and 20%, respectively and, from then on successively. In this form, the tenth blend was a combination of 10% of gasoline C and 90% of hydrated ethanol. Finally, the last was a sample of pure alcohol 92.5±0.7º INPM. These eleven test tubes were kept closed and in rest for several days. After one week, no phase (compound) separation was observed. This separation could have happened by the presence of water (contained by hydrated alcohol).

In this way, it is possible to affirm that any blend of Gasoline A (or even gasoline C) does not present compounds separation or, in other words, blends of gasoline (A or C) and hydrated alcohol are chemically stable. But, other experiments (not object of this article) showed that when the amount of water was increased in the blend (gasoline A, alcohol and water) water separation (deposit on test tubes bottom) was observed.

This is the first focus of the present work. It has been demonstrated that any blend (gasoline + ethanol 92.5±0.7º INPM) is stable. This is the first necessary condition for a possible operation of a vehicle, projected to consume gasoline C, with fuel containing up 40% of hydrated alcohol and 60% of gasoline A, for example.

2.2. Vehicle tests on chassis dynamometer

Before beginning tests with the vehicle on the chassis dynamometer, exactly 03 (three) liters of each blend were prepared, as shown in Tab. 1. It is important to mention that these blends contained water due to the presence of hydrated alcohol. For example, the blend C40 contained about 2% of water in volume base. There was also a sample of three liters of gasoline C, bought directly at a gas station. The same procedures adopted on the stability chemical tests (ABNT NBR 13992, 1997 and INPM, 1967) were followed in this phase of the present research in order to guarantee the quality of the fuels.

Table 1. Blends of gasoline A and hydrated alcohol (92.5±0.7º INPM).

Blend	Gasoline A (%v/v)	Hydrated alcohol (%v/v)
C25	75	25
C30	70	30
C35	65	35
C40	60	40

In order to follow the same procedure for all tests, first of all, the vehicle was left to run on the chassis dynamometer until its original fuel ended (the engine ran out of fuel). A similar procedure was adopted between each of the tests with different blends, as explained ahead.

In other words, after supplying the vehicle tank with a determined fuel (three liters), its engine was left operating at 1000rpm (idle condition) for three minutes. The intent of this procedure was "to clean" any small amount of the previous blend contained in the vehicle tank and its engine fuel injection system. By following this procedure, it is possible to guarantee that each test was made under only one fuel condition. After this preliminary phase, the test, with the vehicle positioned on the chassis dynamometer, running the established cycle was initiated, as shown in Fig. 1.

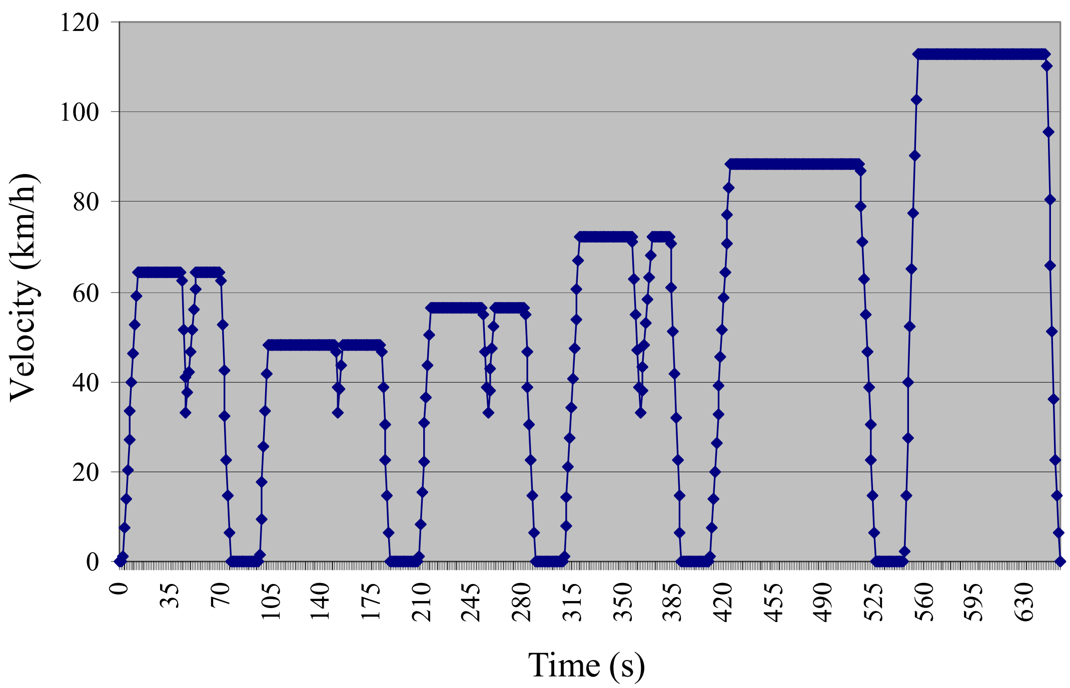

Figure 1. Established cycle for the vehicle test on chassis dynamometer

It is possible to observe that the cycle presents different conditions: idle (zero velocity at the beginning of the test (time equal to zero) and close to times 90, 200, 300, 400, 540 seconds, and at the end of the cycle). Ten periods with the vehicle running at constant speeds (from 49 up to 113 km/h) are also shown in Fig. 1. Between these periods of constant velocity, there are accelerations (10 positives and 9 negatives). Typically, with three liters of each blend, the vehicle performed three complete cycles (it just began the fourth cycle), before the tank became empty and, consequently, the engine stopped. The distance run by the vehicle in each cycle was very close to eleven kilometers (about 10.8 km). The time necessary for the car to complete one cycle was 655 seconds (10 minutes and 55 seconds). Table 2 presents more details of one cycle, giving the time and the vehicle velocity for each change in the gear box made by the pilot-robot.

Table 2. Gear box changes versus time and velocity (for one cycle)

GEAR	Time (s)	Velocity (km/h)	GEAR	Time (s)	Velocity (km/h)	GEAR	Time (s)	Velocity (km/h)
1	0	0.0	1	287	14.6	3	420	58.8
2	6	26.9	N	289	0.0	4	424	83.3
3	11	59.1	1	308	0.0	5	427	88.5
4	16	64.4	2	313	27.5	4	518	62.9
3	45	41.0	3	318	60.4	3	521	31.7
4	54	64.4	4	322	72.4	1	524	14.6
3	72	42.4	5	326	72.4	N	526	0.0
1	75	14.6	4	358	62.9	1	545	0.0
N	77	0.0	3	361	38.8	2	550	52.5
1	96	0.0	4	371	72.4	3	554	102.7
2	101	33.6	5	376	72.4	N	655	0.0
3	106	48.2	4	384	61.0	4	557	113.0
1	186	14.6	3	387	31.9	5	560	113.0
N	188	0.0	1	388	22.5	4	649	51.0
1	207	0.0	N	391	0.0	3	651	22.6
2	212	30.8	1	410	0.0	1	652	14.6
3	216	56.3	2	416	32.7	N	655	0.0

Observation: "N" means the neutral (idle) position of the gear box and numbers 1, 2, 3, 4 and 5, the respective forward gear positions.

The main specifications of the chassis dynamometer (AVL, 1997), that was bought by PUC/Rio in Europe two years ago, are given below:

- Cylinder diameter: 1,219 mm (48 inches);
- Maximum weigh by axle: 4,500 kg (45,000 N);
- Maximum velocity for test: 200 km/h;
- Maximum continuous power: 150 kW;
- Capacity to accelerate or brake the vehicle.

The vehicle was driven by a pilot-robot (STÄHLE, 2002) that controlled the accelerator, brake, clutch and also the gear box of the car. It has a program (software) that can be adjusted for any vehicle to carry out a determined route (cycle). This procedure guaranteed that the vehicle ran very close to the established cycle, independently of the fuel used. Figures 2 and 3 show the pilot-robot already installed in the vehicle.

The vehicle used in the tests had the following basic specifications:

- Manufacturer: Ford of Argentine;
- Model: Escort (station wagon);
- Year: 2002;
- Mechanical gear box: five forward, one reverse;
- Total displacement engine : 1,800 cm^3;
- Maximum power: 115 hp;
- Electronic system for fuel injection and ignition control;
- Original fuel: gasoline C.

It is important to emphasize that no alteration in the vehicle was made, including interventions on the electronic system for fuel injection and ignition control. Therefore, all tests were performed with the vehicle with its original configuration. Finally, the tested Ford Escort was a used car in good conditions, but already having run about 100,000 km. During the tests the vehicle did not present any kind of problem.

The total distance run by the vehicle consuming the 03 liters of each fuel was obtained by its odometer reading. With this distance (D), it was possible to estimate the specific consumption presented by the car in km/liter (D/3).

Figure 2. Pilot-robot installed in the vehicle showing the detail of its mechanism for gear box change

Figure 3. Detail of pilot-robot “legs” operating the accelerator, brake and clutch

Figure 4 shows the vehicle already positioned on the chassis dynamometer for tests with different fuels. In this picture, the vehicle's forward wheels can be seen over the superior part of the dynamometer cylinder (48 inches).

Figure 4. The vehicle utilized for tests positioned on the chassis dynamometer

3. Experimental results and reccomendations

The tests were begun with the vehicle being supplied with three liters of the regular gasoline used in Brazil (gasoline C). After the above mentioned idle operation for three minutes with the car on the chassis dynamometer, the start up of the cycle was begun. The test was considered finished when the engine stopped due to lack of fuel. At this point, the total distance run by the vehicle was verified and registered.

The same procedure was adopted for the four other blends C25, C30, C35 and C40, in this order.

The vehicle presented, basically, the same performance using the five different blends. It did not have any driving problems consuming the five different fuels. The car ran nearly the same total distance in the five experiments (approximately 32.5 km). It always stopped at the beginning of fourth cycle. The specific **consumption presented by the car was in the range 10.8 ± 0.4 km/liter (± 3.7%) for all blends tested**. Although this deviation (± 3.7%) can be attributed to experimental measurement uncertainties, it was observed that for the blends containing more alcohol (C35 and C40) the best results in terms of fuel consumption (more km/liter) were presented.

Obviously, it is necessary to carry out more experiments to confirm the above results, including tests with other vehicles/engines and different blends of gasoline A and hydrated alcohol 92.5±0.7º INPM. It is also advisable to develop a numerical simulation model, emphasizing the combustion (power stroke), intending better understanding of the experimental results here shown.

The effects of the higher hydrated alcohol content in the blends on the system engine/vehicle were not yet investigated.

Also, no evaluations of engine emissions (pollution) using those kind of fuels were made. Tests in this sense are already scheduled in a near future.

Finally, the results of the present experimental research confirm, preliminarily, the viability of hydrated alcohol 92.5±0.7º INPM added to gasoline A, alternatively to 25% of anhydride ethanol used today in Brazil. It would also be possible to increase this (25%) alcohol content in the case of using hydrated ethanol for addition to gasoline A. The main advantage for the Country would be to have a "new gasoline C" with lower price and the excess of anhydride alcohol produced could be exported (high value).

4. References

ABNT – Associação Brasileira de Normas Técnicas, NBR 13992, 1997, “Gasolina automotiva – determinação do teor de álcool etílico anidro combustível (AEAC)”, Rio de Janeiro, Brazil.

Almeida, J.R. de, 1952, “O Álcool como Fonte de Energia Motora”, Revista Brasil Açucareiro, S. Paulo, Brazil.

AVL, 2004, "Chassis Dynamometers for Passenger Cars and MD Vehicles - Brochure AVL 05/2004”, Kiel, Germany

Braga, C.V.M. and Vargas, A.S., 1983, “Influência do Teor de Hidratação do Álcool Etílico sobre o Rendimento Térmico de um Motor do Tipo Ciclo Otto”, Proceedings of I Simpósio de Engenharia Automotiva e XI Encontro dos Centros Tecnológicos de Apoio Técnico, Brasília, Brazil, pp. 267- 282.

Braga, C.V.M., 1985, “Desenvolvimento de um Motor do Tipo Ciclo Otto para a Utilização de Álcool Etílico Altamente Hidratado como Combustível”, Proceedings of II Simpósio de Engenharia Automotiva e XII Encontro dos Centros Tecnológicos de Apoio Técnico, Brasília, Brazil, pp. 485-502.

Instituto Nacional de Pesos e Medidas (INPM), 1967, “Tabelas de redução de massa específica e volume de misturas álcool etílico e água”, Rio de Janeiro, Brazil.

Lima, N. de P., 1981, “Motores a Álcool”, Emus Livraria Editora Ltda., S. Paulo, Brazil.

STÄHLE, 2002, “Brochure AUTOPILOT SAP 2000”, Neuhausen-Steinegg, Germany.

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