THERMODYNAMIC CYCLE OF COMBUSTION ENGINE WITH HYDROGEN FUELLING

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Abstract

Shortage of crude oil gives the reason to look for any alternative engine fuel. One of them is the hydrogen, which will be the most lean fuel between others. Knowledge of hydrogen as an engine fuel, its properties, production and storage problems were analyzed in this paper. At the end own hydrogen concept based on Fiat engine 900ccm was shown. Theoretical comparison between thermodynamic cycles for engine run on conventional petrol and hydrogen was done. Results have given the green light to future development.
Petroleum recourses run out have given the reasons to find alternative fuel. One of them could be hydrogen. According to analyze done in the project it can be found similarity between hydrogen engine with λ=1,0 to petrol engine with λ=0,9. Pressure of hydrogen charge is in this case higher of 0.42 MPa and there is calculated in strength of existing engine. The results of estimation show possibility to use hydrogen as a engine fuel, maybe first as a dual-fuel engine like LPG system. Emissions of NOx for hydrogen engine as well as theoretical engine work cycles for analyzed cases are illustrated in the engine.

Keywords: *Combustion engine, thermodynamics, hydrogen*

1. Introduction

Twenty Century was the time of motorization developing. Nowadays, there are over 700 millions vehicles in the world. They influence on environment in negative way. Toxic emission from exhaust gases like NO_x, CO, CO_2, HC etc cause pollutants and disasters. It is because olmost 97 % of whole amount of vehicles are supplied with fuel made of crude oil. From year to year, the number of cars is growing caused shortage in petroleum pools. It effects on politics and economy all countries. It assumed, that petroleum resources an be operated for next 40 years, only [6].

So, new engine technology is focused on economical and ecological solutions. On the another hand car operated with less fuel consumption lead to reduction traveling expenses to promote car journeys. That case causes increasing fuel consumption and all disadvantages of pollution in general point of view.

Because of all thing mentioned above some years ago engineers have started looking for new – alternative fuels. There are LPG, LNG, CNG, Biofuels and … hydrogen – the object of this project.

2. Hydrogen as a engine fuel

Hydrogen could be an alternative engine fuel. It is the most ppular chemical element in the world. It is the lightest and the most simply structure element. Hydrogen is odorless and colorless combustible gas. In each of the state (gas or liquid) hydrogen has got the lowest density, so specific hest of hydrogen for weight unit is the highest. Hydrogen is characterized by high level of diffusion factor and because of this its molecules in gas state are the fastest. Fire range is 4 to 75 % in mixture with the air. The combustion of hydrogen is environmental friendly. Water steam, heat and trace of NO_x as well as HC and CO can be found in exhaust gas of hydrogen engine, but HC and CO they are rather effect of combustion of lubricating oil existed in chamber than because of hydrogen fueling. Hydrogen is not the source of energy like crude oil. It is a energy carrier.

2.1 Hydrogen – properties of fuel

Hydrogen differs in properties from conventional fuel. Some parameters are given in table 1.

Tab. 1. Basic properties of hydrogen against to petrol [2]

Properties		Units	Hydrogen	Petrol
Calorific value		MJ/kg	120	42 – 44
		MJ/m^3	10,77	~34500
Calorific value for stechiometric mixture		MJ/m^3	2,97 – 3,17	3,50
Theoretical air need		kg/kg	36,6	~14,7
Octane number	Test	-	-	91 - 98
	Road	-	70	81 - 88
Density	at 20 °C	kg/m^3	0,0840	720 - 750
	at 0 °C		0,0898	-
Explosion range		% vol. in the air	4 - 75	1,16 - 7,00
Laminar combustion velocity		m/s	2,70 - 3,15	0,30 - 0,60
Temperature of self-ignition		°C	585	480 - 550
Boiling point		°C	- 253	35 - 215
Minimal ignition energy		mJ	0,02	0,24

Hydrogen has got appropriate properties to use as a engine fuel in aprk ignition engine. There are:

Wide burning range

Hydrogen with air mixture can be burnet in the range 4-75%. It is advantage to use lean charge, what is important during start operating and in reduction of fuel consumption as well as combustion process an be more completed. Temperature of mixture is less than in petrol case, but the power is also low when lean hydrogen mixture supply engine.

Low ignition energy

Hydrogen needs only 0,02 mJ energy to ignite. It is ten times less than for petrol. On the one hand it is advantage – to help burning lean mixture but on the another hydrogen can be ignited from foe example hot walls of combustion chamber. It can cause combustion out of control.

Short extinguish distance

For hydrogen, extinguish distance is lower than for petrol. It means hydrogen flame can be very closed to chamber walls and it could be difficulty to extinguish it if necessary.

High sel-ignition temperature

Temperature of hydrogen self-ignition is relatively high. It is important when hydrogen-air mixture is compressed. This properties decides compression ratio in engine – higher causes higher one in this way.

High compression factor

Higher compression factor for hydrogen mixture than for petrol gives higher thermal efficiency. But, on the another hand high compression factor eliminates hydrogen from diesel engine application.

Fast flame velocity

Flame speed for hydrogen–air mixture is ten times higher than form petrol charge. It causes that hydrogen thermodynamic cycle much better fill work ideal cycle.

High diffusion

Hydrogen has got high diffusion. Its dissipation into air is big advantage of hydrogen as a fuel. First because of getting homogenous mixture and second because of safety reason.

Low density

Density of hydrogen is very low. There are two main disadvantages of this parameters: problem with hydrogen storage in the tank and low volumetric energy [8, 9].

2.2 Hydrogen combustion process

Combustion is a physical and chemical process based on rapid oxidization. For hydrogen, combustion in stechiometric mixture with oxygen and air is carry out as follow:

$$2H_2 + O_2 \rightarrow 2H_2O\,, \tag{1}$$

number of moles H_2 for completed combustion – 2 moles,
number of moles O_2 for completed combustion – 1 mole,
number of moles N_2 in the air – O_2 x (79% N_2 in the air / 21% O_2 in the air) =
= 1 mol O_2 x (79% N_2 w pow. / 21% O_2 w pow.) = 3,762 moles of N_2,

number of moles of the the air – mole O_2 + mole N_2 = 1 + 3,762 = 4,762 moles of air,
mass O_2 – 1 mol O_2 x 32 g/mol = 32 g,
mass N_2 – 3,762 mole N_2 x 28 g/mol = 105,336 g,
mass H_2 – 2 mole H_2 x 2 g/mol = 4 g,
mass of air – 32 g + 105,336 g = 137,336 g.

Stechiometric ratio air/fuel:

mass – 137,336 g / 4 g = 34,336 : 1,
volumetric (moles) – 4,762 / 2 = 2,4 : 1.

Percentage of hydrogen filling in combustion chamber:

$$\%H_2 - \text{vol. } H_2 / (\text{vol. air.} + \text{vol. } H_2) = 2 / (4{,}762 + 2) \approx 0{,}296 \approx 29{,}6\% \ \ [5, 6]. \tag{2}$$

Calculation, mentioned above that low density of hydrogen causes low air access factor in stechiometric state – hydrogen fill 30% of chamber displacement against 2-4% for petrol only.

For outside preparation of mixture (carburetor type) power of hydrogen engine is less even 25% in comparison to petrol [4, 5, 6]. For direct injection (hydrogen split directed to chamber) power is higher up to 20%. Combustion process of hydrogen can be realized for very wide range of air/fuel factor (λ = 0,14÷10). It gives completed burning process, easy start and supply with lean mixture. The results are lo temperature and reduction NO_x trace level [4, 8].

In practice, hydrogen prototype engines are fueling with mixture for λ = 0,2÷5. It gives possibility controlling combustion process by hydrogen flow – not y air throttling.

Chemical process of hydrogen combustion can be presented as on equations (3-5).

$$H + O_2 \rightarrow O + OH, \tag{3}$$

$$O + H_2 \rightarrow H + OH, \quad (4)$$

$$OH + H_2 \rightarrow H_2O + H. \quad (5)$$

Reactions (3) and (4) give ramification of element chain. And equation (5) results with combustion products [4].

2.3. Thermal efficiency

Theoretical, thermal efficiency of spark ignition engine (Otto cycle) based on compression ratio and specific heat of fuel. When both of them are high thermal efficiency is growing, too. Compression ration is limited by knocking resistance of fuel. Lean hydrogen mixtures are better than petrol stechiometric and higher compression ratio can be applied.

Specific heat factor depends on fuel molecular structure and for simply structure is higher: for hydrogen γ = 1,4, for petrol γ = 1,1 [4, 5, 8].

2.4. Emission – toxic products of hydrogen combustion

Only one non-toxic product is result of hydrogen combustion in oxygen – water (6):

$$2H_2 + O_2 = 2H_2O. \quad (6)$$

For burning in the air it an be found (7)

$$H_2 + O_2 + N_2 = H_2O + N_2 + NO\,. \quad (7)$$

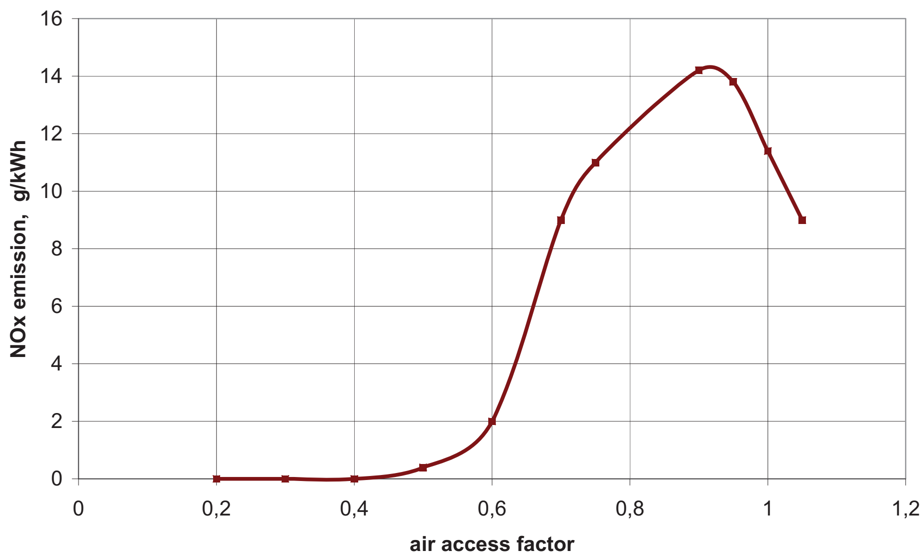

Fig. 1. Emission of NO_x for hydrogen engine [9]

Nitric oxides are results of high temperature inside combustion chamber. It depends on air/fuel factor as well compression ratio, engine revolution, ignition delay.

3. Theoretical engine work cycle for hydrogen fueling

Thermodynamic cycle of combustion engine supply with hydrogen was calculated using standard theory and right formulas. Estimations were done for different air/fuel factor. Basic data was taken from Fiat Seicento engine with displacement of V_c= 899 ccm.

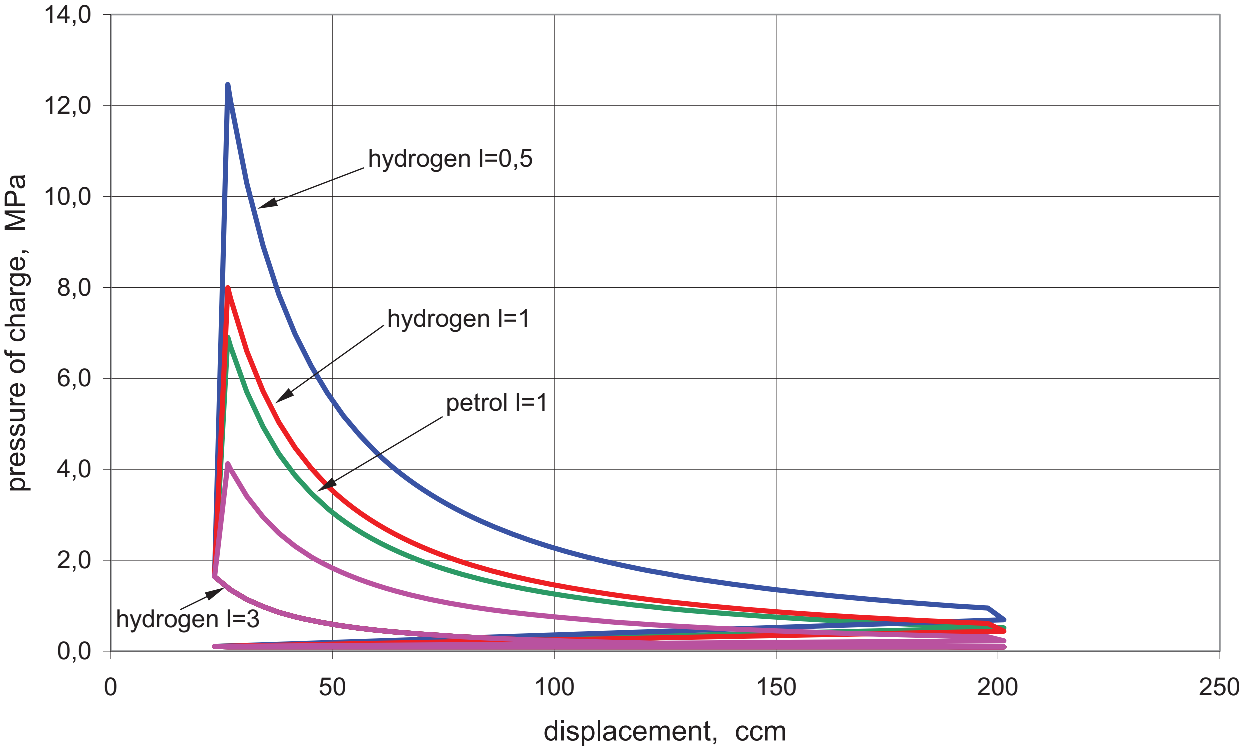

Fig. 2. Theoretical engine work cycles for analyzed cases

Diagrams, mentioned above show different examples of fueling. Engine work cycles were compared for petrol and hydrogen fuel and for λ=0,5, 1,0 and 3,0. Using too rich mixtures it could effect on durability because of temperature and high pressure (for petrol and λ=1,0 - p_{max} = 6,9 MPa, T_{max} =2502 K; for hydrogen and λ=1,0 - p_{max} =7,99 MPa, T_{max} =3437 K; for hydrogen and λ=0,5 - p_{max} =12,5 MPa, T_{max} =2575 K). In these cases hydrogen engines have to be redesigned.

On the another hand lean mixture give poor engine parameters but low fuel consumption (for petrol and λ=1,0: g_e =309 g/kWh, for hydrogen and λ=3,0: g_e =133 g/kWh).

4. Summary

Petroleum recourses run out have given the reasons to find alternative fuel. One of them could be hydrogen. Before engine application some problems should be solved: production, storage, safety, materials etc.

According to analyze done in those project it can be found similarity between hydrogen engine with λ=1,0 to petrol engine with λ=0,9. Pressure of hydrogen charge is in this case higher of 0,42 MPa and there is calculated in strength of existing engine. Because of high temperature, cooling system should be redesigned.

The results of estimation show possibility to use hydrogen as a engine fuel, maybe first as a dual-fuel engine like LPG system.

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