# Explosion of free hydrogen jet release

**Aleksandrov A.O.[1], Alekseev V.I[1], Chernenko E.V.[1], Efimenko A.A.[1], Gavrikov A.I.[1], Mayorov A.S.[1], Matsukov I.D.[1], Schepetov N.G.[1], Velmakin S.M.[1], Zaretskiy N.P.[1]**

[1] Institute of Applied Chemical Physics,
Russian Research Centre Kurchatov Institute, 123182, Kurchatov Sq. 1, Moscow, Russia

## 1 Introduction

Hydrogen is a renewable energy which could meet most of our future energy needs and reduce our reliance on oil. The hydrogen utilization in industry and everyday life will require new safety codes and standards. Hydrogen safety development requires detailed data in such fields as hydrogen distribution processes at ejections, explosive mixtures formation, ignition conditions, and possible combustion regimes. Now there is a set of reviewed publications devoted to safety issues of use of hydrogen as a perspective kind of fuel, capable to replace traditional hydrocarbon ones [1-2]. Recent workshop on unintended hydrogen releases stated that one of the most common release scenarios involves leaks from pressurized hydrogen-handling equipment [3]. These leaks range from small-diameter, slow-release leaks originating from holes in delivery pipes to larger, high-volume releases resulting from accidental breaks in high-pressure storage tanks. In all cases, the resulting hydrogen jet and corresponding combustible cloud represents a potential hazard.

A scenario in which a high-pressure leak of hydrogen is ignited at the source is best described as a classic turbulent-jet flame [4]. While laboratory-scale, subsonic-jet flames burning hydrocarbon fuels have been studied extensively, data for larger-scale, subsonic and, in particular, sonic (choked) jet flames is less available.

It is worth to note works connected with spontaneous ignition of hydrogen at the moment of ejection from a vessel [5-6]. The authors studied initial conditions for spontaneous hydrogen ignition and conditions for stable combustion of jet numerically and empirically. However the data on experiments in the open air, modeling hazardous hydrogen ejections, are rather limited now. Processes of hydrogen distribution at powerful ejection or leakage of hydrogen are not studied enough. Possibility of spontaneous hydrogen ignition at powerful jet ejections is not evaluated.

Most of the known experimental works are laboratory investigations of small hydrogen ejections (up to 50 g) [7]. Explosion processes in nonuniform mixtures formed at powerful jet ejections are not explored also. The objective of the present work is to investigate distribution and combustion of high pressure jet releases under different geometrical conditions. The mass of ejected hydrogen varied from 0.05 to 1.00 kg.

## 2 Experimental details

The present experimental investigation is dedicated to hydrogen distribution and combustion at large ejections of hydrogen both into free space and into congested area. Experimental setup scheme is

**Correspondence to:** gavrikov@iacph.kiae.ru 

shown in Fig. 1. The experimental setup allowed producing high pressure hydrogen ejections from 0.05 to 1.00 kg mass. Hydrogen concentration and combustion parameters were recorded by the specially designed data acquisition system. Hydrogen ejections were controlled by the special high speed electromagnetic valve mounted on the pipeline end. The welded cubic framework was set on the path of hydrogen jet for mounting wooden obstacles and different types of transducers (pressure, light, hydrogen concentration, heat flux). Video filming and BOS photography (Background Oriented Schlieren technique) were used to visualize hydrogen distribution and combustion processes in experiments. Two values of blockage ratio (BR) were used in experiments – BR=0.3 and BR=0.54. Roof cover for cube was used in a part of experiments for modelling of worst case scenario. In some experiments additional small congested area together with main congested area was used. Additional small congested area was set up at nozzle axe 12 cm from the nozzle end.

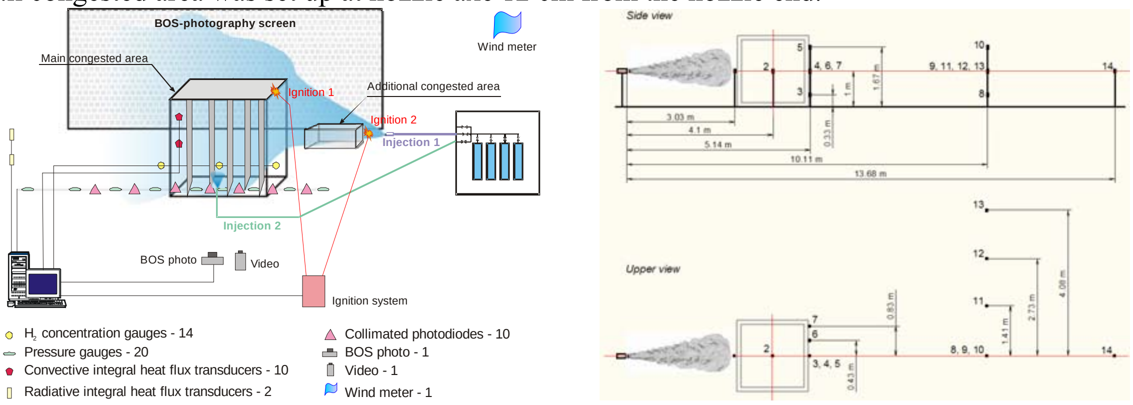


Figure 1. Schemes of experimental facility and hydrogen concentration sensors location in experiments.

A special high speed valve was set at the exit of general pipeline. Orifice diameter varied from 6.0 to 5.3 mm to provide hydrogen flow rate in the range from 180 to 220 g/s. Most experiments were carried out with the orifice diameter 5.3 mm.

Two kinds of ignition sources were used in experiments. One ignition source was a heated nichrome wire installed on the upper tube of the front cube face. The ignition source was developed in such a way that 10-mm heated nichrome wire fell down through the hydrogen jet at the moment of ignition. Another ignition source was an electric spark of approximately 1-J energy. The ignition source was installed on the upper tube of the front cube face.

The following data was recorded in the experiments on hydrogen distribution and combustion at high pressure ejections:

- Schlieren photography of high pressure hydrogen jets.
- Hydrogen concentration in jets.
- Video recording of combustion processes.
- Combustion and explosion parameters (pressure, light, and heat flux data).

Locations of hydrogen concentration sensors are shown on Fig. 1.

Ambient temperature varied from 7 to 18°C and atmospheric pressure was around 760 Torr. Wind speed was less than 0.5 m/s during all experiments.

## 3 Results and discussion

All experiments on distribution and combustion of high pressure hydrogen jet ejections were carried out in two stages. The first stage – experiments without ignition on hydrogen content in high pressure jets and their visualisation by means of BOS photography. The second stage –experiments with recording of dynamic parameters of hydrogen jets combustion. In total more than 100 experiments were conducted. Different scenarios of ignition of high pressure jet release took place:

- Quenching mode without combustion of jet release

- Diffusion combustion of jet release without overpressure
- Slow combustion of jet release with small overpressure
- Fast combustion of jet release with high overpressure

One the possible scenarios of high pressure jet release ignition are releases without combustion. This scenario is possible only for open area without congestion.

Second possible scenario of high pressure jet release ignition cloud is diffusive combustion of release. This scenario is possible only for open area with congestion, but level of congestion may vary. Average flame velocity along the hydrogen cloud turned out to be 37 m/s. Very weak conductive heat flux was recorded in this experiment with the value about 2.6 kJ/m2. Estimation of average conductive heat flux density gives 26 kW/m2.

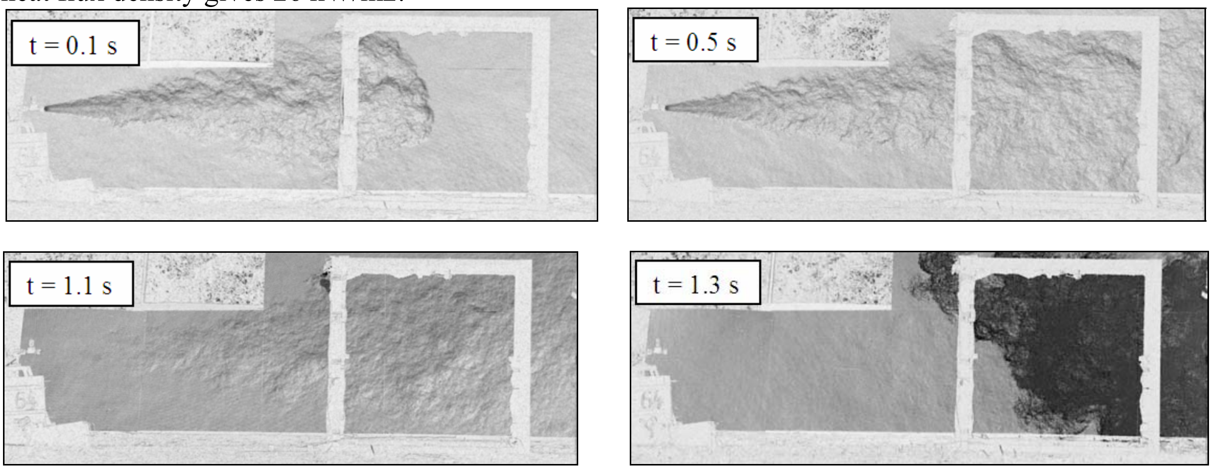


Figure 2. Sequence of BOS-photos of diffusive combustion experiment ($M_{H2}$=203 g, $W_{aver}$=188 g/s).

Third possible scenario of high pressure jet release ignition cloud is slow combustion of release with small overpressure. This scenario is possible only for open area with high level of congestion or with additional congested area or with cube roof. Maximum pressure reaches 0.38 bar in one of the experiments and visible flame speed of combustion process was 160 m/s. Heat flux reached 224 kJ/m2 (gauge located at the center of the cube) and radiative heat flux was 221 J/m2 at distance 16.8 m from the center of the cube.

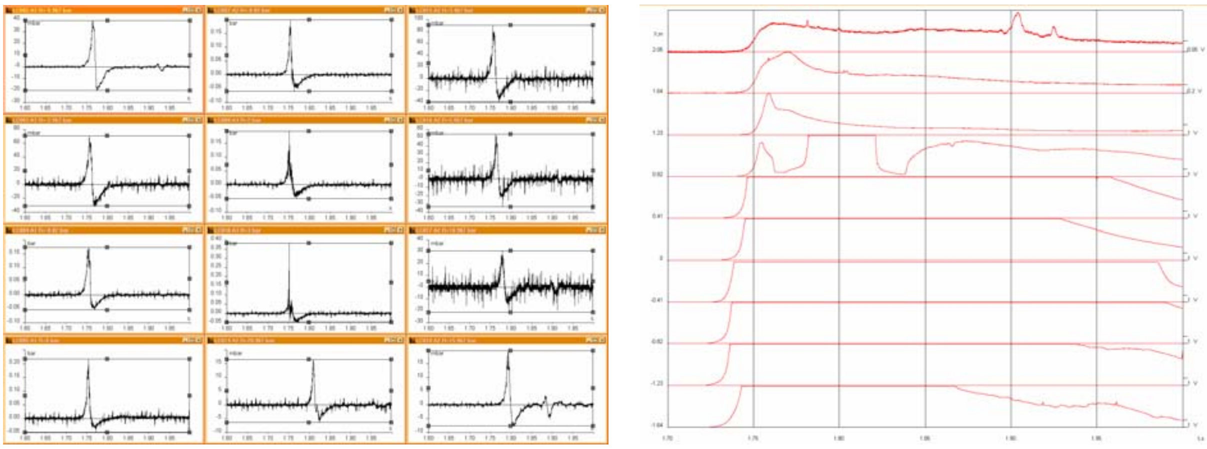

Figure 3. Pressure records of all gauges and X-t diagram based on light signals from photodiodes, slow combustion experiment.

For a modeling of possible severe accident scenario of high pressure hydrogen jet release another experimental configuration was chosen. Cube was enclosed with thin polyethylene film and top was covered with hard cover. The additional small congested area was set up on a top cover and top of that

area was open to air. Effective BR for this configuration was 0.6. Ejection was performed from the ground at the center of the cube bottom. Overall ejection time was 7 s, mass of hydrogen – 346 g. The resulting mixture was well premixed with the average concentration ≈40% vol. Hot wire ignition source was set up under additional small congested area at 59 cm height from top.
Maximum overpressure in experiment reached ΔP=10.9 atm. Combined increase of congestion and confinement results in significant rise of blast parameters (about 30 times overpressure increase).

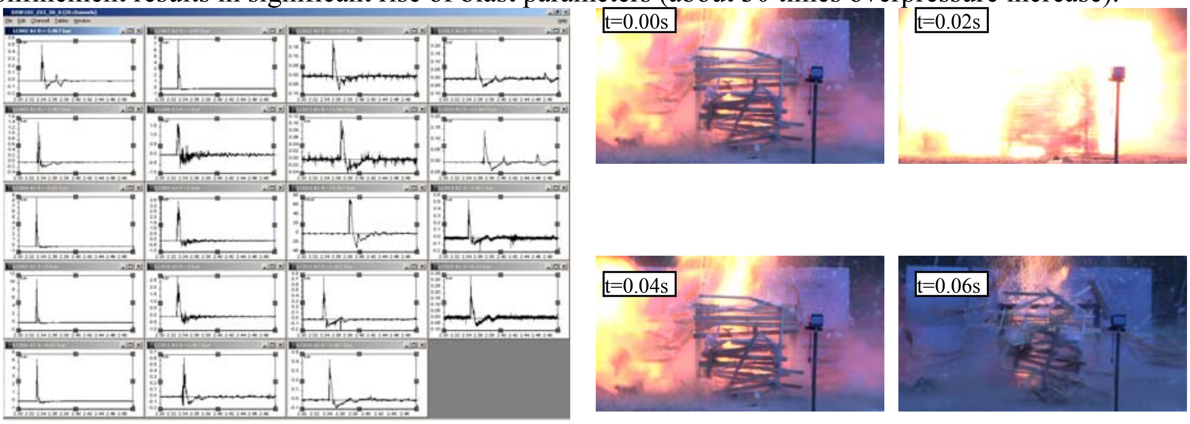


Figure 4. Pressure records of all gauges and video frames of strong combustion experiment.

## 4 Conclusions

Mechanical loads resulting from hydrogen jet release explosion depend significantly on geometrical characteristics of surrounding space. Hazardous level of loading is possible. Explosion hazard of strong hydrogen ejection needs further investigation.

## References

[1] Fischer, M. (1986) Safety aspects of hydrogen combustion in hydrogen energy systems. Int. J. Hydrogen Energ., 11, 593–601.

[2] Introducing Hydrogen as an energy carrier. Safety, regulatory and public acceptance issues. (2006). Directorate-General for Research Sustainable Energy Systems, EUR 22002.

[3] Schefer R.W., Houf W.G., Moen C.D., Chan J.P., Maness M.A., Keller J.O., et al. Hydrogen codes and standards unintended release workshop: workshop analysis. Workshop held December 12, 2003 at Sandia National Laboratories, Livermore CA, 2004.

[4] S.R. Turns, An introduction to combustion (second ed.), McGraw-Hill, New York (2000)

[5] Dryer F. L., Chaos M., Zhao Z., Stein J. N., Alpert J. Y., and Homer C. J. (2006). Spontaneous ignition of pressurized releases of hydrogen and natural gas into air. Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ.

[6] Astbury G.R. and Hawksworth S.J. (2007). Spontaneous ignition of hydrogen leaks: a review of postulated mechanisms. International Journal of Hydrogen Energy, 32:2178-2185.

[7] Friedrich, A., Grune, J., Kotchourko, N., Kotchourko, A. Sempert, K., Stern, G., Kuznetsov, M., Experimental study of jet-formed hydrogen-air mixtures and pressure loads from their deflagrations in low confined surroundings. In Proceedings of the 2nd International Conference on Hydrogen Safety, 1.1.125, San Sebastian, 2007.