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Energy Effect of the Degree of Hydration of Ethanol and the Air Excess Coefficient (a) on the Use of Ethanol-Gasoline Mixtures in Spark Ignition Engines

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ABSTRACT

The objective of this study was to evaluate energetically the effect of hydration degree and mixture type (rich mixture α = 0,85 and lean mixture α = 0,15) on the use of ethanol and gasoline mixtures in spark ignition engines. The experiments were carried out in the Propulsion Laboratory of the Faculty of Engineering Sciences of Agrarian University of Havana (AUH). The JACTO model engine used has an effective power of 1,2 kW, speed 580 rpm, combustion chamber volume 34 cm^3. Before combustion, the degree of ethanol hydration was determined (80 %; 85 %; 90 %; 95 %). Taking into account the influence of the percentage of purity of ethanol and air excess coefficient (α), when using combustible mixtures, analyses were carried out on the following parameters: air-fuel ratio ($r_{a/f}$) and fuel-air ratio ($r_{f/a}$); internal energy of combustion products (U_z); the number of moles of raw materials in the mixture for gasoline engines (M_1) and the number of moles of products during combustion (M_2). Based on the experimental work performed and the energy analysis of the combustion process, it was shown that the mixture of gasoline E-10-EH-80 % received more air and fuel than ratio necessary to achieve combustion, reaching 11,781 kg (air)/kg (fuel) for α = 0,85 and 15,309 kg (air)/kg (fuel) for α = 1,15. This is due to the fact that this is a mixture with increased moisture, because it contains more oxygen atoms, which impoverishes the mixture, and guarantees the best quality in the combustion process. But rich mixtures (α = 0,85) were the most energy efficient, which is associated with an increase in the octane number, that is, the antiknock ability of the fuel mixture used, which improves the quality of combustion, although it reduces the energy output during an explosion (detonation).

Keywords: *transport, hydrocarbon, fuel, gasoline, mixture, standard energy, engine, air, gas, hydration, combustion, ecology.*

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Текст статьи, изначально представленной на английском языке, публикуется на русском языке в первой части данного выпуска.

INTRODUCTION

Scientists and various world organisations have been warning about the threat of the depletion of fossil hydrocarbons for more than four decades. They claim that the «oil peak» is an inevitable reality and predict it for different dates. But the important thing is that no one doubts that this will happen and will have serious consequences for the world economy [1].

The gradual depletion of fossil fuel reserves, the uncertainty of their prices and the degradation of the environment make humanity seriously reflect on the energy problem and look for alternative sources. For this reason, there is now a general tendency to look for and use renewable energy sources [2].

However, renewable energy is not the only source available. New directions of search should be carefully studied. Today, many industrial processes generate large amounts of waste containing the potential for energy use. Through physical or chemical processes, these wastes can be used to produce energy, thus saving not only primary resources, but also minimizing the problems of managing these wastes [3].

Given the threat posed by the depletion of hydrocarbons and climate change, norms and methods have been developed at the global level to reduce dependence on them. Some modern developments indicate a tendency to reduce the consumption of fossil hydrocarbons, gradually moving to the use of alternative fuels, such as biofuels [4].

Switching to mixed fuel makes it possible to improve the traction properties of transport, increase its performance, reduce diesel fuel consumption and reduce the amount of harmful emissions [5–9].

Studies show that gasoline mixtures with 10 % or 15 % of ethanol have better environmental and energy performance, due to the increase in octane, that is, the anti-detonating ability of the fuel mixture, which improves the quality of combustion, although the energy during the explosion (detonation) decreases [10].

Taking into account the above, the work shows the results of thermodynamic studies on the use of gasoline mixtures and 10 %-ethanol mixtures in spark ignition engines.

RESEARCH METHODOLOGY

1. Theoretical Foundations of the Combustion Process

To analyse the theoretical foundations of the combustion process, several works on this topic were considered [11, pp. 8–69; 12, pp. 8–20; 13, pp. 13–42; 14, pp. 43–58; 15], which established:

1. The theoretical amount of air required for fuel oxidation (L_0) is determined from the expression:

$$L_0 = \frac{1}{0,21}\left(\frac{C}{12}+\frac{H}{4}+\frac{O_0}{32}\right). \quad (1)$$

In this case, the average elementary components of the fuel can be taken, for gasoline: carbon – C = 0,85; hydrogen – H = 0,15; oxygen – O_0 = 0.

2. Number of moles of raw materials in the mixture for gasoline engines (M_1):

$$M_1 = \alpha \cdot L_0 + \frac{1}{\mu_c}, \quad (2)$$

where m_c – molecular weight of the fuel, for gasoline m_c = 110…120 kg/kmol;

a – air excess coefficient.

3. Number of moles of products in combustion (M_2):

If α < 1 $M_2 = \frac{C}{12}+\frac{H}{2}+0,79\cdot\alpha\cdot L_0$. (3)

If α ≥ *1* $M_2 = (M_2)$ α = 1 = 1 + *j*, (4)

where $(M_2)_{\alpha=1} = \frac{C}{12}+\frac{H}{2}+0,79\cdot L_0$. (5)

4. The necessary amount of air (J) is determined from the expression:

$$J = (\alpha - 1)\cdot L_0. \quad (6)$$

5. The theoretical coefficient of molecular variation is determined from:

$$\mu_0 = M_2 / M_1. \quad (7)$$

6. The actual coefficient of molecular variation (β) is determined from:

$$\beta = \frac{M_2 + M_r}{M_1 + M_r} = \frac{M_2 + M_1 \cdot \sigma_r}{M_1 + (1+\sigma_r)} = \frac{\mu_0 + \sigma_r}{1+\sigma_r}. \quad (8)$$

The value β fluctuates: for gasoline engines – β = 1,02…1,12, diesel engines – β = 1,01…1,06.

The lower heat of combustion (H_u) of the fuel is formed: for gasoline engines – H_u = 44000 KJ/kg; for diesel – H_u = 42500 KJ/kg; and for gasohol (Flex fuel) –H_u = 26279 KJ/kg.

7. The internal energy of the combustion products (U_z) is determined from the expression:

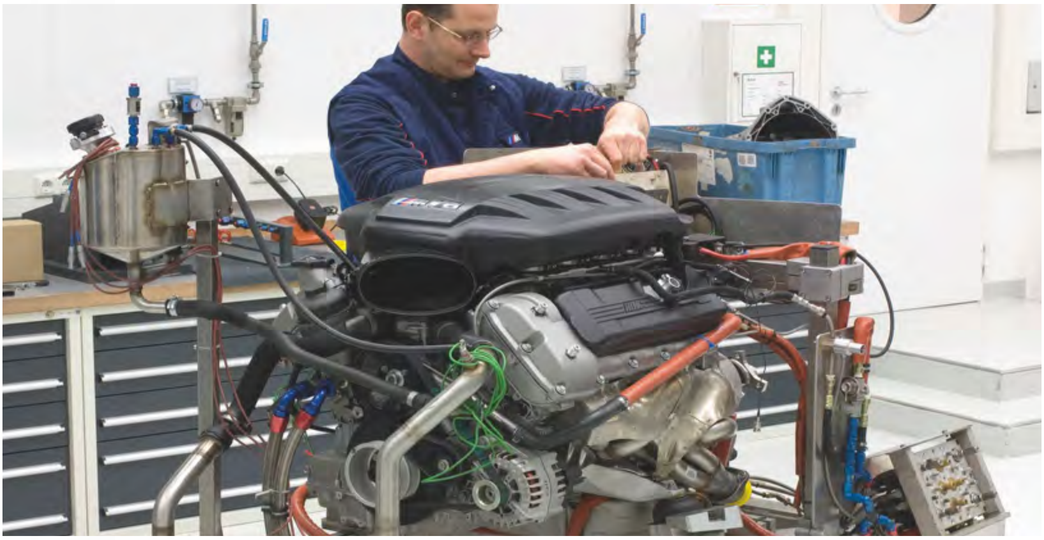
$$U_z = \frac{1}{\beta}\left[\xi\frac{(H_u - \Delta H_u)}{M_1(1+\sigma_r)} + \frac{\left[U_c - \sigma_r \cdot U_c^{"}\right]}{1+\sigma_r}\right], \quad (9)$$

where s_r – the exhaust gas coefficient. For gasoline engines s_r = 0,06…0,12; for diesel engines s_r = 0,02…0,06.

Table 1

Air-fuel ratio ($r_{a/f}$) and fuel-air ratio ($r_{f/a}$) [compiled by the authors]

Mixtures	α = 0,85		α = 1,15	
	$r_{a/f}$ kg air/kg fuel	$r_{f/a}$ kg fuel/ kg air	$r_{a/f}$ kg air/kg fuel	$r_{f/a}$ kg fuel/ kg air
E-10-EH-95 %	11,303	0,088	15,293	0,063
E-10-EH-90 %	11,31	0,088	15,303	0,065
E-10-EH-85 %	11,311	0,088	15,304	0,065
E-10-EH-80 %	11,781	0,085	15,309	0,065



ξ – heat utilization coefficient. For different engines in rated mode: for gasoline engines ξ = 0,85…0,95; for diesel engines ξ = 0,65…0,85.

U_c – the internal energy of gases (it can be taken from air) for the temperature at the end of compression in degrees Celsius (°C).

U_c'' – the internal energy of the combustion products for the critical temperature of the products (t_c).

2. Hydration of Ethanol

Steps to consider while obtaining different degrees of ethanol hydration:

• Measurement with an alcohol tester of the degree of hydration of ethanol for the experiment.

• Increase in the degree of hydration of ethanol to the desired values by adding distilled H_2O without impurities.

RESULTS

1. Experimental Research

The experiments were carried out in the Propulsion laboratory of the Faculty of Technical Sciences of Agrarian University of Havana (AUH). A single-cylinder engine of the JACTO model was used. Analysis of the combustion process based on mixtures of 10 % ethanol and conventional gasoline of category B-85 (E-10). Before combustion, the degree of hydration of ethanol was determined (80 %; 85 %; 90 %; 95 %), and type of mixture (rich mixture α = 0,85 and lean mixture α = 0,15). The engine used has an effective power of 1,2 kW; rotation speed of 580 rpm, combustion chamber volume of 34 cm³.

The ethanol used in the experiments, with a % purity (EH) of 97 %, of which 95 %, 90 %, 85 % and 80 % were obtained, with this % purity the various combustion conceived in the study were carried out.

2. Thermodynamic Analysis of Experimental Studies of the Combustion Process

Taking into account the materials and methods described above, the influence of % ethanol purity and the air excess coefficient, the following parameters were analyzed in the use of fuel mixtures: air-fuel ratio ($r_{a/f}$) and fuel-air ratio ($r_{f/a}$); internal energy of combustion products (U_z); number of moles of raw materials in the mixture for gasoline engines (M_1) and number of moles of combustion products (M_2).

Table 2

Internal energy of combustion products (U_z). Number of moles of raw materials in the mixture for gasoline engines (M_1) and number of moles of combustion products (M_2) for α = 0,85 and for α = 1,15 [compiled by the authors]

Mixtures	α = 0,85				
	M_1, kg/kmol	M_2, kg/kmol	m_0	β	U_z, kJ/kmol
E-10-EH-95 %	28,632	26,113	0,912	0,616	27749,510
E-10-EH-90 %	28,432	25,873	0,91	0,614	28202,971
E-10-EH-85 %	28,230	25,661	0,909	0,612	28664,544
E-10-EH-80 %	28,027	25,420	0,907	0,609	29134,443
α = 1,15					
E-10-EH-95 %	21,474	19,606	0,913	0,633	26852,127
E-10-EH-90 %	21,242	19,288	0,908	0,631	27294,547
E-10-EH-85 %	21,009	19,013	0,905	0,629	27744,519
E-10-EH-80 %	20,773	18,779	0,904	0,627	28202,227

In the case of the air-fuel ratio ($r_{a/f}$) and the fuel-air ratio ($r_{f/a}$) these coefficients are the ratio of the kilograms of fuel or air that exist in the mixture per kilogram of air or fuel during combustion. Moreover, a large amount of air, with a small amount of fuel becomes the cause of rapid combustion at high temperatures, while on the contrary, with a large amount of fuel, the mixture burns slowly and at low temperatures. An air-fuel ratio of less than 14,7 means a rich mixture, while a ratio of more than 14,7 means an impoverished mixture. This air excess coefficient is determined as α = 0,85 and α = 1,15, for a mixture of 10 % ethanol with % purity 95 % + gasoline (E-10-EH-95 %), 10 % ethanol % purity 90 % + gasoline (E-10-EH-90 %), 10 % ethanol% purity 85 % + gasoline (E-10-EH-85 %) and 10 % ethanol % purity 80 % + gasoline (E-10-EH-80 %) Table 1.

As we can see in the Table 1, in the above E-10-EH-80 % a greater proportion of the air/fuel needed in order to achieve combustion is obtained and reaches 11,781 kg (air)/kg (fuel) for α = 0,85 and 15,309 kg (air)/kg (fuel) for α = 1,15 this is due to the fact that the mixture is more hydrated, because it has more number of atoms of oxygen, which impoverishes the mixture and provides a better quality of the combustion process, while for α = 0,85 the fuel/air ratio is greater, that for α = 0,15 because the air induction decreases.

In turn, from the expression (9), the internal energy of the combustion products was determined for each of the analyzed mixtures (Table 2).

As we can see in the Table 2, when using a mixture E-10-EH-80 % in rich and lean mixtures, we get more internal energy than in the mixtures remaining, reaching a value of 29 134,443 kJ/kmol for rich mixtures and 28 202,227 kJ/kmol for lean mixtures, resulting in a maximum difference; for rich mixtures of 1 384,934 kJ/kmol in connection with the mixture of E-10-EH-95 % and for lean mixtures 1 350,1 kJ/kmol with respect to the mixture E-10-EH-95 %. The increase in energy may be due to an increase in the hydrogen and oxygen content of the mixture, the components of water added to ethanol.

While the higher internal energies in rich mixtures compared to lean mixtures, this may mainly be due to an increase in octane, that is, the anti-detonating ability of the fuel or the fuel mixture used, which improves the quality of combustion, although it reduces the energy capacity during explosion (detonation).

Summing up, in the combustion analysis, the highest value of the internal energy of the combustion products is achieved using a mixture E-10-EH-80 % for rich mixtures (α = 0,85). This behaviour is due to an increase in the octane number, that is, the anti-detonating ability of the fuel used or the fuel mixture, which improves the quality of combustion, although the energy during the explosion (detonation) decreases. It should be noted that this does not mean that as the hydration of ethanol increases, the internal energy increases.

CONCLUSION

1. For a mixture E-10-EH-80 %, we get more air/fuel ratio needed to achieve the combustion, which reaches 11,781 kg (air)/kg (fuel) for α = 0,85 and 15,309 kg (air)/kg (fuel) for α = 1,15, this is because it is a mixture with more humidification, because it has more oxygen atoms, which impoverishes the mixture and ensures a better quality in the combustion process.

2. In rich mixtures (α = 0,85), the fuel/air ratio is higher than in lean mixtures (α = 0,15) because the supplied air decreases.

3. The mixture E-10-EH-80 % for rich mixtures (α = 0,85) was the most energy efficient, due to the increase in octane, that is, the anti-detonating capacity of the fuel mixture used, which improves the combustion quality although it reduces the power of the explosion (detonation).

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