Detonation in narrow channel for a needleless device application

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1 Introduction

It is known that a convention method of introduction of medicinal substances by means of syringe has a number of shortcomings: painfulness of procedure, possibility of vessels injury, a needle breakage, spread of infection, syringe disposal problem. There are no mentioned shortcomings in a needleless injections method, which is based on an introduction of medicinal substance in form of a small high-speed jet. In spite of obvious advantages currently used needleless devices haven't been yet widely spread. The main feature that makes working the needleless injection device is the energy input, which accelerates the jet to be introduced into the human tissue. Nowadays it can be either a compressed gas or solid fuel detonation[1]. The devices based on compressed gas can carry out a few (10-15) injections without recharging. it was proposed to use a detonation of a hydrogen-air mixture for medicinal substance acceleration in [2]. An impulse of detonation wave is given to a medicine by means of a deformable diaphragm. Several problems are related to the employment of the abovementioned method and are mainly connected to the minimization of the device. It had been investigated the possibility of using of gas detonation in a capillary in order to produce a narrow jet of fluid capable in particular to penetrate into the human tissues and to deliver the medicine by means of a sort of needleless device.

2 Experimental setup

An experimental prototype of the needleless device had been created and includes: a detonation combustion chamber, a membrane or a piston that transfers the impulse of detonation wave, a feeder of a medicine and a nozzle, in which the medicine is placed. The detonation combustion chamber is equipped by spark plug for detonation initiation, electrical valves for separate injection of a fuel (hydrogen, methane) and an oxidizer (oxygen) and for a withdrawal of combustion products. Fuel and oxidizer consumption and detonation ignition moment are controlled in order to tune the injection time (20-200 mks). The detonation ignition moment can be varied from 12 to 171 mks from the injection moment. The general scheme of device is given in Fig. 1 with a relative photograph of the experimental set up. The fuel and the oxidizer are supplied separately through the electrical valves into the detonation combustion chamber and fill it till the nozzle. In the inlet of the nozzle a membrane or a

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piston is placed. When a spark plug in a wider forechamber ignites the detonation it passes through the narrower chamber with an optical section and gages and hits on the membrane or the piston. The detecting equipment enables defining experimentally the velocity of detonation wave and the coincidence of flame and shock fronts in order to proof that the detonation wave had been observed. When the detonation wave in filled by new portion of combustible mixture the combustion products are pushed through the valve located in the end of detonation chamber. The entire process is operated automatically. The diameter of the forechamber is 16 mm while the diameter of main chamber is 3 mm.

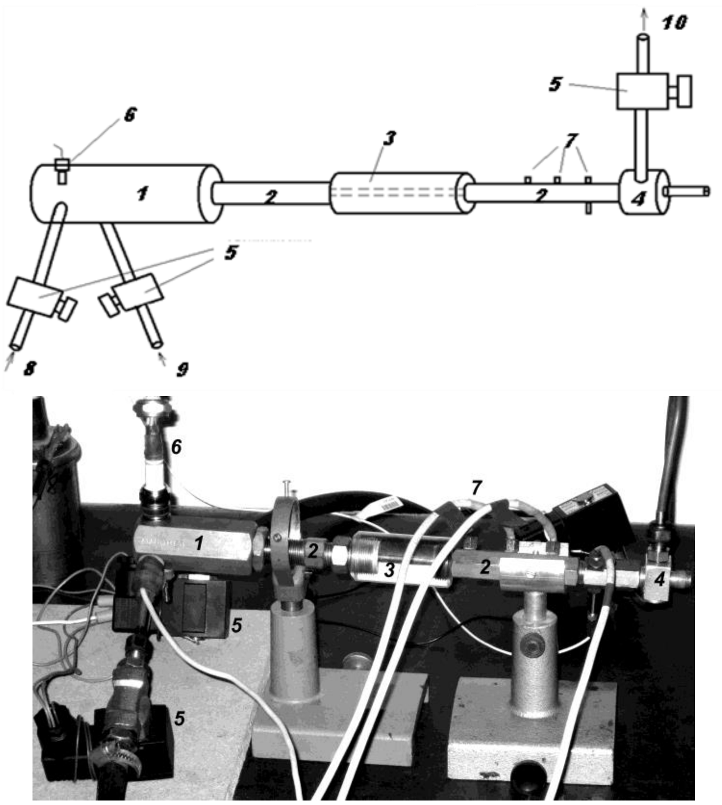


Figure 1. Needleless device experimental set up. 1-forechamber, 2-narrow channel, 3-optical section, 4-nozzle, 5-electrical valve, 6-spark plug, 7-light and pressure gages, 8-hydrogen, methane, 9-oxygen, 10-combustion products

It had been achieved the formation of gas detonation of methane-oxygen mixtures at lower initial pressure in a channel with subcritical diameter at short distance by transition of combustion from the forechamber of bigger diameter into the narrow channel (Fig. 2).

One of the problems of the organization of periodic burning of the mixture in a narrow channel is the formation of water vapor, which slow down the process of deflagration to detonation transition. This problem can be effectively solved by using methane instead of hydrogen. The combustion of methane produced significantly less water. But the main difference - the pressure of cooled combustion products does not change because they do not change the total molar amount of the components after combustion.

The products of combustion in the combustion chamber have maximum temperature and pressure during several tens of milliseconds. A period between injections in the range from a few seconds to minutes. During this time the products of combustion cool down to room temperature. Therefore the purging of the combustion chamber by inert gas is impractical.

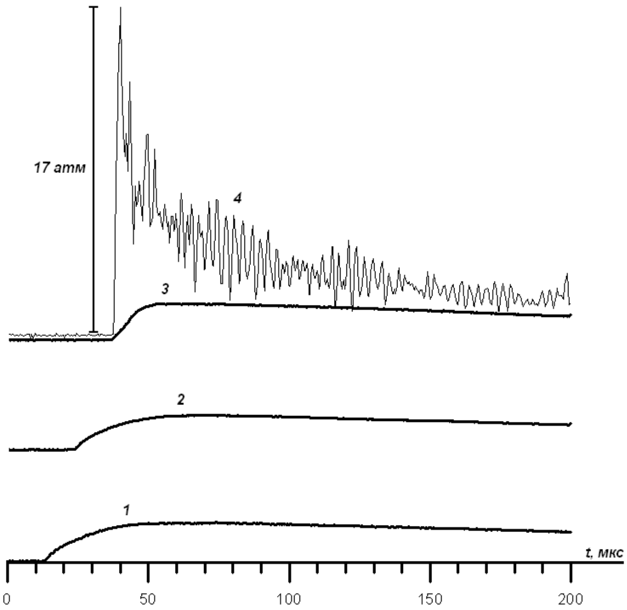


Figure 2. Luminiscence and pressure oscillograms in the combustion chamber of injector. 1,2,3-flame luminescence in the channel, 4-pressure at the front of detonation wave

3 Deflagration-to-detonation in subcritical channel

The effect of geometrical parameters of the forechamber on the deflagration-to-detonation transition (DDT) in the subcritical 3 mm diameter had been investigated. There were observed several scenarios of combustion propagation in narrow channel with the forechamber and it was introduced a non-dimensional parameter defining these scenarios. Suggested parameter *k* defines the rate of DDT in the narrow channel and takes into account the following factors that effect on the predetonation distance:

$$k = E_{chem}/E_{cr} \; * t_{comb}/t_{ind} * L/D,$$

E_{chem} – the energy of combustible mixture in the forechamber [J], E_{cr} – the energy required for generation of 3D detonation in the ignition location, t_{comb} –full time of combustion of mixture in the forechamber [s], t_{ind} – induction time of combustible mixture [s], L – forechember length [m], D – forechamber diameter [m]. This criterion has been tested only for a narrow channel with a diameter = 0.3 λ.

This parameter takes into account the energy release in the forechamber (Echem) depending on the detonable ability of mixture (Ecr), the compression time of detonation products in the channel (tcomb), relative distance passed by the flame front in the forechamber (L/D) and the chemical activity of combustible mixture (tind). Fig. 3 shows the effect of the parameter *k* on the effectiveness of the forechamber. With increasing value of the parameter k the flame front velocity increased in the initial part of the narrow channel. For the forechambers with relatively low value of *k* the monotonous flame acceleration was observed and the predetonation distance was found to be the minimal and varied in the range of 50-65 channel calibers. The non-monotone flame acceleration and the appearance of local velocity maximum were observed at the value of k less than 150. It had been shown that the detonation in stochiometric hydrogen-air mixture in the channel of 3 mm diameter achieves a stationary velocity at 154 mm from the channel inlet.

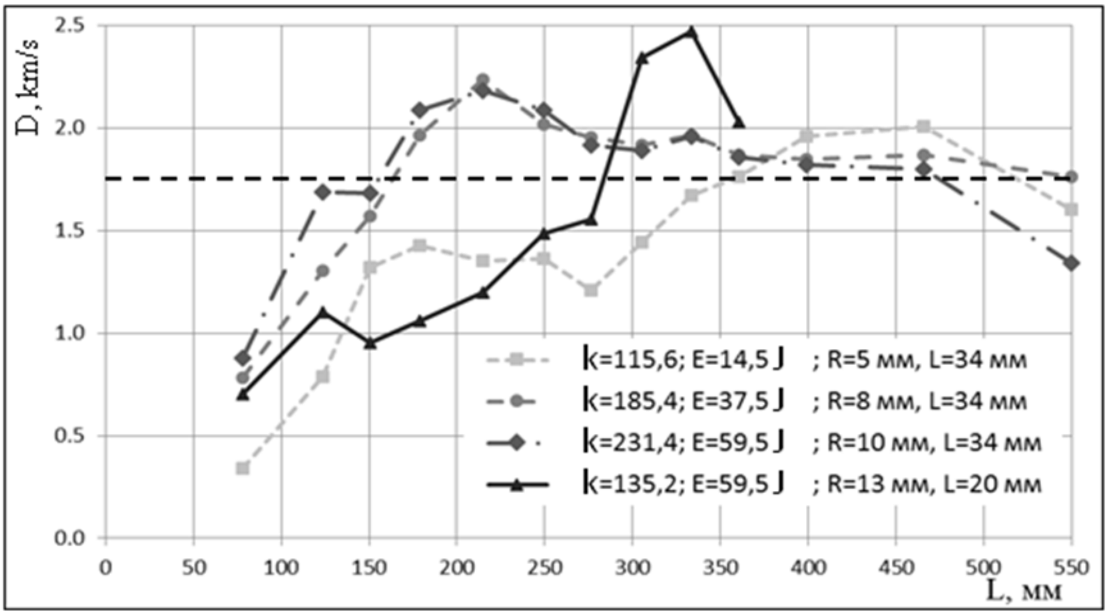
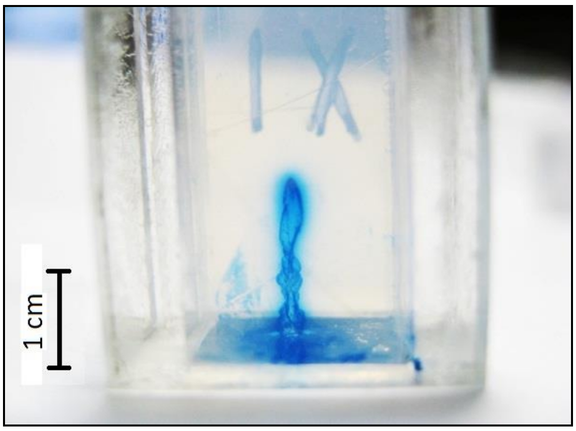


Figure 3. Flame front velocity evolution in the narrow channel for different efficiency parameter k. Dashed line corresponds to C-J velocity in wide channels (1880 m/s)

Deflagration-to-detonation transition is not carried out in the forechamber. However, the expanding combustion piston effect created at the inlet to the narrow channel. This leads to a constant acceleration of the gas behind the shock wave head, and further compression. The piston effect lasts for a limited time, which is defined by the mass of the combustible mixture in the forchamber and its geometrical parameters. If during the duration of the piston effect deflagration to detonation transition in a narrow channel has not occurred, the detonation can not subsequently be formed.

4 Penetration

In Fig.4 the results of colored water penetration into the agarose gel that models the human tissue and subcutaneous fat of pig are given. Copper and steel diaphragm thickness of 0.05-0.15 mm were used. By means of photographic method the velocity of the jet had been measured that achieves 70 m/s. The tests showed that the velocity of the water jet enables providing the penetration of the water into the material and can be used as a prototype of the needleless device.



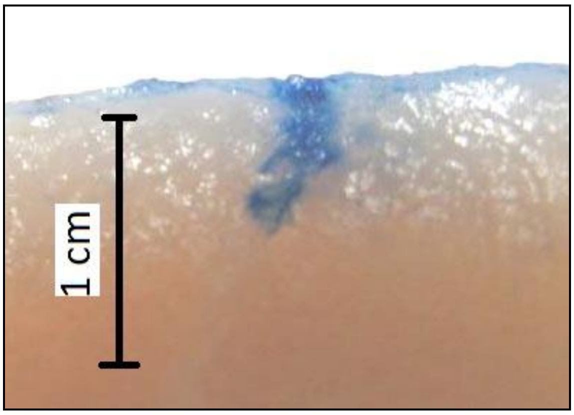


Figure 4. The penetration a colored water into the agarose gel (upper) and subcutaneous fat of pig (lower)

References

[1] Indian Patent Application 260/CHE/2009.

[2] Golub VV., Ivanov KV., Krivokoritov MS., Baklanov DI. (2011) Application of gas detonation for a needleless device development. 28th ISSW, Manchester, UK, Paper 2784.