

Detonation of Propane-Air Mixture in the Perforated Tube and Release of Detonation Products

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Basic mechanisms of the deflagration-to-detonation transition (DDT) in the unconfined clouds of emergency industrial releases are formulated in [1, 2] which state that these are: *(i)* large-scale energetic eddies found in the unburned gas in the turbulent pockets behind obstructions or ahead of flame wakes, *(ii)* a sufficiently intense fine structure of turbulence required to enhance the mixing of hot combustion products with initial reagents in the above eddies, *(iii)* a gradient field of induction time in the turbulent pocket; this field is needed to bring about shock wave amplification by the coherent energy release.

RFNC-VNIITF proposed the way and TSD-01M facility, which are used to investigate these mechanisms “under the magnifying glass” [3,4]. The facility has a small internal partially perforated tube. The purpose of this tube is to create hot detonation products (HDP) of the fuel mixture and their release from it into the main tube of the facility through the holes arranged uniformly in staggered rows over the surface of the small tube portion.

Objective of this work was: *(i)* verifying operability of TSD-01M facility small tube (absence of detonation attenuation at different perforation extent), registering profiles of detonation waves in the tube, experimental quantification of HDP release, *(ii)* constructing the calculation model detonation and release of HDP for the perforated tube.

Experiment

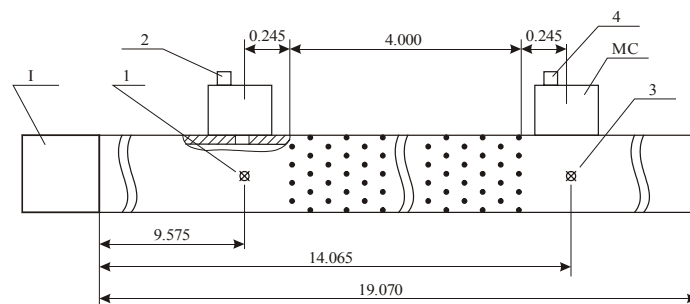
Experiments were performed with measuring chambers (MC) arranged above holes of the perforation tube portion, just at the front end and at the back end of this portion (Fig. 1).

Pressure-time ratios in measuring chambers (Fig.2) allow calculation of HDP mass injected into the chamber through one hole in a tube wall as well as determination of the jet head velocity in the chamber and sound velocity in HDP jet, i.e. its temperature assessment, by pulse shift and oscillations (Fig 3, 4). Obtained profiles of the detonation wave at different perforation of the tube portion (Fig. 5) indicate, firstly, absence of detonation quenching and, secondly, a shortened wave profile at the perforated tube portion, if compared with the profile in a smooth tube.

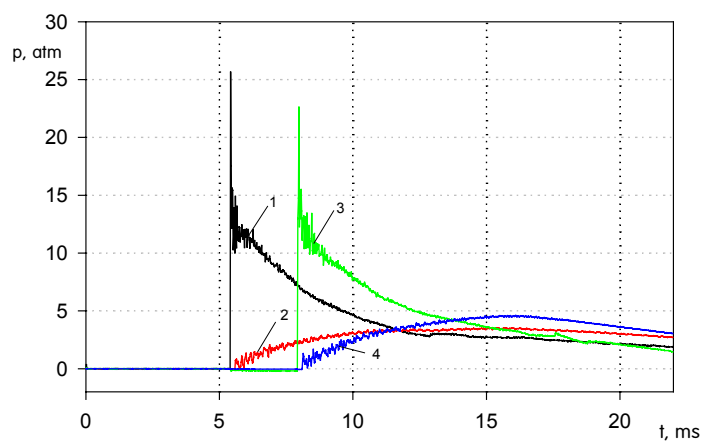
Computer simulation

One-dimensional computer code “Prognoz” is developed to simulate viscous gas detonation with the outflow of detonation products thorough the holes of the perforated tube.

Program operation is. Initially, one specifies distribution of basic flow parameters (pressure, density, velocity and specific energy) obtained for nonperforated tube for the time



a)



b)

Fig. 1. Registration of detonation parameters and jet release of detonation products prior to (transducers 1 and 2) and behind (transducers 3 and 4) the perforated portion of the tube.

a) experimental setup (outflow hole diameter in the MC – 10 mm, volume MC – 0.52 l); b) analog-digital record of the detonation profile in the tube (transducers 1 and 3) and pressure in MC (transducers 2 and 4) with plugged holes at the perforated portion (204 holes $\varnothing 6$ mm, concentration – 3.9% C_3H_8).

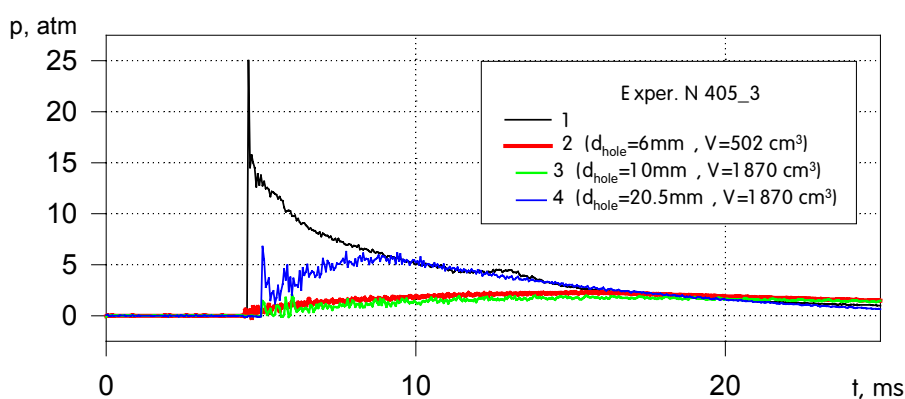


Fig. 2. Analog-digital records of pressure vs time in the case of the unit with measuring chamfers.

1 – pressure in tube; 2, 3, 4 – pressure in measuring chambers.

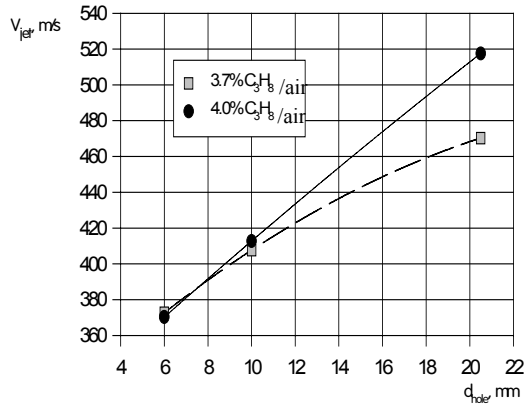


Fig. 3. Average velocity of hot detonation products jet in measuring chamber vs outflow hole diameter for different concentration of propane.

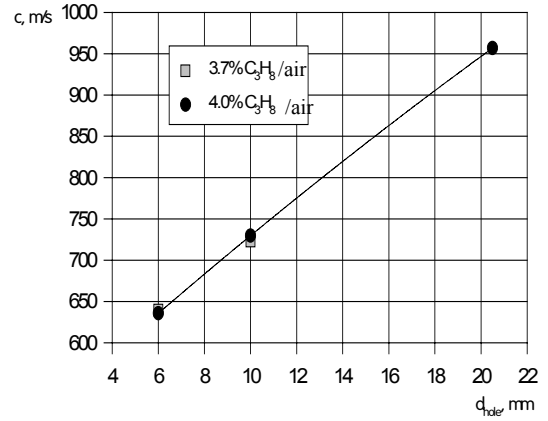


Fig. 4. Sound velocity of hot detonation products jet in measuring chamber vs outflow hole diameter for different concentration of propane.

when detonation wave reaches the front end of the perforated portion. Then, the finite difference method is used to solve the Navier-Stokes system of equations in which the outflow through the perforated wall is accounted for by the introduction of additional terms.

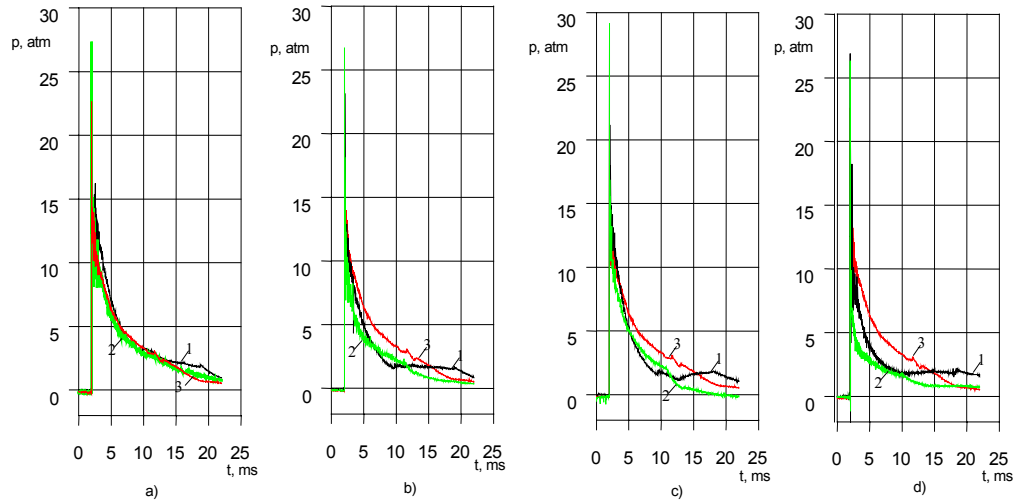


Fig. 5. Comparison of detonation profiles prior to the perforated portion of the tube (1), after the perforated portion (2) and after to the perforated portion with plugged holes (3).

- a) – 34 bands of holes 6 mm, 6 holes per band, step 121 mm, $\Sigma S_{hole}/S_{side surf.} = 0.31\%$, 3.3 vol. C_3H_8 ;
- b) – 34 bands of holes 10 mm, 6 holes per band, step 121 mm, $\Sigma S_{hole}/S_{side surf.} = 0.83\%$, 3.2 vol. C_3H_8 ;
- c) – 34 bands of holes 10 mm, 12 holes per band, step 121 mm, $\Sigma S_{hole}/S_{side surf.} = 1.67\%$, 3.5 vol. C_3H_8 ;
- d) – 68 bands of holes 10 mm, 12 holes per band, step 60 mm, $\Sigma S_{hole}/S_{side surf.} = 3.3\%$, 4 vol. C_3H_8 ;

Major difficulty of simulating the complex process under consideration consists in the identification of the law according to which the gas mixture outflows from the hole. In this case the theory of the outflow from a nozzle is applied [5].

The velocity of outflow from the hole, U_{hole} , and HDP mass flow rate, m_{hole} , are described by formulae:

$$U_{\text{hole}} = \sqrt{2[\gamma/(\gamma-1)\alpha]p_1V_1\left[1 - \left(\frac{p_2}{\alpha p_1}\right)^{\frac{\gamma-1}{\gamma}}\right]}, \quad m = \beta S U_{\text{hole}},$$

where p_1 and p_2 – pressure at the hole inlet and outlet, V_1 – specific gas volume at the hole inlet, S – hole square, γ – adiabate index, α and β – correction factors for model calibration, which take into account available jet narrowing in the hole and the difference between the true pressure at the hole inlet and the one measured in the experiment. This difference is due to the gauge remoteness from the hole in the tube cross-section.

The model was calibrated using the above results of experiments with measuring chambers.

Obtained characteristic profiles of pressure along the tube for the time when detonation wave reaches the front end, the middle, and the back end of the perforated portion are given in Fig. 6.

Comparison of calculated profiles of detonation pulses prior to and in the end of the perforated portion with experimental profiles (Fig. 7) demonstrate satisfactory agreement.

Example of the forecast calculation with the usage of the calculation model for one experiment [4] is given in Fig. 8.

Conclusions

The calculation model for the fuel mixture detonation in the perforated tube is developed. The model describes profiles of detonation wave parameters at the perforated portion and beyond it as well as the flow rate of hot detonation products from perforation holes. The model is calibrated using results of specially arranged experiments.

Acknowledgements

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References

1. G.O. Thomas, A. Jones, Some Observations of the Jet Initiation of Detonation. *Combustion and Flame* 120: 392-398, 2000.
2. A.M. Khokhlov, E.S. Oran, J.C. Wheeler. A Theory of Deflagration-to-Detonation Transition in Unconfined Flams. *Combustion and Flame* 108: 503-517, 1997.
3. V.I. Tarzhanov. The Mixture of Initial Reagents with Hot Detonation Products as the Subject of Investigations in the Shock Tube. *Submitted to 18th ICDERS*, Seattle, USA, 2001.
4. V.I. Tarzhanov, I.V. Telichko, V.G. Vildanov, V.I. Sdobnov, A.D. Zinchenko, A.E. Makarov, A.F. Khanin, A.V. Vorob'ev, I.G. Koretsky, C.L. Mukhin, A.N. Grachev, V.A. Matkin. Spontaneous Detonation in the Mixture of Initial Reagents with Hot Detonation Products. *Submitted to 18th ICDERS*, Seattle, USA, 2001.
5. L.A. Vulis. Thermodynamics of Gas Flows. Gosenergoizdat, 1950.