EXPERIMENTAL STUDIES OF STRATIFICATION AND COMBUSTION OF STRATIFIED HYDROGEN-AIR MIXTURES IN A VERTICAL CLOSED CHANNEL

S. A. Yakovlev, V. V. Stakhanov, E. V. Bezgodov, A. A. Tarakanov, S. D. Pasyukov, M. V. Nikiforov, I. A. Popov

FSUE «RFNC—VNIITF named after Academ. E. I. Zababakhin», Snezhinsk, Russian Federation

Currently, there is a growing interest in hydrogen energy, since the use of hydrogen as a means of accumulation and an energy source allows to reduce the amount of greenhouse gas emissions into the atmosphere.

Hydrogen has the highest diffusion coefficient and the lowest ignition energy, and a mixture of hydrogen with air is flammable in a wide concentration range of fuel measurement, therefore, when using it, increased requirements are imposed on the safety of infrastructure facilities compared to the use of hydrocarbons.

An emergency situation with the combustion of a hydrogen-air mixture is preceded by a hydrogen leak. In the event of a hydrogen leak near the earth's surface, a hydrogen-air mixture with a «negative» concentration gradient directed against the Archimedes force can form. The probability of the formation and ignition of gradient mixtures during an emergency is significantly higher than uniformly mixed ones. In turn, the presence of a concentration gradient can have a reinforcing effect on the flame acceleration process. The impact during combustion is assessed using validated calculation codes.

The combustion of stratified hydrogen-air mixtures was studied using a vertically oriented BM-K setup, which is a closed channel with a square cross-section of 0.6×0.6 m and a height of 12 m.

The purpose of this work was to obtain experimental data on the stratification and combustion of stratified hydrogen-air mixtures with a «negative» hydrogen concentration gradient for the validation of calculation codes.

The initial conditions and the results of the experiments on the stratification and combustion of stratified hydrogen-air mixtures are presented in Table 1. Gradient mixtures were characterized by the degree of heterogeneity gamma, defined as the ratio of the maximum volume fraction of hydrogen to the average.

Initially, the setup contained air under atmospheric pressure. Hydrogen was fed into the channel volume through three inputs located on the lower cover with a total flow rate of 10 l/s until the mixture pressure P was reached. After the hydrogen was fed, the mixture was held for some time t (from the moment of feeding) and ignited from below by a spark discharge with an energy of 20 mJ.

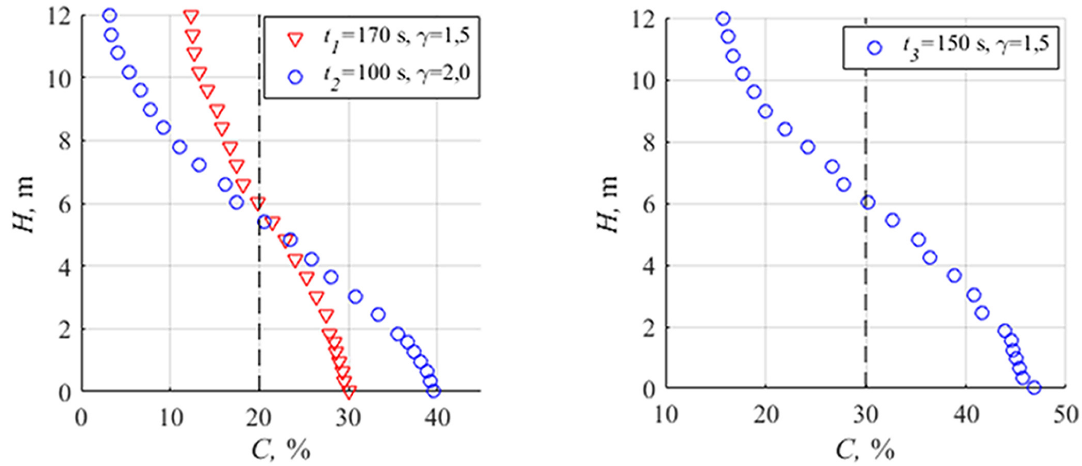
Table 1

Initial conditions and results of experiments

№	P_0, kPa	$\overline{C}$, %*	P_1, kPa	t_f, s	γ	ΔP, kPa	u_{max}, m/s
1	79.9±0.2	20.9±0.3	101.0±0.3	900	–	–	–
2	80.0±0.2	20.7±0.3	100.8±0.3	900	–	–	–
3	70.0±0.2	31.3±0.3	101.6±0.3	900	–	–	–
4	70.0±0.2	31.4±0.3	101.7±0.3	900	–	–	–
5	80.0±0.2	20.5	100.6±0.3	170	1.5	521±13	286
6	79.8±0.2	21.5	101.7±0.3	170	1.5	540±13	318
7	80.0±0.2	21.5	101.9±0.3	170	1.5	538±13	280
8	80.0±0.2	21.2	101.5±0.3	100	2.0	669±13	489
9	80.0±0.2	21.0	101.3±0.3	100	2.0	449±13	282
10	80.1±0.2	21.3	101.8±0.3	100	2.0	521±13	313
11	70.0±0.2	31.7	102.5±0.3	150	1.5	660±13	182
12	70.0±0.2	31.5	102.2±0.3	150	1.5	547±13	172
13	70.0±0.2	30.6	100.9±0.3	150	1.5	550±13	169

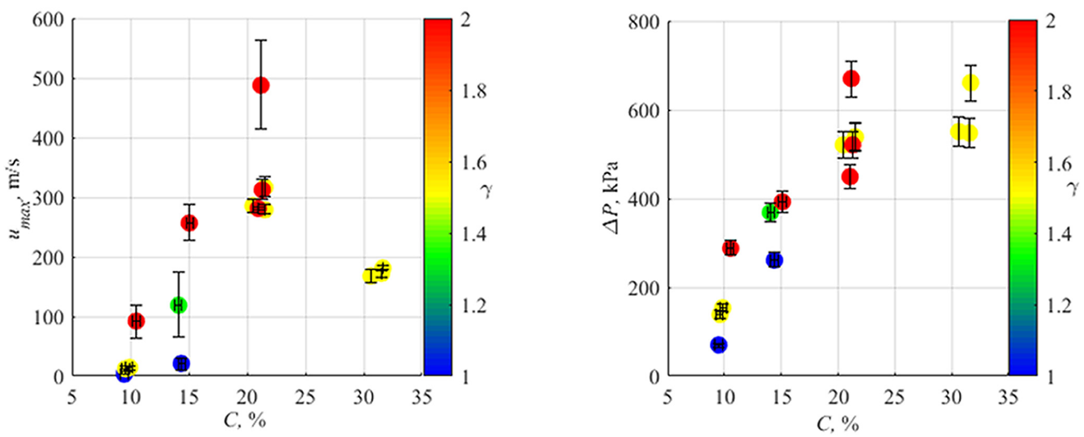
* – in experiments without initiation, the combustion is determined by the readings of the hydrogen sensors, in experiments with combustion – by the manometric method using the pressure sensor.

Based on the results of the experiments, the distributions of the volume fraction of hydrogen at different moments in time (Fig. 1), the maximum flame front velocity and the peak excess pressure (Fig. 2) in the combustion experiments were obtained. Fig. 2 shows the results obtained in the works carried out earlier.



a *b*

Fig. 1. Distribution of the volume fraction of hydrogen at different time points in combustion experiments with (*a*) $\overline{C}$ = 20 %, (*b*) $\overline{C}$ = 30 %



a *b*

Fig. 2. Maximum flame front velocity (*a*) and peak overpressure (*b*) in combustion experiments

It has been determined that in stoichiometric and rich hydrogen-air mixtures the presence of a gradient reduces the flame's ability to accelerate.

References

1. **Gelfand, B. E.** Termodinamika gorenija i vzryva vodoroda [Text]. – St. Petersburg : Politech. Inst. Publs, 2009.
2. **Vollmer, K. G.** Deflagration-to-detonation transition in hydrogen/air mixtures with a concentration gradient [Text] / K. Vollmer, F. Ettner, T. Sattelmayer // Comb. Sci. Tech. – 2012. – Vol. 184. – P. 1903–1915,
3. **Yakovlev S. A.** Experimental studies of combustion processes of stratified and uniform hydrogen-air mixtures [Text] / Yakovlev S.A., Bezgodov E.V., Stakhanov V.V. // Atomic Energy. – 2023 – Vol. 134, No. 5–6. – P. 380–385. Doi: 10.1007/s10512-024-01069-9 2023.
4. **Yakovlev, S. A.** Experimental study of the combustion of hydrogen-air mixtures with a negative concentration gradients [Text] / S. A. Yakovlev, V. V. Stakhanov, E. V. Bezgodev, et al. // Abstracts XVII All-Russian Symposium on Combustion and Explosion. – 2024. – P. 108–110.