HYDRODYNAMIC INSTABILITIES AND TURBULENT MIXING IN SOME REAL-WORLD PROBLEM

E.E.Meshkov

RFNC - VNIIEF, Sarov
SarFTI

Hydrodynamic instabilities and turbulent mixing play an important part in the problem of inertial confinement fusion (ICF) and in astrophysics; it, first of all, defines interest to the given problem.

In ICF hydrodynamic instabilities and turbulent mixing *hamper* the achievement of thermonuclear fuel ignition. At the same time, there are some other real-world problems where hydrodynamic instabilities and turbulent mixing are the factors *that can be usefull.*

«Harmful" properties of hydrodynamic instabilities and turbulent mixing can be used for the solution of a wide spectrum of various tasks

In ICF, turbulent mixing of a thermonuclear target shell material with thermonuclear fuel results in dramatic reduction in temperature and rate of thermonuclear reaction.

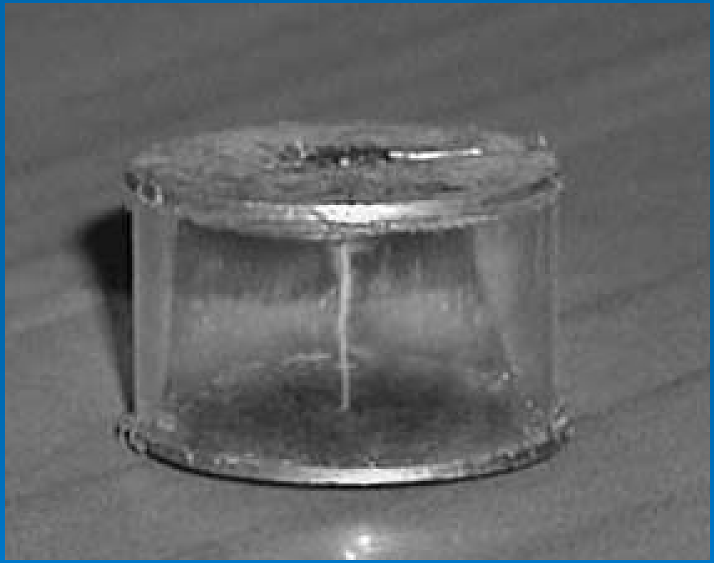
At the same time, there is a problem of extinguishing fires. The flame too is a reaction, but chemical, and it`s rate too strongly depends on temperature. Turbulent mixing of a relative small amount of water with a flame in volume where is a chemical reaction of burning, results in sharp reduction of its rate and extinction of flame.

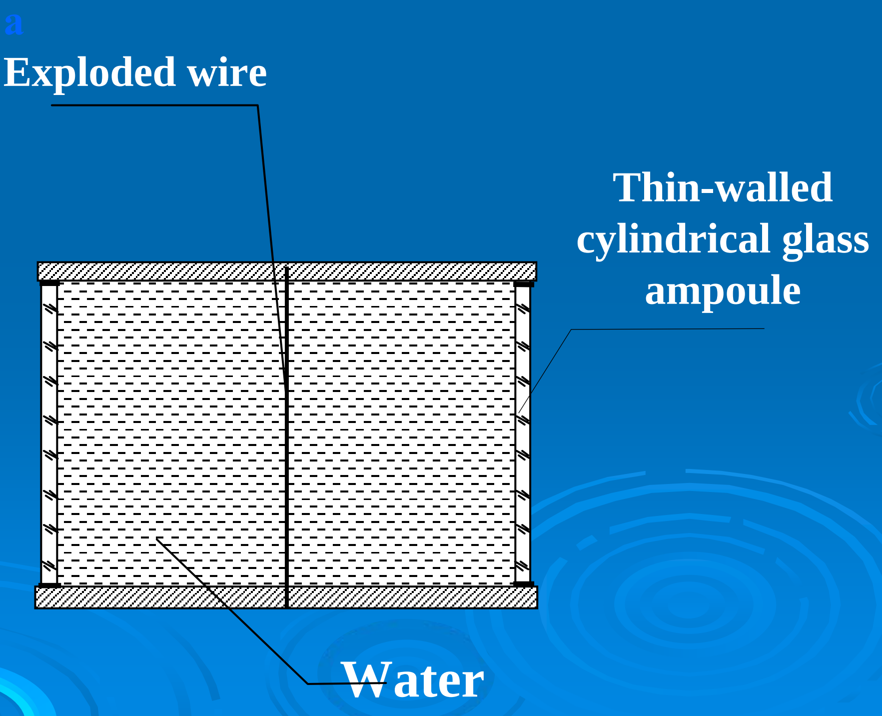
It is necessary only to carry out fast and full mixing of flame with water

INTERACTION OF DISPERSED WATER WITH FLAME (1)

Presented below experiments illustrate results of similar interaction of water with a flame (*Alekhanov et al.Techn. Phys. Letters. V.29, 2003, pp.218-220***).**

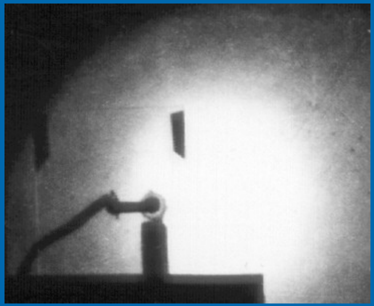
In these experiments the scattering cloud of dispersed water (DW) is created under action of electric explosion of the wire located on an axis of a thin-walled cylindrical glass ampoule, filled with water



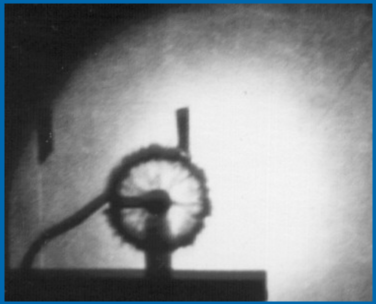


INTERACTION OF DISPERSED WATER (DW) WITH FLAME (2)

Electric explosion of a wire in a thin-walled cylindrical glass ampoule filled with water results in the formation of a disperse water (DW) cloud having a ring shape, which rapidly expands in the radial directions and slowly in the axial direction. The expanding ring surface features strong perturbations which grow with time and eventually (at t > 2 ms) lead to decay of the ring into separate fragments. This can be related to development of the Rayleigh–Taylor instability



t = 0 MS



0,82 MS

1,34 MS

2,09 MS

Registration along an axis of an ampoule

t = 0 MS

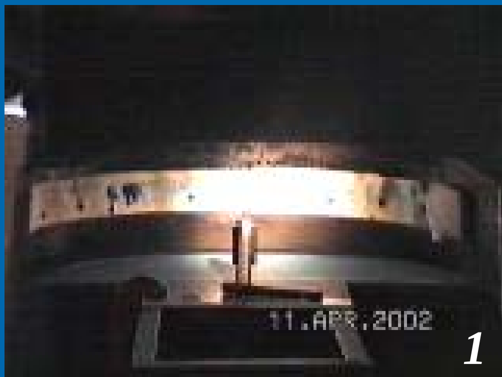
0,97 MS

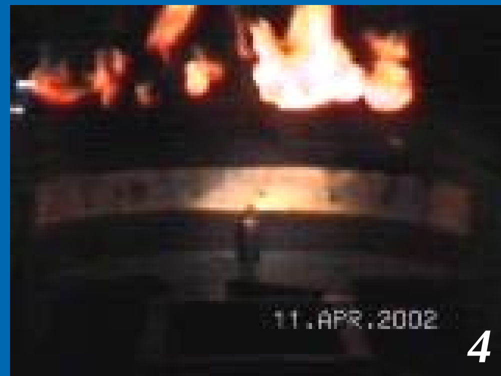
1,35 MS

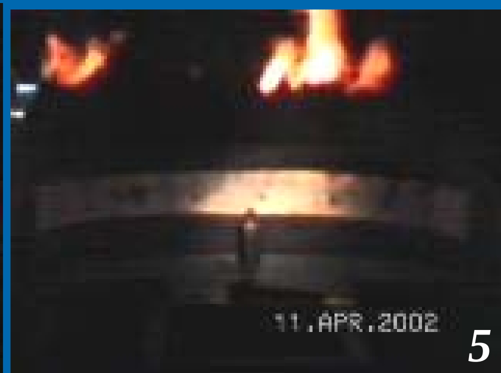
2,17 MS

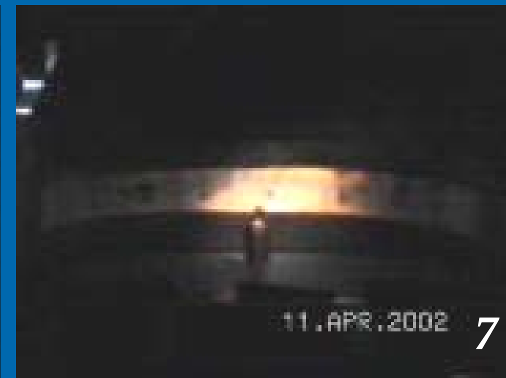
Registration is normal to an axis of an ampoule.

INTERACTION OF DISPERSED WATER (DW) WITH FLAME (3)



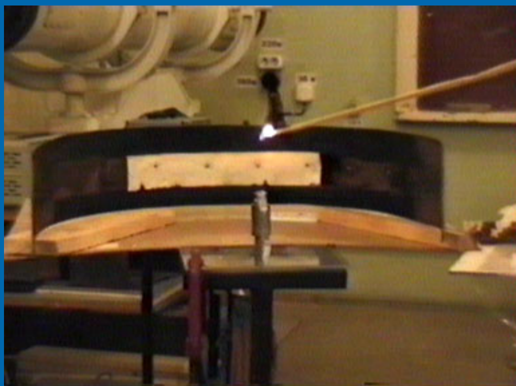


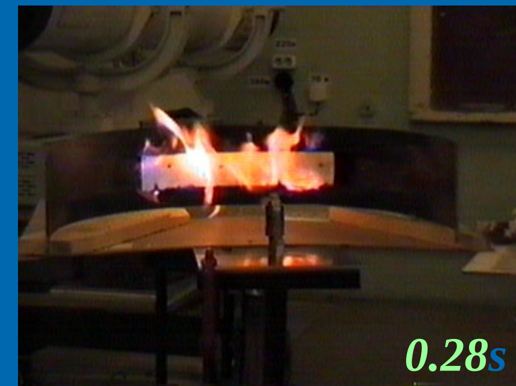




Sequential shots illustrating quenching of the flame at a paper strip (impregnated with acetone) under the action of an expanding DW cloud. DW strikes the lower part of the flame, in which the ignition and initial burning stage of acetone vapor takes place. Cooling of this region (as a result of water evaporation) and dilution of the reaction components with water vapor results in instant quenching of the flame. The upper part of the flame (not accessible for DW) keeps burning to completion (t = 0.08–0.2 s).

INTERACTION OF DISPERSED WATER WITH FLAME (4)





Renewal of burning from a source of the flame located below

INTERACTION OF DISPERSED WATER (DW) WITH FLAME (5)

Evidently, the efficacy of the flame quenching by a DW aerosol is determined by the water access to a region where the burning of evaporated acetone vapor is initiated.

Rapid cooling of this region leads to a sharp drop in the reaction rate, retards acetone evaporation, and breaks connection with the heated flame regions.

The results of our model experiments and the obtained estimates imply, despite their rough character, a simple physical meaning: the flame quenching in the region of fire requires injecting an amount of DW approximately equal to the mass of gaseous reaction products in the flame zone.

For suppression of a large-scale fire DW cloud of large dimensions should

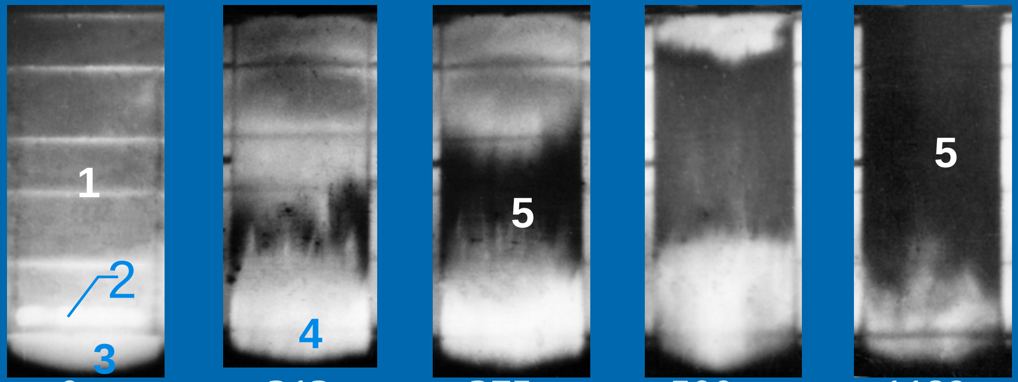
be generated by synchronously initiating charges placed in containers (readily broken without fragments) with water, uniformly distributed over the flame volume.

Note that the dispersion of water can be accompanied by a sharp drop in the explosive load.

HYDRODYNAMIC INSTABILITIES AT CREATION OF AEROSUSPENSIONS OF DISPERSED LIQUIDS AND FRIABLE MEDIUM:

- acceleration of liquid (or friable medium) layer by pressure of compressed gas;
- a method of reception of a mix dispersed liquid with gas by means of piston machine

CREATION OF AEROSUSPENSIONS OF DISPERSED LIQUIDS

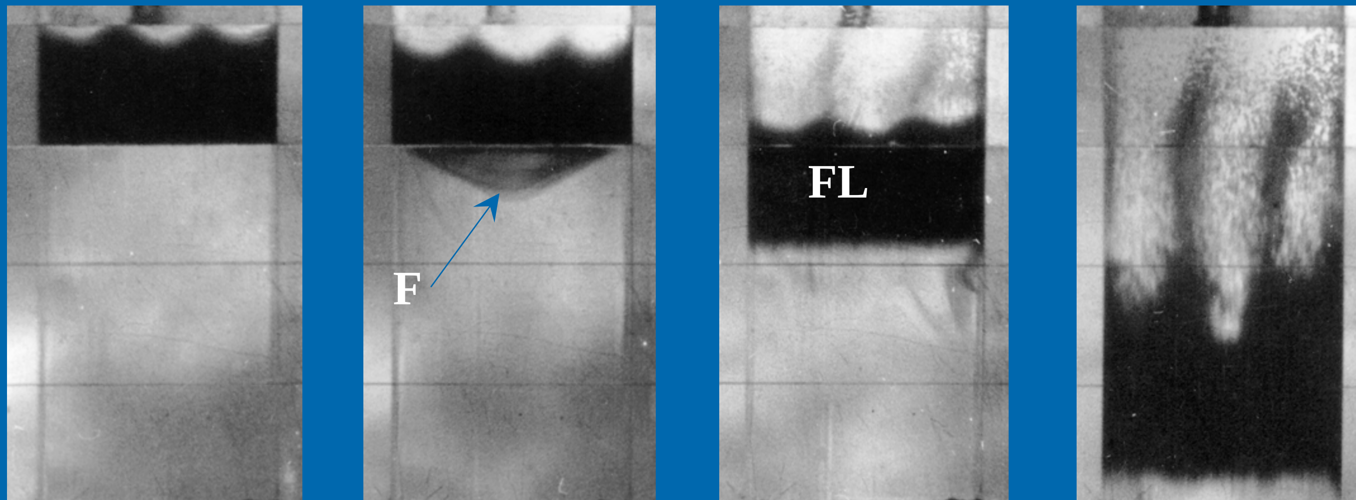


0 μs 313 μs 375 μs 500 μs 1189 μs

1–air; 2–thin water layer; 3–gas explosive mixture; 4–explosion products; 5–a cloude of dispersed water.

As a result of development of turbulent mixing the thin layer of water, accelerated by pressure of the compressed gas, turns to a cloud of fine drops (*Meshkov&Nevmerzhytski, Techn. Phys. Letters. Vol.28, 2002, p.323* **)**

CREATION OF AEROSUSPENSIONS OF FRIABLE MEDIUM

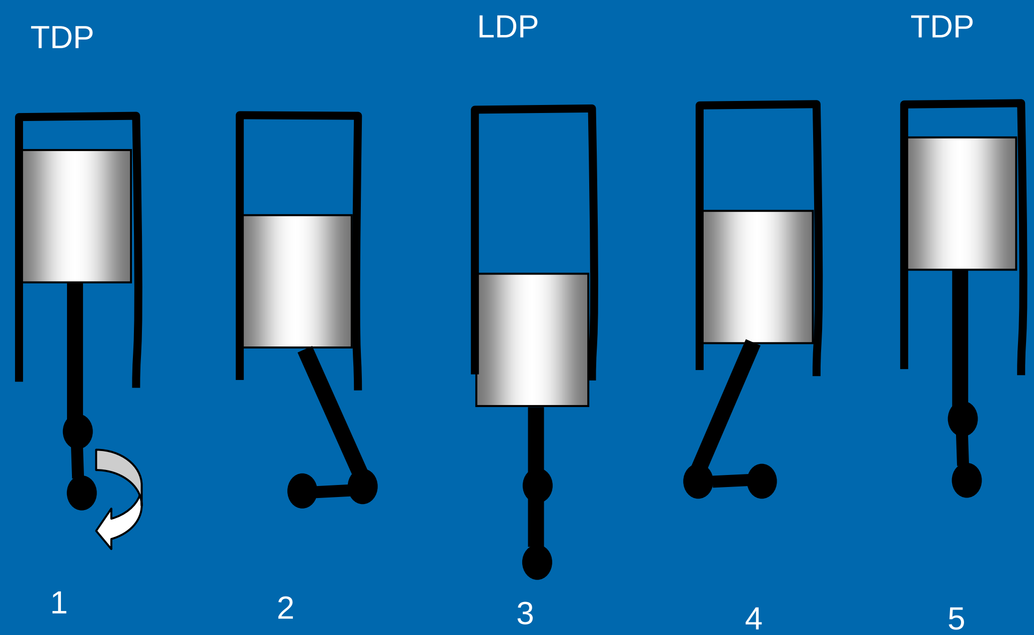


S=0.1мм **S=2.5мм** **S=20.4мм** **S=54.9мм**

F-thin film, FL- the layer of friable medium , S-the way gone by a layer

Development of RT-instability at the interface of friable medium layer, accelerated by compressed gas (*Bliznetsov et al, Techn. Phys. Lett. Vol.28, 2002, p.80*).

THE METHOD OF RECEIPT OF A DISPERSED LIQUID MIX WITH GAS BY MEANS OF THE PISTON MACHINE (1)



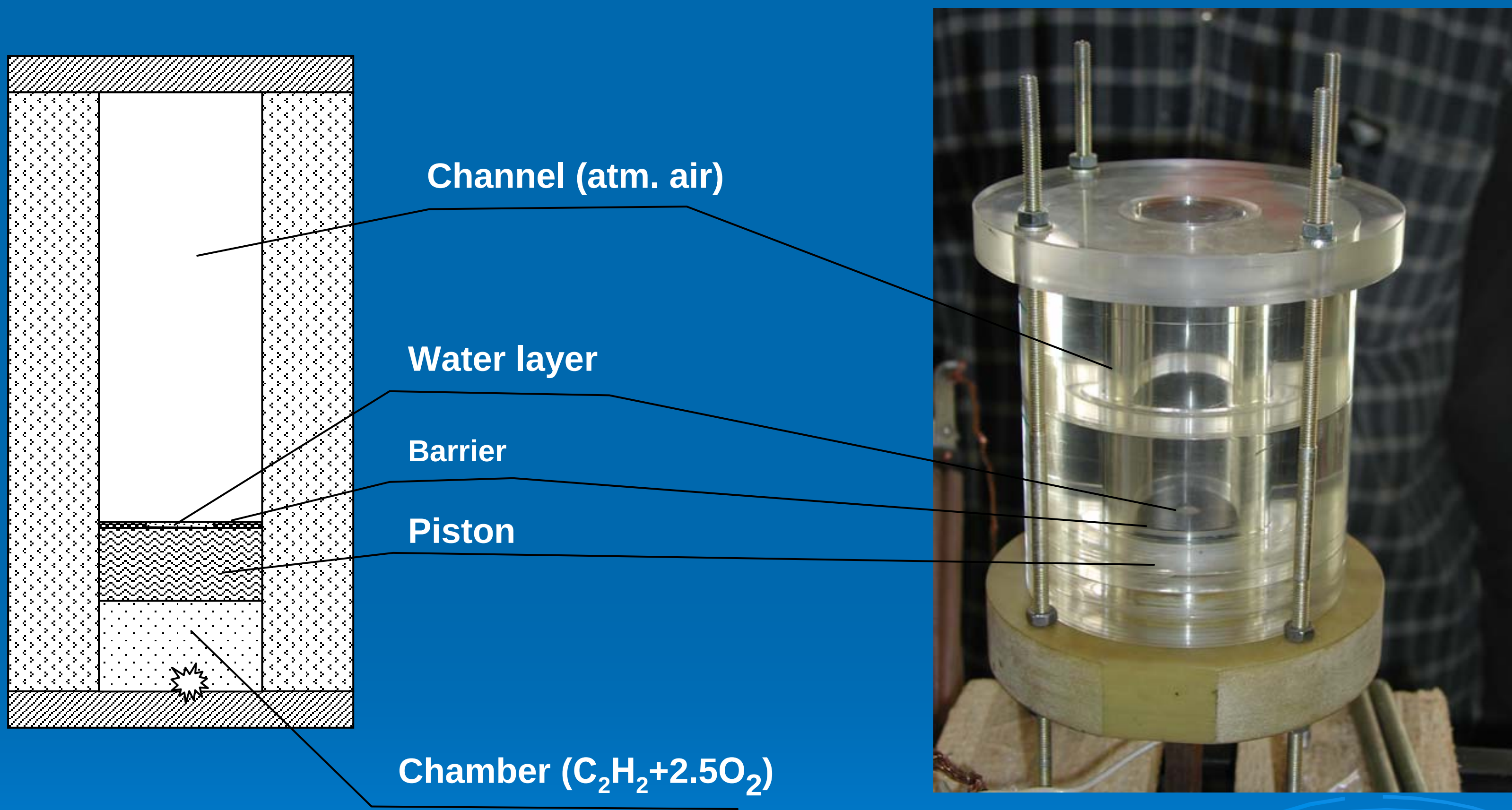
The method is based on application of effect of RT-mixing of a thin layer of a liquid at an end face of the piston with gas, at a stage of its deceleration near top dead point (TDP)

(*Meshkov & Nevmerzhitski, Patent RF #2220009, 2001*).

Preliminary experiments confirm practicability of a method (*Alekhanov et al., Alternative power and ecology. №5, 2002, p.54* **) .**

THE METHOD OF RECEIPT OF A DISPERSED LIQUID MIX WITH GAS BY MEANS OF THE PISTON MACHINE (2)

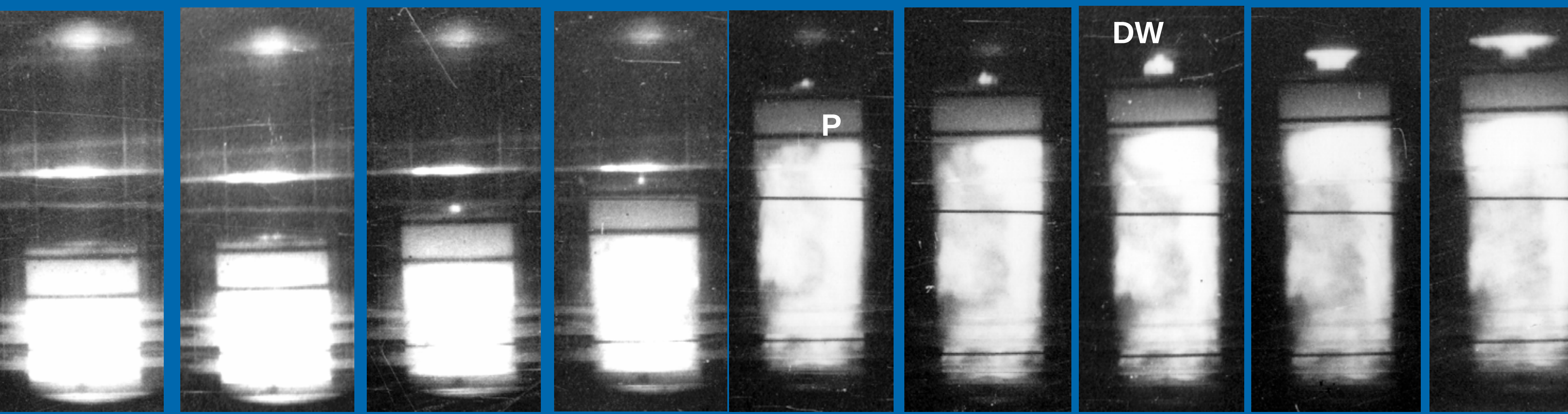
EXPERIMENTAL SETUP



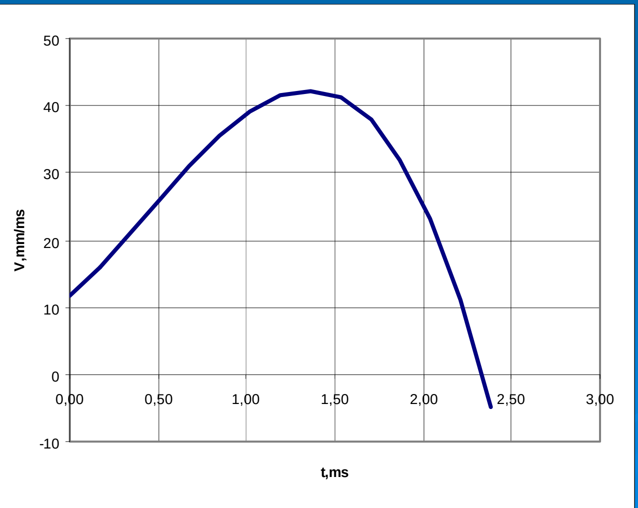
Statement of experiments (*Alekhanov et al., 2002*) on research of development of RT-mixing with gas of a thin layer of water on a surface of the piston accelerated by pressure of detonation products of gas explosive mixture and after decelerated by pressure of compressed air in channel

THE METHOD OF RECEIPT OF A DISPERSED LIQUID MIX WITH GAS BY MEANS OF THE PISTON MACHINE (3)

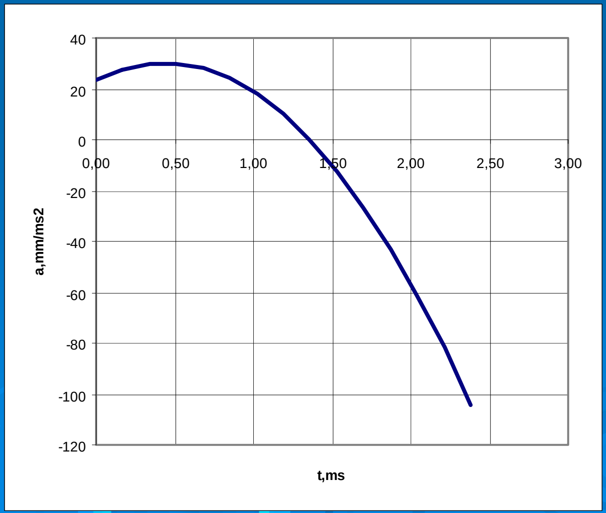
Development of a cloud of dispersed water (DW) at a stage of deceleration of the piston (P)



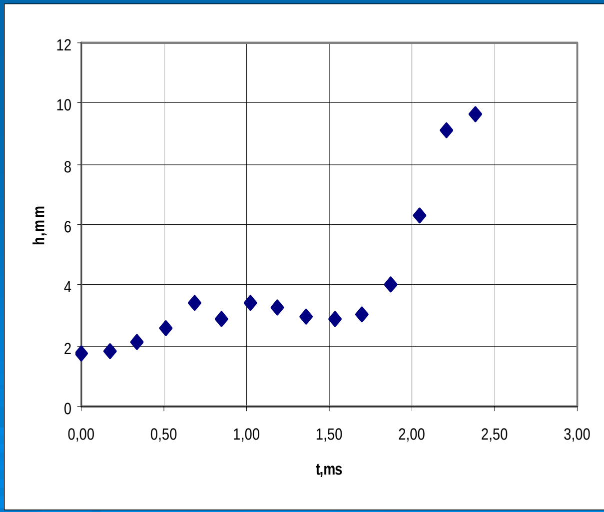
t=0,29ms 0,46ms 0,71ms 0,96ms 1,78ms 1,95ms 2,12ms 2,29ms 2,45ms



V(t)



g(t)



H(t)

THE METHOD OF RECEIPT OF A DISPERSED LIQUID MIX WITH GAS BY MEANS OF THE PISTON MACHINE (4)

Possible applications:

- For continuous reception of great volumes of mix dispersed water with air (for example, for suppression of fires);
- *Essentially new* method of reception of a fuel-air mix in engines of internal combustion, in particular, in diesel engines *without application of sprayer*.

This method can provide more uniform mixing of fuel with air and, accordingly, more full combustion of fuel and reduction of air pollution.

Other advantages (increase of efficiency, increase in a resource of the engine, etc) are possible also

AEROSUSPENSIONS CAN FIND WIDE APPLICATIONS:

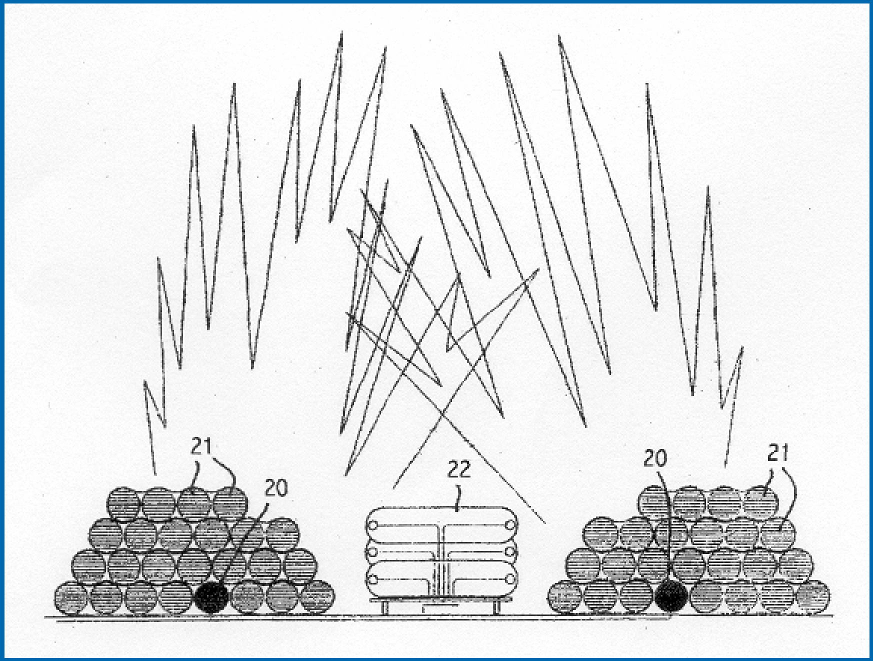
- for suppression of fires;
- as means for decrease in explosive loadings;
- for localization of harmful (radioactive) aerosols and a dust;
- for preparation of gas mixtures in engines of internal combustion, etc.

DECREASE IN EXPLOSIVE LOADINGS

A layer of dispersed media is capable *to reduce in times* peak pressure of the non-stationary shock waves (*Buzukov, FGV, 2000; Gelfand et al, FGV , 2001)*

In VNIIEF the methods of decrease in explosive loadings and localizations of aerosols are developed by means of using of aerosuspensions (*Afanas`ev et al., Patent RF, 2003***). Aerosuspensions are created at development hydrodynamic instabilities on surface of layers of a liquid or powders, accelerated by the compressed gas.**

DECREASE IN EXPLOSIVE LOADINGS



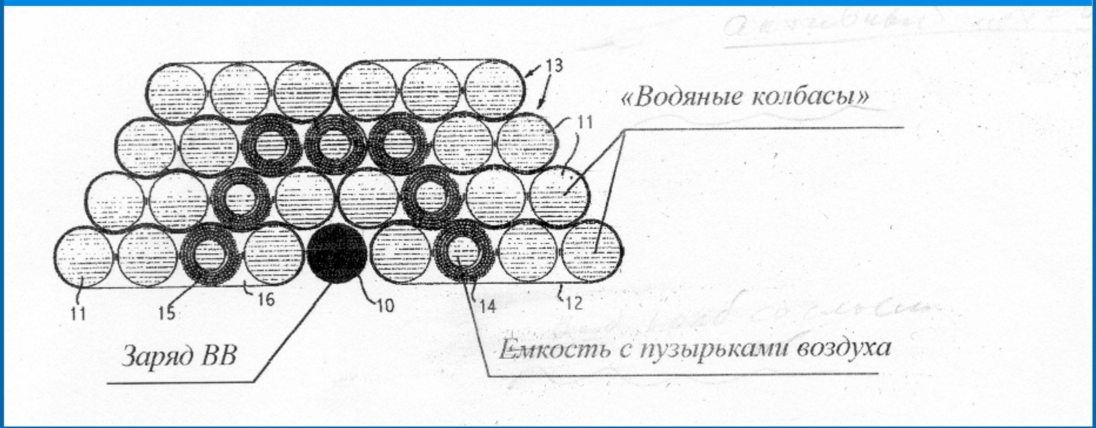
There is a number of patents in which methods of application dispersed water for decrease in demolition action of explosion are presented

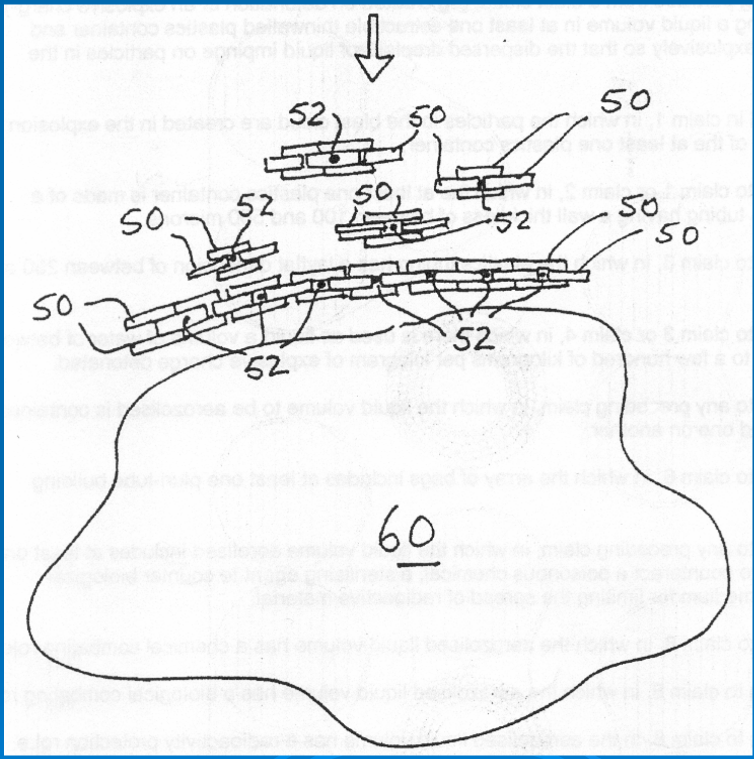
(*Parkes &Salter, UK patent, GB 2 292 997, 1996;*

Parkes, UK patent, GB 2 306 884, 1998)

SORPTION OF AEROSOLS

Parkes J., UK patent, GB 2 292 997, 1996





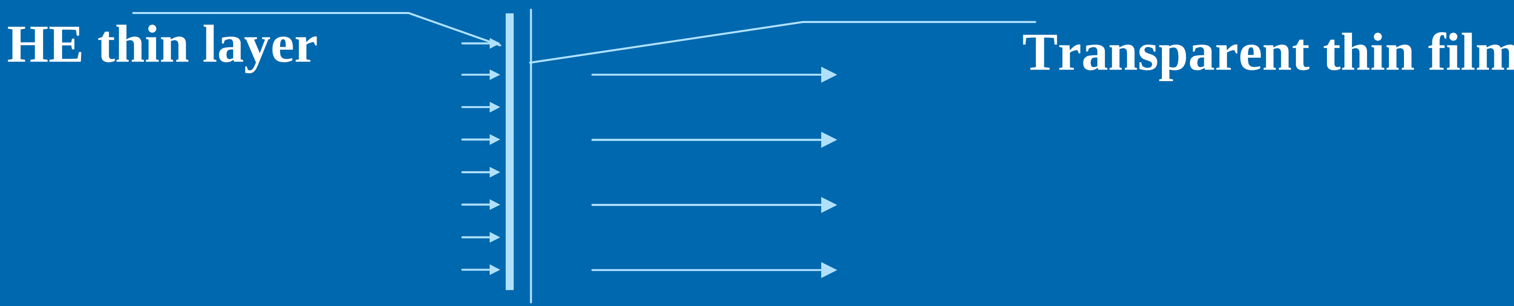
Dispersed water can effectively be used for *sorption of aerosols, poisonous gases, a dust*, etc. from a cloud of explosion

Parkes J.H., Salter S.H. 1996, UK patent, GB 2 294 105

EXPLOSIVE LIGHT SOURCE

for reception of short powerful light pulses

(Gerasimov S., Meshkov E. Patent RF 215 26 65, 2000)



The transparent thin film on a way of a radiating shock wave to gas simultaneously is used for increase brightness temperatures (in the reflected wave) and for cut-off radiations *(due to fast mixing of (easy)* gas heated up by a shock wave with *(heavy)* cold destruction products of film.

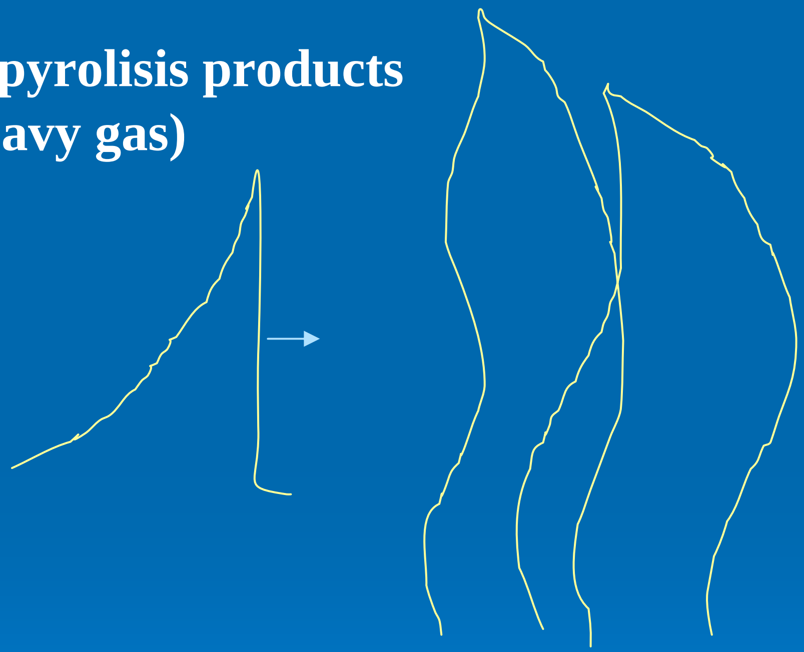
In result are reached duration of a light pulse (~0.3мks) at peak brightness temperatures (up to ~40000°).

EXPLOSIVE SUPPRESSION OF FOREST FIRE

There is a hypothesis (*Meshkov, Proc. of the 7th IWPCTM, 1999, p.477*), according to which mechanism of method of explosive suppression of forest fire (*Grishin A.M., Kovalev J.M., FGV,1989*) is connected to development hydrodynamic instabilities

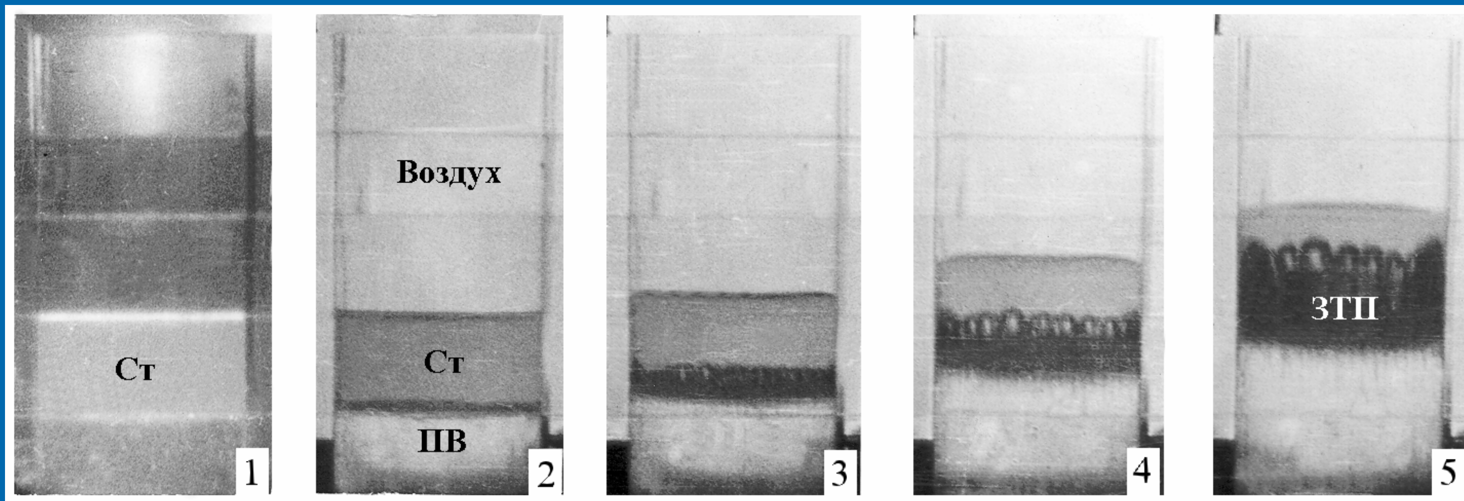
Flame (light gas)

Mixture of pyrolisis products and air (heavy gas)



As a result of development of instability - intensive mixing of flame and a mix of air and products of pyrolysis and fast burning out of this mix.

При ускорении сжатым газом слоя жидкости вследствие развития неустойчивости границы слоя формируется зона турбулентного перемешивания (*Жидов и др., 1990*).
В развитой зоне турбулентного перемешивания легкая жидкость (или газ) проникают в более тяжелую в виде пузырей.
Жидкость проникает в газ в виде струй, которые дробятся на краю зоны ТП в мелкие капли в виде “дождя”.



At acceleration of a liquid layer by the compressed gas owing to RT-instability on interface of a layer the zone of turbulent mixing is formed (*Zhidov et. al., 1990*).

In the advanced zone of turbulent mixing an easy gas penetrates into heavier liquid in form of bubbles.

The liquid penetrate into gas as jets, which atomize at the edge of TM zone in drops as "rain"

Scales achievable in experiment

- **Acceleration (a~2 10^4-10^5 m/s^2) and**
- **Speeds (v ~30-40 m/s).**

Compression of air and mix in the channel:

- **No more than $\sigma_1 \approx 7.5$ (from the beginning of movement of the piston and till the moment of the maximal compression) and, accordingly,**
- **No more than $\sigma_2 \approx 3$ (from the moment of the beginning of braking of the piston till the moment of the maximal compression).**

SUPPRESSION OF FIRE

Efficiency of suppression of fire by dispersed water (with the size of drops less than 100 microns) reaches 100 % (at suppression by a compact jet efficiency of use of water up to 5 %)

(Korolchenko, 2001)