Hydrogen Power Capabilities in Water Transport

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Abstract. The analysis of the hydrogen power current state and, in particular, the development of hydrogen fuel cells for water transport has been carried out. To ensure safety and diagnostics of hydrogen leaks the possibility of the concentration measuring of hydrogen molecules in the concentration range of $10^{13}...10^{17}$ cm$^{-3}$ in the atmosphere at ranging distances up to 100 m has been fulfilled and obtained that the measurement time from 400 ns to 26.5 min is sufficient and this can be realized in one Raman lidar at the specific experimental conditions.

Keywords: Hydrogen molecule; Fuel cell; Raman Lidar; Atmosphere; Concentration; Measurement time

1. Introduction

Wood, coal, peat, petroleum products, including natural gas, have served as fuel in traditional energy for many centuries. Natural gas, as is known, consists mainly of propane C$_3$H$_8$ and butane C$_4$H$_{10}$. These fuels, at least for decades, will serve as the basis for energy. There are complaints to such an energy. Heat engineering and mechanics are characterized, as a rule, by a low efficiency factor. Combustion of these fuels is characterized by the emissions of carbon oxides, nitrogen ones (and not only), which dramatically worsens the environmental situation. Therefore, the views of the power engineers focus on other energy carriers and other energy exchange (for example, turning chemical energy directly into electric energy). International projects are emerging to eliminate fossil energy from energy up to 2050 [1]. It is proposed to switch to fuels that less clog the environment with harmful impurities, require less consumption per unit of energy received. One of the most attractive fuels is hydrogen. This applies to power plants, transport, etc. This is especially important in the water transport, since it allows not to have fuel on board, does not contaminate the atmosphere and water. Therefore, it makes sense to consider this issue in more detail.
2. Hydrogen

Hydrogen, apparently the most common in nature element of the D. I. Mendeleev Table [2, 3]. Hydrogen in the gas phase is filled with Cosmos. In the form of plasma, it makes up a significant mass of stars, including the Sun. Cosmic rays, including the corpuscular radiation of the Sun, are largely consist of hydrogen nuclei (protons). Hydrogen accounts for about 1% of the weight of the Earth's crust. As part of the most common substance on the Earth - water, the mass of hydrogen is more than 11%.

Hydrogen is the lightest and most energy-intensive fuel. Therefore, it is supposed to be used as one of the main heat carriers of the future energy. You should not think that this was the only reason for interest in the hydrogen. It is known that the hydrogen production was interested in England back in the 19th century [4]. Hydrogen is used to improve the quality of gasoline, the production of fertilizers (primarily nitrogen-containing), improve the quality of steel, for hydrotreating, catalyst regeneration, in the food industry, etc.

Apparently, hydrogen is the most effective fuel in the thermonuclear reaction [5]. At the same time, the largest energy yield per unit mass of the fuel used and the most economical reaction, taking into account the amount of hydrogen in nature, and the most environmentally friendly, are observed. In more than half a century, man has not yet achieved the controlled thermonuclear fusion. The problem of obtaining energy using "micro-explosions" has not yet been solved. Therefore, there is a question about other methods of hydrogen burning. The results of combustion also depend on the degree of hydrogen purity, and it depends on the method of production.

3. Hydrogen production

The very pure hydrogen is obtained by electrolysis of water, which is usually carried out at the direct current. However, in this electrolysis method, the electric energy consumption for hydrogen production exceeds the energy from its combustion. The hydrogen obtained by electrolysis is called "green." Other pure hydrogen is obtained by electrolysis from nuclear power. It is called "yellow" or "orange."

The commercial production of hydrogen today is usually carried out by converting natural gas or methane ("gray" hydrogen): water vapor (at 700-1000 °C) is mixed with natural gas or methane under pressure in the presence of a catalyst. The "brown" hydrogen is obtained from coal using water vapors. These are the dirtiest kinds of hydrogen. If "gray" hydrogen is purified from the formed carbon dioxide, which is converted into solid carbon, then "blue" hydrogen is obtained, which is cleaner than "gray", but inferior to "green".

When water is electrolyzed, hydrogen is released in an acidic medium, and oxygen is released in an alkaline one. The recovery efficiency is determined by the catalysts. For example, hexaferrites with nickel or titanium [6] are used to isolate oxygen.

A major step forward in the production of hydrogen was Stanley Meyer's fuel cell (hydrogen cell) [7, 8]. This cell works on water and the catalyst is soda. Hydrogen and oxygen are released from water, which is a dielectric medium in the electric resonance circuit. Figure 1 and figure 2 help to understand the principle of this cell operation. Figure 1 shows the forces acting in the water molecule. The external electric field attenuates the interaction forces of hydrogen and oxygen atoms, and tears the water molecule. Figure 2 shows the electrical scheme of the Meyer cell. It is a resonant charging throttle 4 connected in series to an excitation cell 5.
Figure 1. The electrical charges in the water molecule.

Figure 2. Circuit scheme of the layout [8]: 1 – alternating pulse voltage, 2 – isolated pulse transformer, 3 – blocking diode, 4 – resonance charging throttle, 5 – excitation cell (capacitor), 6 – natural water, 7 – adjustable resonance charging throttle, 8 – isolated electric ground

The improved Meyer fuel cells are described in [9-13]. An overview of later variants, including laser ones, of this article authors is given in [14]. The advantage of all the listed works is that the proposed equipment operates at the 1-2 kV voltage and several mA currents. The cells remain cold.

It may seem that all these cells are the laboratory samples that cannot provide a large hydrogen yield and are only suitable for the small objects moving. It's not yet. Meyer showed a film in which a hydrogen-powered motorboat was moving. The prototype tram with a hydrogen engine was created in St. Petersburg and operated. Japanese and German firms report about the experimental models of hydrogen-powered cars.

Some ones do not burn the hydrogen, but use the direct conversion of chemical energy to electric energy. The use of a hydrogen engine is especially promising in water transport: you do not need to carry fuel on board, there are no environmental problems. Naturally, it is necessary to develop the requirements for water treatment and to develop or find suitable equipment from existing ones.
4. Hydrogen leaks diagnosis

The safety precautions are necessary for the successful operation of hydrogen engines and related transport systems. First of all, the hydrogen leaks diagnosis. The best apparatus for this are lidars. This work authors have long been engaged in this field (see, for example, [15]) and expect in success.

Previously, it has been shown in [2], that the Raman lidar can be used to remote measure the hydrogen molecules concentration at the level of the order of $10^{13}$ cm$^{-3}$ and higher in the atmosphere at distances up to hundreds of meters in the synchronous photon counting mode and the optimal parameters of such a lidar can be selected. However for the studied molecules concentration measurement it is necessary to know the differential Raman cross section ($d\sigma/d\Omega$) for the studied molecule H$_2$ at the 532 nm laser radiation wavelength. In the spectrum of combinational scattering of light by the molecule N$_2$, The hydrogen molecule powerful vibration band is observed in the Raman spectrum with the wave number of $\nu_0 = 4161$ cm$^{-1}$ [2]. The Raman band wavelength of the studied hydrogen molecule when probed at the YAG-Nd laser second harmonic at the 532 nm wavelength such a $\nu_0$ wave number wavelength is 683.2 nm. This was taken into account in the experimental Raman lidar, the optical layout of which is shown in figure 3.

![Figure 3. The Raman lidar optical layout](image)

As above noted, the YAG-Nd laser 1 of pulse duration 10 ns and energy 10 mJ at the 532 nm wavelength was sent to a special cuvette with the Brewster angle windows filled with pure hydrogen at the concentration of $2.7 \times 10^{19}$ cm$^{-3}$. Part of the laser radiation by the glass plate 5 and the mirror 4 through the interference filter 3 was directed to the photodiode 2 to control the laser pulse energy and synchronize the whole lidar operation (the $U_0$ signal is a reference signal that sets the start of the time zero, and its amplitude is the laser pulse energy). The Raman backscattered by molecules H$_2$ radiation was collected from the distance up to 2 m by the Newton type telescope with the spherical mirror 10 and a lens 9 into the fiber light guide 6 and through the interference glass filter 7 with a maximum
transmission at the Raman wavelength with the half-width of 2 nm was directed to the photo detector 8, the \( U_R \) signal from which was recorded by the special measuring system [15] online with PC, and was proportional to the Raman pulse energy of hydrogen molecules. The mean \( U_R \) values with errors for multiple measurements at each ranging distance \( z \) are shown in table 1.

Table 1. Measured signal values and hydrogen molecules Raman scattering pulse energy values for different ranging distances

| \( z, \text{ м} \) | \( U_R, \text{ В} \) | \( \Delta U_R, \text{ В} \) | \( E(z), \text{ мкДж} \) |
|---|---|---|---|
| 0.97 | 0.95 | 0.12 | 0.36 |
| 1.1 | 0.80 | 0.14 | 0.31 |
| 1.3 | 0.68 | 0.15 | 0.23 |
| 1.6 | 0.35 | 0.16 | 0.13 |
| 1.75 | 0.19 | 0.17 | 0.09 |

To recalculate the Raman lidar signal amplitude into the Raman pulse energy, the calibration experiments have been carried out to measure the transfer coefficient of the photodetector module [2]. These experiments results processing made it possible to obtain the transfer coefficient of the optoelectronic block \( K_f = 0.4 \pm 0.1 \text{ μJ/V} \). According to the data of the Raman scattering energy values given in the fourth column of Table 1 the dependence of the hydrogen molecules Raman scattering pulse energy \( E_r \) on the ranging distance \( z \) is plotted in figure 4.

![Figure 4](image_url)

**Figure 4.** The plot of the hydrogen molecules Raman scattering pulse energy \( E_r \) on the ranging distance \( z \) dependence.

5. \( \text{H}_2 \) molecules Raman scattering differential cross section

The Raman signal power in general case was connected with the measured energy at the \( \lambda \) wavelength registered by the photo detector in the \( \tau_l = 50 \text{ ns} \) measurement time duration by the next dependence \( P(\lambda,z) = E(\lambda,z)/\tau_l \), where \( P(\lambda,z) \) is the Raman signal power at the photo detector at the \( \lambda \) wavelength from the distance \( z \); \( E(\lambda,z) \) is the Raman pulse energy at the same wavelength and \( \tau_l \) is the laser pulse duration.

The registered Raman scattering power in our experimental condition with the suggestion about one time back scattering and the radiation extinction absent at the atmospheric path up to 2 m can be described by the Raman lidar equation as [2, 15]:
where $P(\lambda , z)$ is the Raman signal power at the photo detector at the $\lambda$ wavelength from the distance $z$; $P_L$ is the laser power; $\lambda_w$ – the laser radiation wavelength; $K_1$ – the lidar constant; $\Delta z$ – the step by distance; $\Delta z = c\tau / 2$; $A_0$ is the receiving telescope cross section; $(d\sigma/d\Omega)$ is the studied molecule Raman differential cross section at the laser radiation wavelength and $N_o$ – the molecules concentration.

Further, for our Raman lidar variant we can single out in the lidar constant $K_1$ the factor $\xi(\lambda)$ depending on the spectral sensitivity of the photo detector photocathode in the form of the expression $K_1 = K_2 \xi(\lambda)$, where $K_2$ is the new lidar constant equal to 0.495 at the 532 nm wavelength (according to our measurements in [15]). The photocathode relative spectral sensitivity at the 683.2 nm wavelength is equal to $\xi(\lambda) = 0.25$ by the data [16].

The solution of the Raman lidar equation (1) with such a parameters allowed to find the Raman differential cross section of $H_2$ molecules $(d\sigma/d\Omega)$ at the 532 nm laser radiation wavelength excitation. It is equal to $(4.3 \pm 0.9) \cdot 10^{-30}$ cm$^2$/sr, which is in good agreement with the data of other authors [2].

Using this value we perform the lidar equation (1) computer simulation, rewriting it for the photons number [2, 17], for the 405, 532, and 650 nm laser radiation wavelengths with the laser pulse repetition rate of 100 kHz, pulse energy 1 mJ and the ranging distance from 5 m to 100 m and we obtain the measurement time $t$ on the ranging distance $z$ dependences shown in figure 5 for the hydrogen molecules concentration $N(z) = 10^{13}$ cm$^{-3}$ and the selected laser radiation wavelengths at the Raman lidar remote sensing in the atmosphere shown in figure 3.

Figure 5. The plot of the measurement time $t$ (in a logarithmic scale, in s) on the ranging distance $z$ dependence for hydrogen molecules concentration $N(z) = 10^{13}$ cm$^{-3}$ and 405 (1), 532 (2) and 650 nm laser radiation wavelengths when such a lidar remote senses the atmosphere

Therefore, for hydrogen molecules lidar remote sensing the measurement time from 400 ms to 2.65 min is sufficient, that can be implemented in a single Raman lidar at the specific experimental conditions [15, 17].
6. Conclusion
Thus, we have found the studied H₂ molecules Raman differential cross section \( \frac{d\sigma}{d\Omega} \) at the 532 nm laser radiation wavelength, using which it is possible to measure the molecular hydrogen concentration of \( N(z) \) in the gas flows and clean atmosphere at the specified distances from the laser with high accuracy and a spatial resolution of 7.5 m. The measurement time range from 400 ms to 2.65 min was obtained for the hydrogen molecules sensing, which makes it possible to use the Raman lidar at the specific experimental conditions.

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