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PISTON "PARADOX" WITH OSCILLATING PROPAGATION OF FLAME IN THE MODEL INTERNAL COMBUSTION CHAMBER

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Content

Experimental results of piston movement and flame propagation behind the piston during propane-air mixture combustion in the channel are presented. Determinative physical parameters and critical conditions for possible effect of piston movement toward flame front called the piston "paradox" are formulated. The physical mechanisms controlled a feedback between the piston oscillations and the time-dependent flame front propagation are proposed.

Motivation

Investigation of hydrodynamic phenomena connected with the flame front propagation in pipes, mines, internal combustion chambers etc. is a typical problem of internal ballistics. The presence of cross walls, movable walls, pistons etc. in the combustion chamber makes hydrodynamic situation generating elements oscillations of the combustion chamber construction, combustion products and flame front. Currently the literature is very limited information about experimental studies of the flame front interaction with elements of combustion chamber constructions.

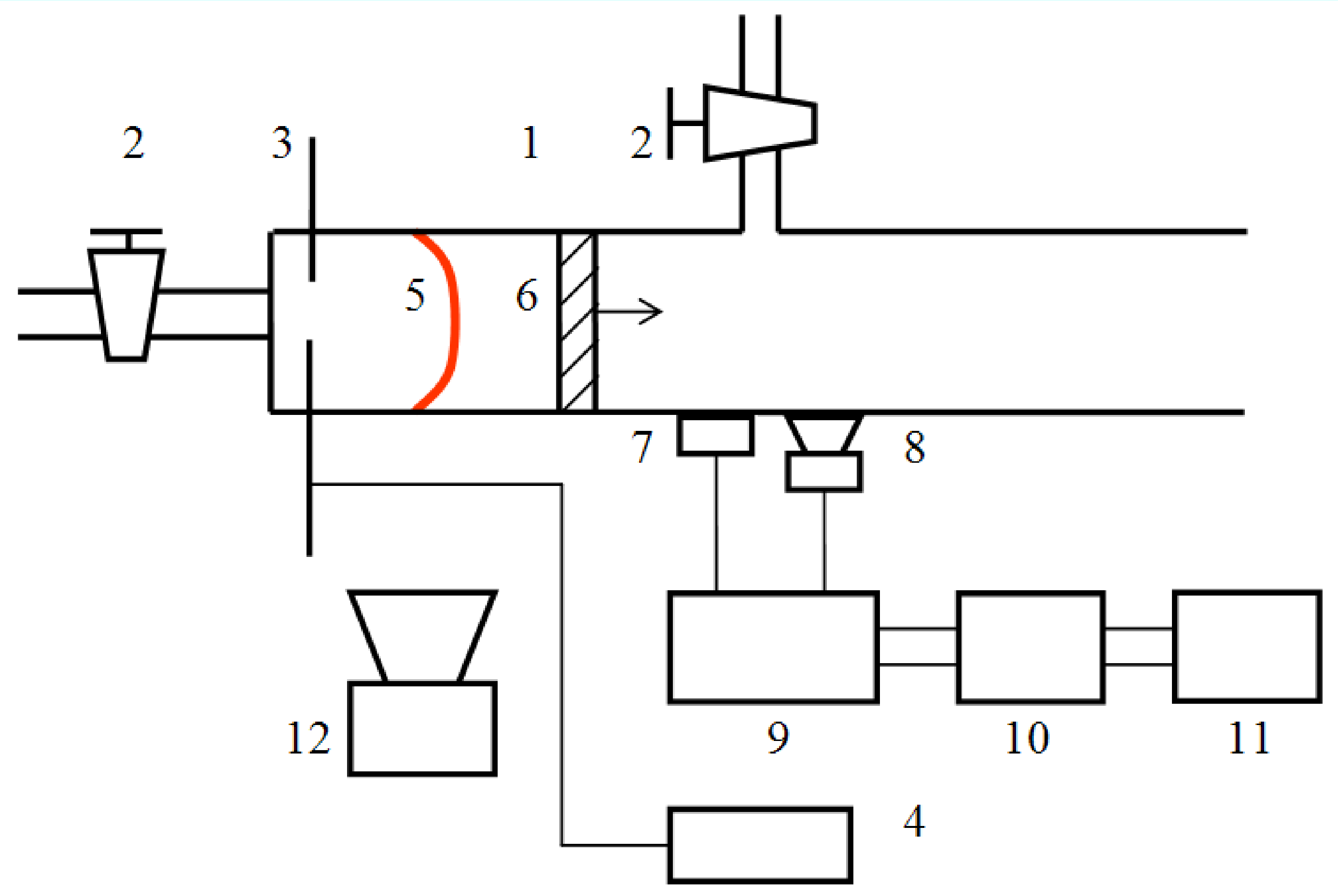
The purpose of this paper is the experimental study of regularities of propane-air flame front propagation followed by the piston in the pipe from its closed end. Distinctive feature of the experiments is exploitation of a small volume combustible gas mixture when combustion products volume equal or less than inside pipe volume. Equilibrium position is reached at equal velocity of the combustion products expansion and the piston when the piston is not affected by pressure forces from expanding combustion products.

Motivation

At the moment when the piston passes equilibrium position, followed by it into unburned combustible mixture and combustion products pressure decline occurs as at finite velocity of mixture combustion the flame front does not have time to compensate pressure drop behind the piston. The piston brakes and starts to move back. There is an oscillatory process when propagation velocities of the flame front and the piston are conformed.

In individual oscillation phases the piston can move towards the flame front. This phenomenon called the piston "paradox" in this paper is accompanied by instability of the flame front and oscillations of its propagation velocity. Velocity of the flame propagation, geometric sizes of the combustion chamber (pipe) and the piston mass determine the fundamental frequency of the oscillating system. In turn, it affects combustion instability in the combustion chamber.

Experimental setup



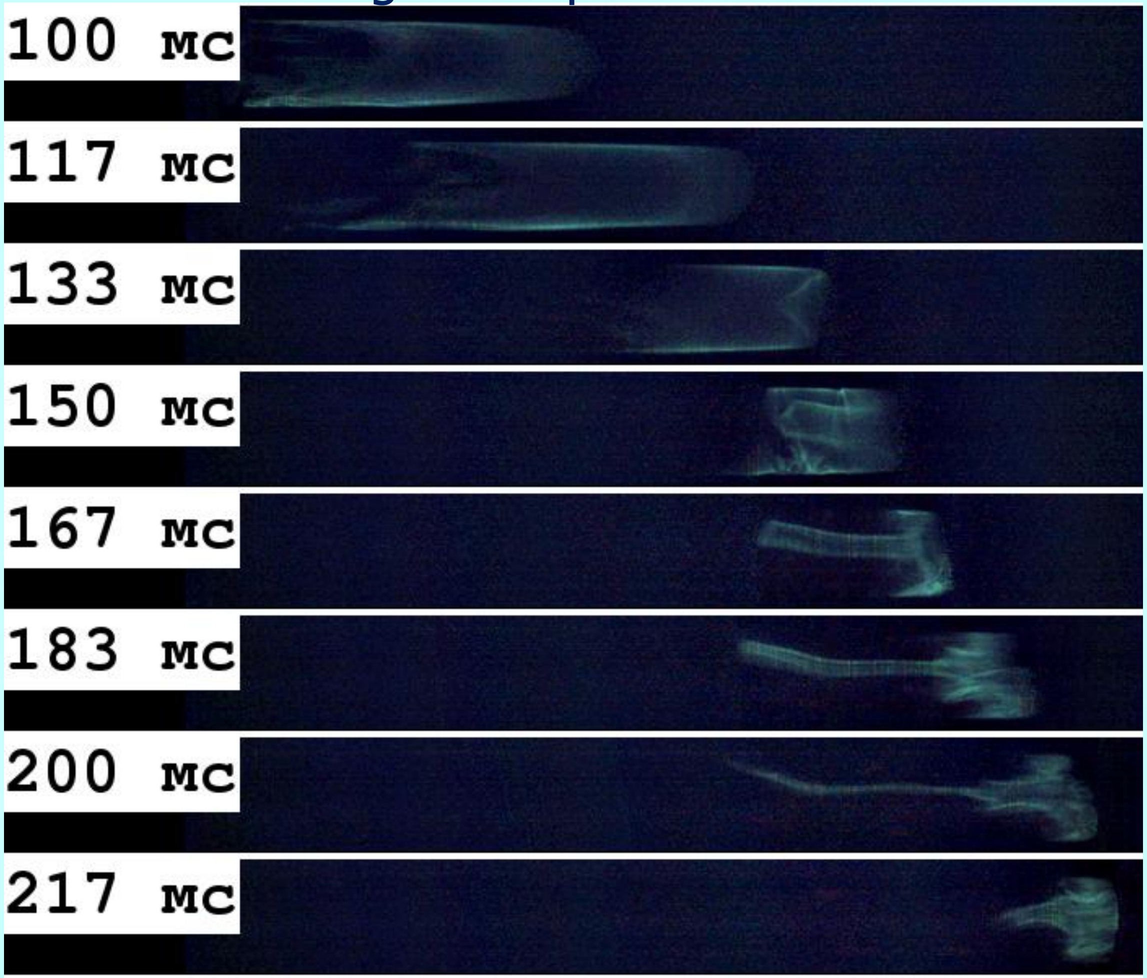
1 – tube; 2 – gas valve; 3 – electrodes; 4 – electric coil; 5 – flame front; 6 – piston; 7 – piezoceramic transducer; 8 – microphone; 9 – mixing console; 10 – analog-digital converter; 11 – computer; 12 – digital camera

Experimental technique

The cylindrical pipes and the pipes of rectangular cross-section were used. The walls of the cylindrical pipes were glass. Pipe diameter was ranged from 5 mm to 110 mm. The walls in the pipes of rectangular cross-section were made from transparent plexiglass. The minimal distance between the walls was equal to 3 mm. Combustible mixtures were prepared in the gasometer of replacement with an inaccuracy less than 0.1%. Velocity of the flame propagation was regulated by changing propane concentration in a mixture with air. The initial volume of combustible mixture was changed from V_0 to $0{,}05V_0$, where V_0 is the internal pipe volume. Propagation velocity, amplitude and oscillation frequency of the flame front and the piston was calculated by changes in the position on their images from video.

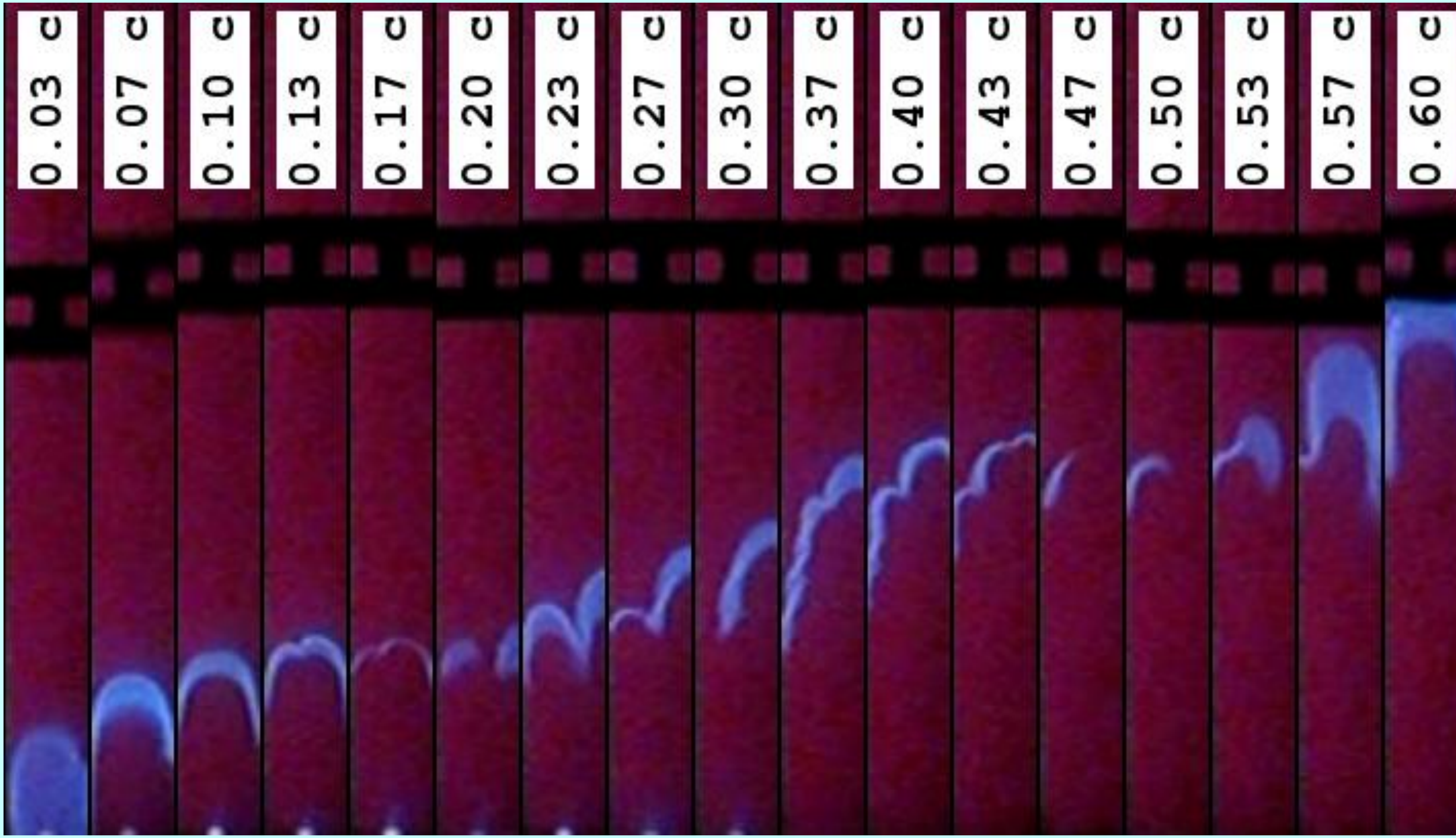
Experimental results

Hydrodynamics of the flame front in a long tube opened at one end



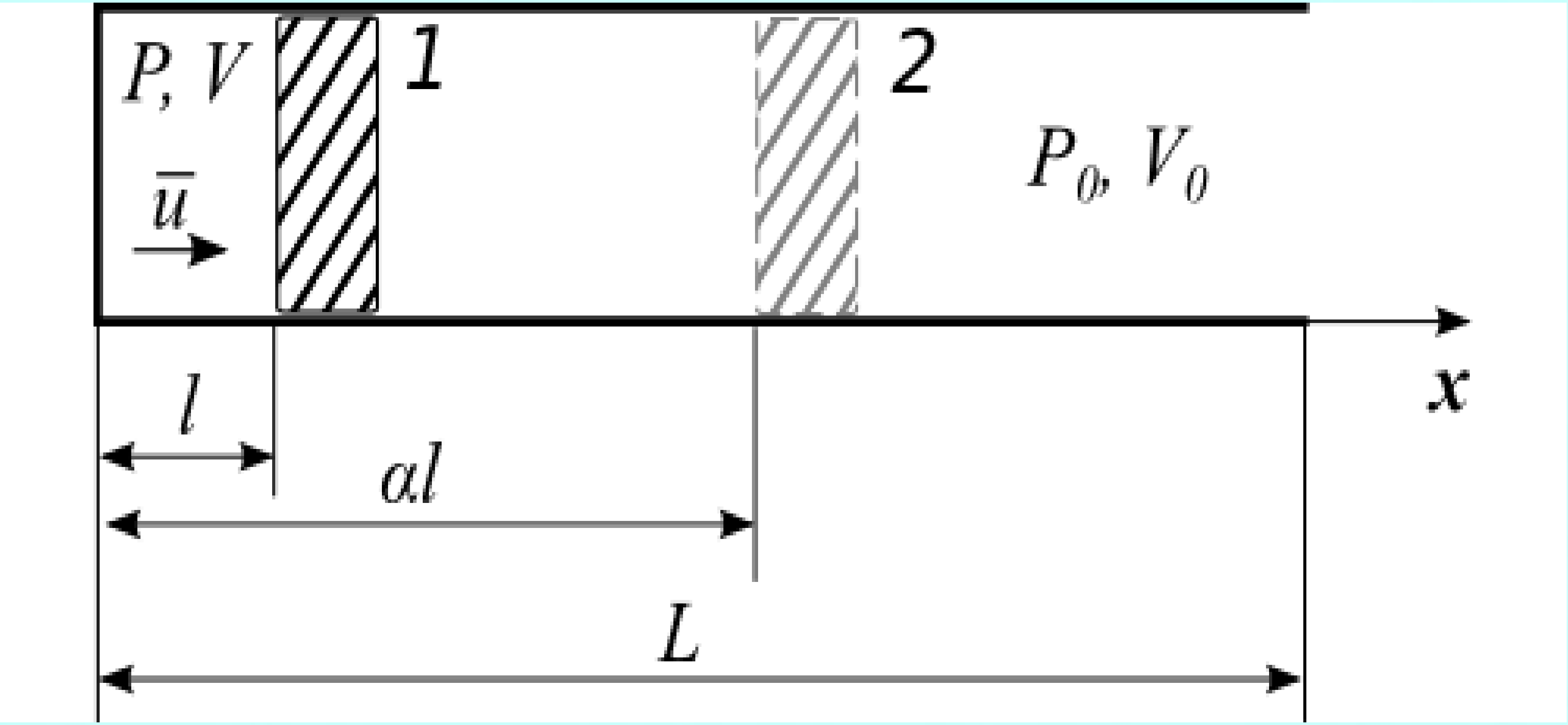
Experimental results

The video fragments illustrate propagation of the flame front and the piston during propane-air mixture combustion in a flat channel



Discussion

Designations connected with construction simplified model



Discussion

We defined the conditions for observing the piston "paradox".
Formula (1) illustrates the connection of minimal normal flame propagation velocity with combustion chamber parameters:

$$u_n = \frac{\pi}{L}\frac{V}{S_f}\frac{\mu_b}{\mu_0}\sqrt{\frac{\beta P_0}{\rho_0(\alpha+\beta-1)}}$$

u_n are normal velocity of the flame, ρ_b and ρ_0 are density of combustion products and fresh combustible gas mixture, S_f and S are surface area of the flame and the pipe cross-section, P_b and P_0 are pressure in combustion products and atmospheric pressure, μ_b and μ_0 are molar mass of the combustion products and initial gas mixture. Filling factor of pipe with gas mixture β is calculated as ratio of combustible mixture volume V to pipe volume $(V+V_0)$: $\beta=V/(V+V_0)$, V_0 is volume of air in the pipe in front of the piston.

Discussion

Intensification of the piston “paradox” in a long tube

$$u_b = \bar{v} + u_n \frac{\rho_0}{\rho_b} \cdot \frac{S_f}{S}$$

visible velocity of the flame front propagation

$$T = 2\pi \sqrt{\frac{m}{k_0}} = 2\pi \sqrt{\frac{\rho_0 L^2 (\alpha + \beta - 1)}{\beta P_0}}$$

period of the piston oscillations in the tube

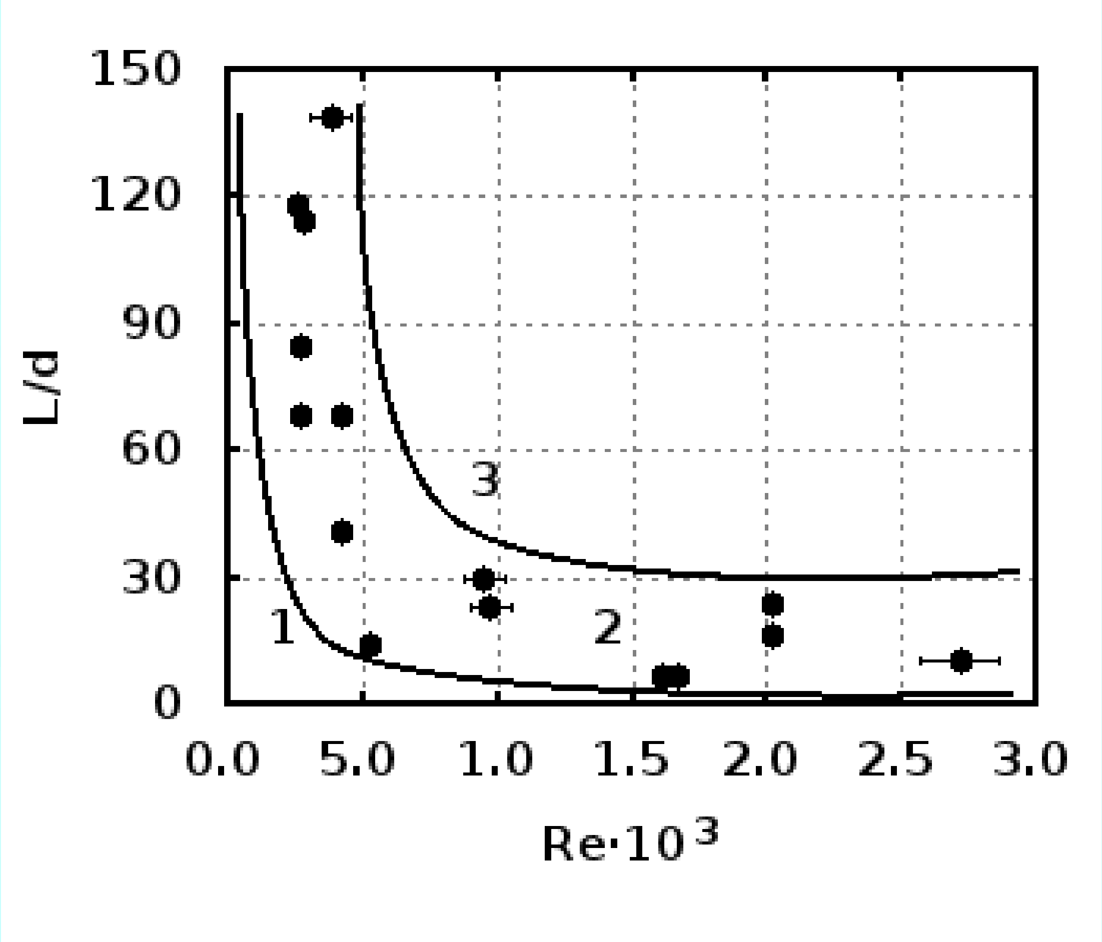
$$u_n = \frac{\pi}{L} \frac{V}{S_f} \frac{\mu_b}{\mu_0} \sqrt{\frac{\beta P_0}{\rho_0 (\alpha + \beta - 1)}}$$

minimal normal velocity of the flame propagation when the piston “paradox” observation is possible

$a = P/P_0$ – expansion coefficient of the combustion products

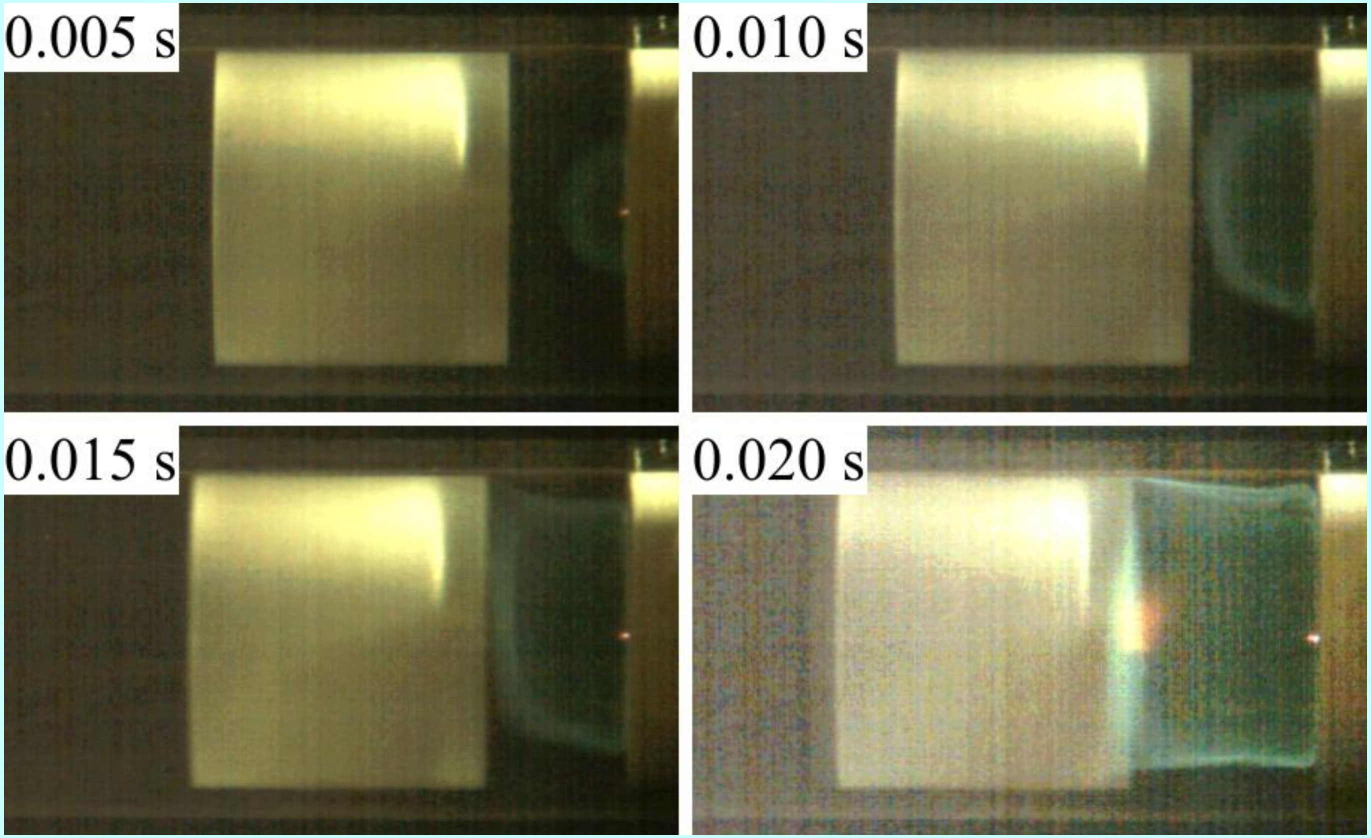
Discussion

Regions of the flame front instability in a long tube opened at one end



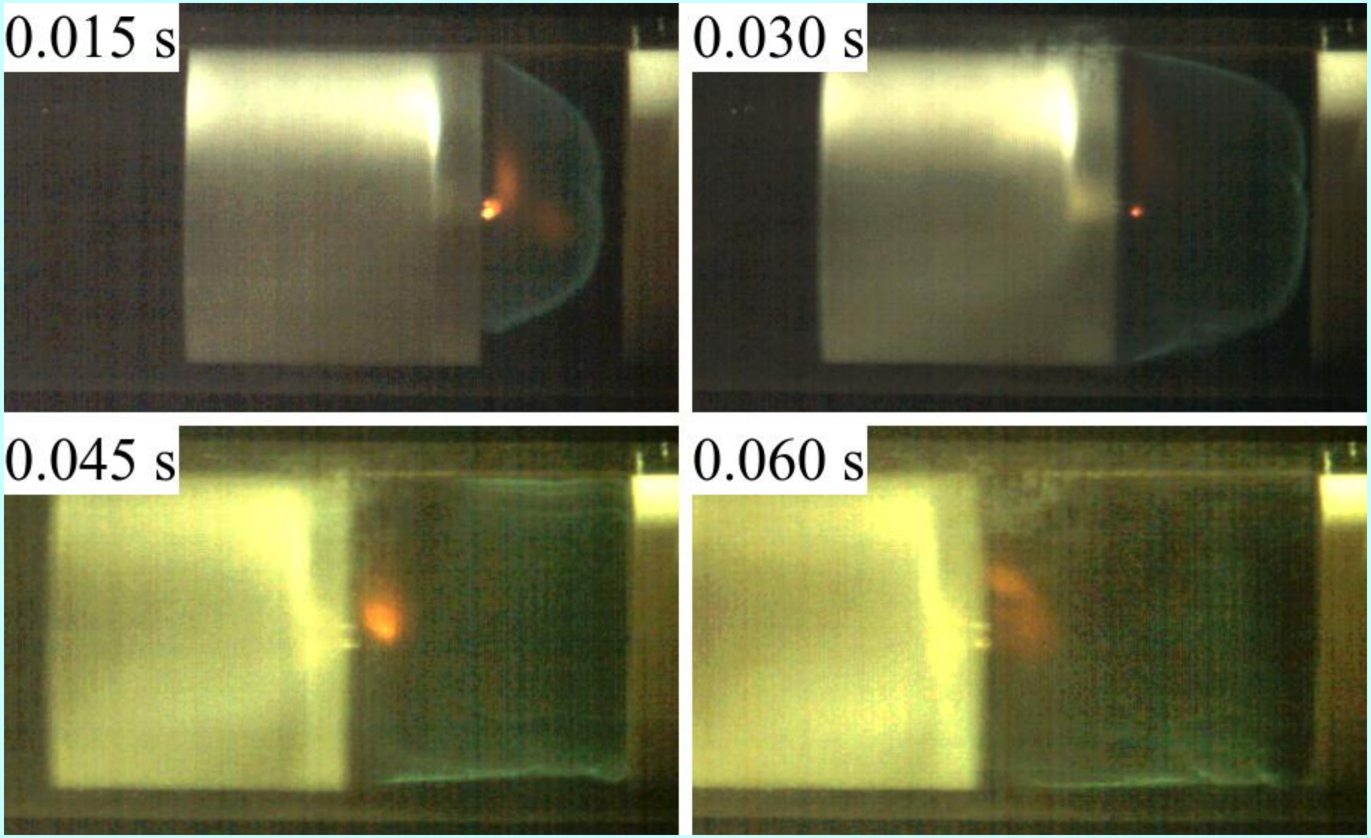
Experimental results

Hydrodynamics of flame behind the piston during ignition at the closed tube end



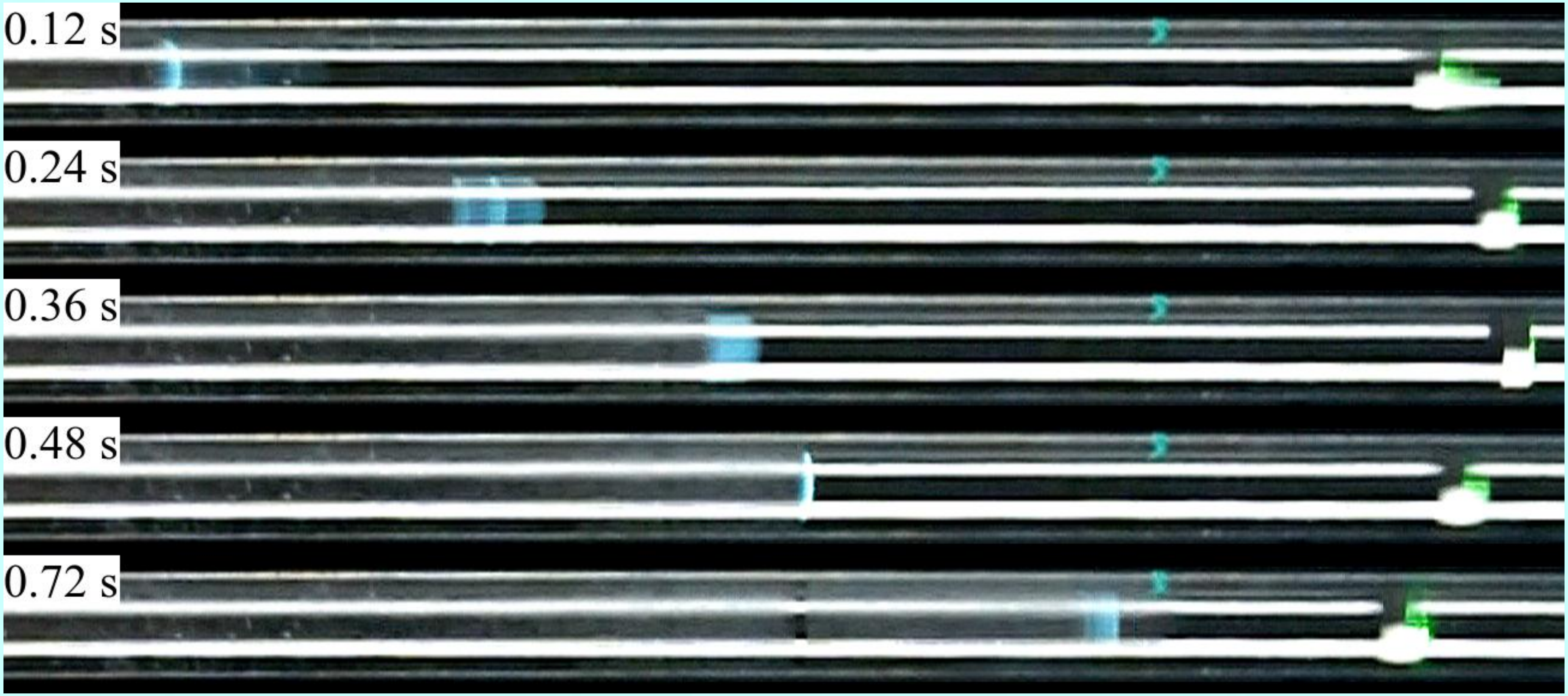
Experimental results

Hydrodynamics of flame behind the piston during ignition on the piston surface



Experimental results

Intensification of the piston "paradox" in a long tube

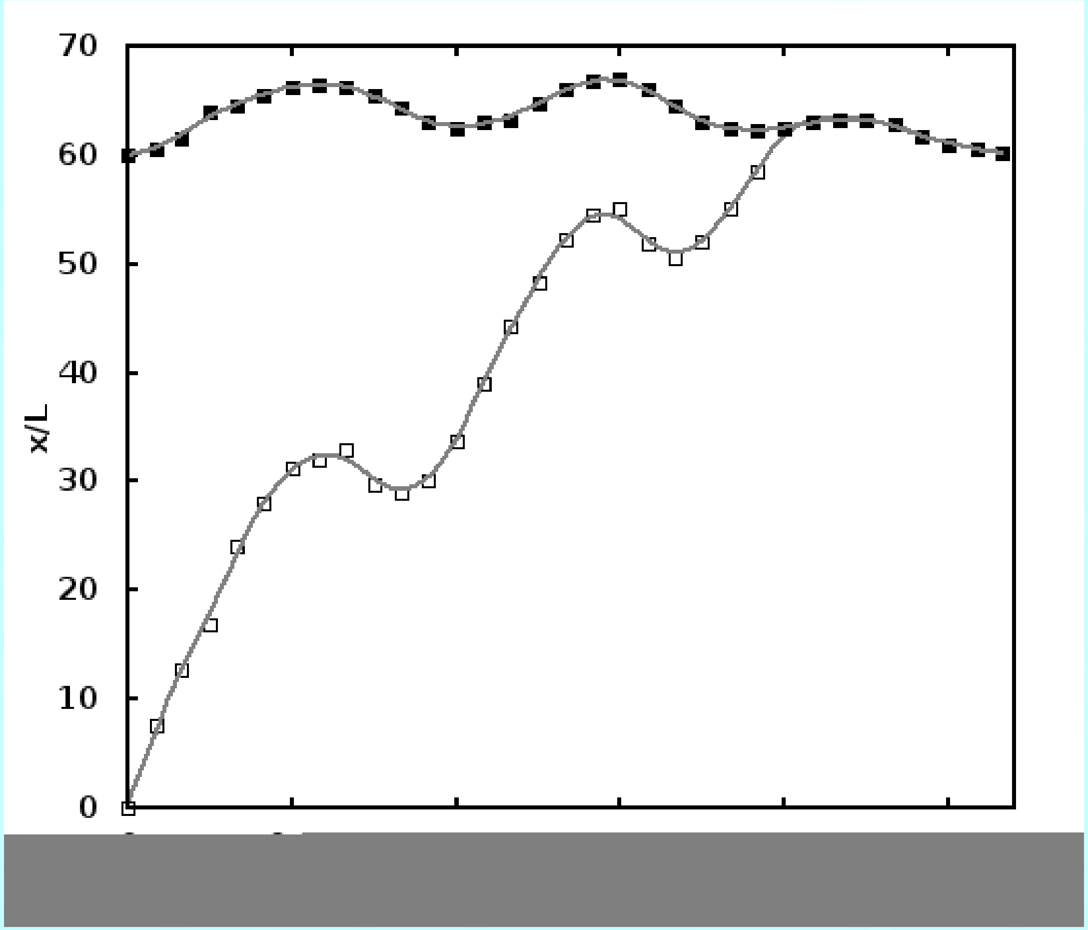


Discussion

In addition to the condition connected with the amplitude of oscillations the accomplishment of phase relations between velocity oscillations of the flame front propagation and the piston is necessary to monitor the piston "paradox". These oscillations are illustrated by the diagrams of dependence coordinate of the piston and the leading point of the flame front from time of a rectangular pipe In addition to the condition connected with the amplitude of oscillations the accomplishment of phase relations between velocity oscillations of the flame front propagation and the piston is necessary to monitor the piston "paradox". These oscillations are illustrated by the diagrams of dependence coordinate of the piston and the leading point of the flame front from time of a rectangular pipe

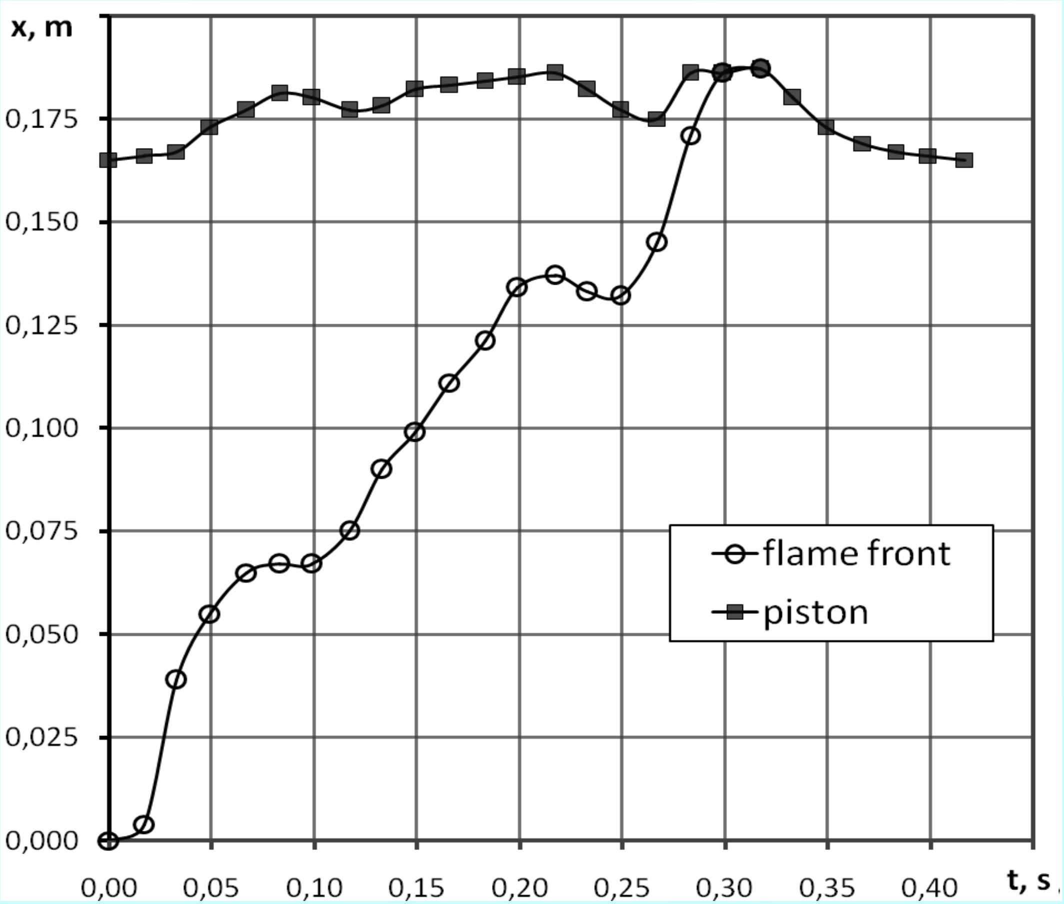
Discussion

Diagram of dependences the piston coordinate and the leading point of the flame front from the time



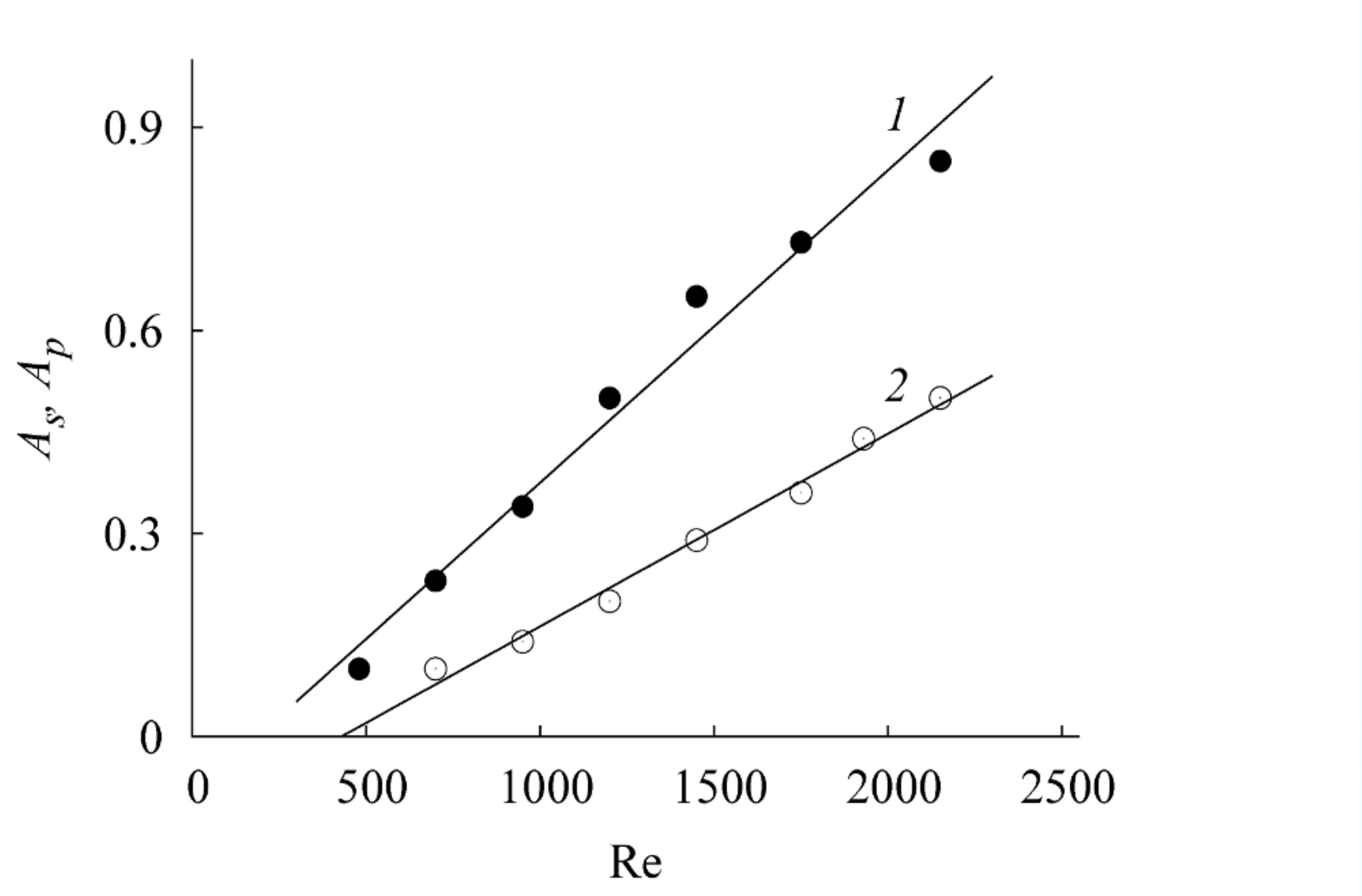
Discussion

Diagram of dependences the piston coordinate and the leading point of the flame front from the time



Discussion

Dependence of the normal flame velocity critical designations from the tube length when the piston "paradox" is observed



Conclusion

The observed oscillations regularities of gas and the piston determine coefficient of efficiency of the combustion chamber. They can be used in the design of gas pipelines, mines, internal combustion engines, machineries and structures to improve coefficient of efficiency combustion setups and to ensure the safe operation conditions.

Thank you
for your attention

Ich danke Ihnen