INVESTIGATION OF HYDROGEN COMBUSTION IN HYDROGEN CATALYTIC RECOMBINERS AND SENSORS

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Hydrogen energy is very perspective, as provides high efficiency and ecological cleanliness of energy conversion. The main requirement to operation with hydrogen is the good ventilation. Except for it effective way of protection against dangerous development of emergencies (for instance, leaks) is neutralization of dangerous hydrogen-air mixtures by a method of controlled catalytic combustion in special devices, so-called recombiners. The basis of these devices is a high porosity cell material (HPCM) activated by platinum deposition. Such a material consists of hollow cells with the characteristic dimension of several millimeters and with walls coated by a thin porous secondary layer from γ-Al_2O_3. The thickness of γ-Al_2O_3 coating is 20–50 μm, the specific surface of HPCM with γ-Al_2O_3 layer is 10–25 m^2/g. Thus, HPCM can be characterized by a double porosity: a macroporosity – ratio of the free volume of cells to the total HPCM volume; a microporosity – a porosity of walls of HPCM cells. Based on provided by the authors experimental and theoretical studies of hydrogen combustion processes, heat- and mass transfer, and also gas flows in catalytic-activated HPCM, hydrogen sensors and recombiners have been developed [1-3].

Developed recombiner consists of a convective case and mounted into it lower part the catalytic element: HPCM plate located in the removable cartridge. The convective case is designed as a rectangular (Fig. 1) or circular pipe. Grids protect the inlet and outlet from the case (to predict ignitions of ambient media). The convective case is placed upright for creation of a natural convection ("the chimney effect"). Then hydrogen concentration becomes higher than critical one (for hydrogen-air mixes more than 0.7 vol. % at ambient temperature) activated HPCM spontaneously starts hydrogen oxidation. As a consequent there is a spontaneous heating of a catalytic element and convective circulation of gas mixture through a recombiner. Thus, the recombiner operates automatically without external energy source and control facilities. Recombiner productivity depends on its dimensions and can be calculated on the basis of a developed physical model of such devices (see below). So, for example, at the about 1 m height of the convective case the linear speed of air circulation exceeds 1 m/sec.

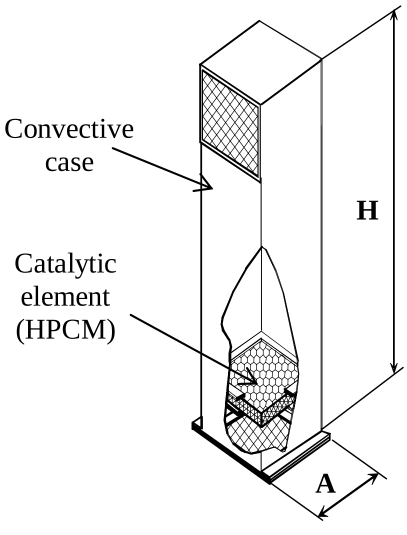

Figure 1. Catalytic hydrogen recombiner

Let's consider stationary moving of air in a vertical pipe (chimney) of recombiner with cross section S and height H, at the bottom of which is placed a thin HPCM plate. Air with a volumetric hydrogen contents C enters from the bottom of the convective case with speed U_o at temperature T_o, heats up to temperature T as a result of an oxidizing of a part of hydrogen in a HPCM volume and, accordingly, is accelerated up to speed U.

An equation of continuity: $\rho_0 U_0 = U\rho$, where ρ_0 and ρ - density of "cold" and heated air.

The change of density is bound to the temperature change: $\rho = \dfrac{\rho_0 T_0}{T}$. The temperature increase of an air flow owing to hydrogen recombination (C_0-C): $\Delta T = T - T_0 = \alpha(C_0 - C)$, where α=83.5 K/1%vol.

In stationary flow the total forces acted on an air pole in a recombiner are equal 0. From the most common reasons it follows that in this case the pressure drop on a HPCM volume is defined by the formula: $\Delta p = p_2 - p_1 - g\int_0^H \rho dz - \dfrac{\Sigma F_{mp}}{S}$. In this formula p_2-p_1 – pressure difference between the top and bottom the pipe, $\frac{\Sigma F_{mp}}{S}$ - total frictional forces of air pole about a chimney wall. As is known from the theory and practice of convection calculations in the atmosphere, the pressure on an inlet and outlet of a pipe coincides with the atmospheric one , varying at the height z under the law: $p=p_0+\rho_0 gz$, thus $\Delta p_a=p_2-p_1=\rho_0 gH\Delta T/T$.

Let's neglect cooling of an air flow in a pipe, for example, in case of application of a heat-insulating convective case, and also all gasdynamics resistance, supposing by their small in matching with a HPCM resistance. In this case ρ=const at the height of a chimney: $\Delta p=gH(\rho_0-\rho)=\rho_0 gH(T-T_0)/T_0$,; $\Delta p = \rho_o gH \frac{\alpha\Delta c}{T_o + \alpha\Delta c}$, $T=T_0+\alpha\Delta C$. Owing to the presence of such a pressure drop air transits through a HPCM volume, overcoming its resistance it is known from experiment: $\Delta p_g=A\,v^n\,(1+\beta\Delta T)$, where A, H and β - experimental constants for a concrete size of a HPCM in real conditions of hydrogen oxidizing; $\Delta T=\alpha(C_0-C)$. Thus, $\rho_o gH \frac{\alpha\Delta c}{T_o+\alpha\Delta c} = A v^n\left[1+\beta\alpha\Delta c\right]$. The rate of flow: $V = \left(\frac{\rho_o g}{A}\right)^{1/n} H^{1/n} \frac{\alpha\Delta c}{(T_o+\alpha\Delta c)(1+\beta\alpha\Delta c)}$. Apparently a recombiner capacity, i.e. speed of hydrogen burning: $Q = SV\Delta C$.

In real conditions of the hydrogen recombination process in used HPCM samples the complete hydrogen burning was observed practically. In this case:

$$Q = S\left(\frac{\rho_o g}{A}\right)^{1/n} H^{1/n} C \frac{(\alpha c)^{1/n}}{T_o(1+\frac{\alpha c}{T_o})(1+\beta\alpha\cdot c)}.$$

The obtained formula defines, apparently, maximal productivity of a concrete recombiner with concrete samples of a HPCM. Provided tests of pilot samples of recombiners have shown rather a good correlation of experimental data with model calculations.

Besides recombiners, HPCM was applied for development of hydrogen sensors intended for measurement and analysis of hydrogen concentration for hydrogen transport and objects of hydrogen infrastructure (including vapor-air media at high pressures and temperatures). The basic idea of a given detector design based on measurements of a temperature difference between an ambient medium and disk HPCM element activated by platinum, through which one convective flow of analyzed gas passes.

Thus, the hydrogen safety system, which can be used for hydrogen transport and objects of hydrogen infrastructure, was developed. Experimental and theoretical studies of hydrogen combustion processes, heat- and mass transfer, and also gas flows in catalytic-activated HPCM have permitted one to optimise a design of recombiners and its location. Pilot samples of hydrogen sensors and hydrogen catalytic recombiners were made and their laboratory tests were successful provided.

References

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