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A review on the technical adaptations for internal combustion engines to operate with gas/hydrogen mixtures

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ARTICLE INFO

Article history:
Received 3 April 2009
Received in revised form
23 July 2009
Accepted 14 September 2009

Keywords:
Hydrogen
Combustion
Engine

ABSTRACT

The use of the hydrogen as fuel in the internal combustion engine represents an alternative use to replace the hydrocarbons fuels, which produce during the combustion reaction a pollutes gases. The hydrogen is the most abundant material in the universe and during its combustion with air only produces nitrous oxides (NO_x) gas, which can collect and avoid their emission to the atmosphere. In this paper we can present the most significant advances and developments made on the technical adaptations in the internal combustion engines which operate with mixtures of gas/hydrogen, doing more emphasis in the fuel injection and cooling systems. To understand such technical adaptations, it is necessary to know the chemical and physical characteristics of the hydrogen, and the processes relate with the chemical reaction between air and hydrogen, from a point of view of the thermo-chemistry and the chemical kinetics, as well as the ratios of the mixtures in the combustion process. Also, it mentions the advantages and disadvantages of the integration of hydrogen as a fuel, such as the pre-ignition, spontaneous ignition, knocking and backfire, also the advances in the research to avoid these phenomena during the combustion. Finally, it describes the best conditions of the ratio-mixtures in the internal combustion engines when they are fed with hydrogen. Also, it describes the perspectives and the futures fields on the future investigation.

1. Introduction

In the last years, the late reports on the environmental contamination and the exhaustion of the resources show the levels have been increased due of intensive use of the internal combustion engines, and for this reason it is looking for a more efficient and clean sources to produce movement and electric power. Hydrogen can be part from an integral and efficient solution for this type of problems. The fuel cells are a promising alternative in terms of power production, however these systems it is going be a reality for the next 20 years when the mass production start. The hydrogen combustion has an important advantage over the fuel cells systems, it is possible to use the infrastructure that exists to adapt the internal combustion engines to use hydrogen as a fuel, and in this manner reduce of emissions. This is the way to introduce in the market this type of conversion of engines in short term. The use of the hydrogen as a fuel in the engines has been studied by different authors [1–3] in the last decade with several degrees of success. However, these reports are not necessarily consistent among several researchers. The tendency in this type of reports is focused in results obtained for specific engines under very narrow operation conditions, and also made emphasis in the emissions and considerations

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doi:10.1016/j.ijhydene.2009.09.070

of efficiency [1]. It should be taken into account what has been achieved in this field, focused in the attractive features as in the limitations associate with the disadvantages that are needed to overcome the hydrogen broadly acceptable as a fuel for engines. It is also necessary to indicate the practical steps to incorporate the different experimental condition in the existent commercial engines to operate with hydrogen gas.

White et al. [4] were made a technical revision of the internal combustion engines operate with hydrogen; their work was emphasis in the use of hydrogen/gas mixtures with light and heavy load in order to reduce the bad combustion engines. Also, they report the effect of variation in the concentration of the mixture hydrogen/air versus the emissions of NO_x.

Akansu et al. [5] also carried out a technical revision on natural gas/hydrogen mixtures. They reported the level of the pollutants emissions, such as hydrocarbons without burning and nitrogen oxides when internal combustion engines operate with natural gas and adding hydrogen. Also, they reported the efficiencies and powers of the engine.

2. Theoretical bases

2.1. Characteristics of the flame

The flame is generally classified according to certain characteristics. The first of them is related with its composition at which the reactants go to the reaction area. If the fuel and the oxidizer mix properly it is called pre-mixture flame. If the reactants are not pre-mixture and should they be mixed in the place where the reaction occurs, the flame is designated as diffusion, because the mixture comes from a diffusion process. The second type of classification of the flame refers to the characteristics of the gas flow through the reaction area: Laminate or turbulent. In the laminate flame the transport occurs due to molecular processes, in other words at low Reynolds numbers, which are defined as the relationship between the inertial and viscous forces. In the turbulent flame, the transport and the mixture of the gas flow cause by the relative macroscopic movement of fluid, in others terms high Reynolds numbers. A third classification area refers to stability of flame. The main characteristic that distinguishes it is the structure and the movement of the flame change with the time. In general, the flame in the internal combustion engine is instable [6].

2.2. Composition of the air

For the purposes of the present work we will consider that the air is composed of 21% Vol. Oxygen and 79% Vol. Nitrogen [6–8]. The molecular weight of the air is obtained by the following equation:

$$M = \frac{1}{n}\sum_{i} n_i M_i \tag{1}$$

the molecular weight of the air is considered as of 28.96 g/g-mol.

2.3. Stoichiometric combustion

The stoichiometric combustion of the octane molecule can represent by the following equation,

$$C_8H_{18} + 12.5(O_2 + 3.773N_2) = 8CO_2 + 9H_2O + 47.16N_2 \tag{2}$$

However, air/fuel mixtures with different amount of air can make combustion. With excess of air, during the combustion, the products are unaffected. With a smaller amount of the air, in other word a rich mixture in fuel, there is not enough oxygen to oxidize all the carbon and hydrogen into carbon dioxide and water, and the result products are mixtures of dioxide of carbon and water with monoxide carbon and hydrogen.

Due that the composition of the combustion products is different when they are light or heavy mixtures and that stoichiometric ratio of air/fuel depends of the composition of the fuel, it is necessary to define a parameter call equivalence ratio ϕ that it is to relate of the stoichiometric ratio of air/fuel with the actual ratio air/fuel [6]:

$$\phi = \frac{(F/A)_{actual}}{(F/A)_s} \tag{3}$$

The inverse value of ϕ is call inverse relative ratio λ. At low values of ϕ, it is considered as of a slight mixture, meanwhile at high values of ϕ it is considered as rich mixture, and equal to 1 it is a stoichiometric mixture. In general, the ultra-light loads are whose equivalence ratio is smaller at 0.5. The flammability limits are considering the values of the mixture ratios of air/fuel that the combustion occurs, and they express in percentage values.

Table 1 – Some physical properties for hydrogen and others fuels under stequimetric conditions [9].

Properties	Hydrogen	Methanol	Methane	Propane	Gasoline	Unit
Flammability limits	4–75	7–36	5–15	2.5–9.3	1.0–7.6	Vol. %
Minimum ignition energy.	0.02	–	0.29	0.25	0.24	mJ
Flame temperature	2045	–	1875	–	2200	°C
Auto ignition temperature	585	385	540	510	230–500	°C
Maximum velocity of flame	3.46	–	0.43	0.47	–	m/s
Explosion range	13–65	–	6.3–13.5	–	1.1–3.3	Vol. %
Diffusion coefficient	0.61	0.16	0.20	0.10	0.05	10^{-3} m^2/s