NEW PRINCIPALS OF CREATING HEAT GENERATORS BASED ON THE METHODS OF PULSE BURNING OF HYDROCARBON FUELS DIRECTLY IN A WATER-BASED HEAT CARRIER

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A principal possibility of burning hydrocarbon fuels directly in a water-based heat carrier is demonstrated. The first experimental results are presented by an example of burning acetylene in water with initiation of gas ignition in the bubble by an electric discharge and in the shock tube with injection of hot combustion materials into water. These examples show that it is possible to pass to new principles of operation of heat generators.

Experimental set-up 1. The experiments were performed with a stoichiometric mixture of acetylene with oxygen (C_2H_2 + $2.5O_2$). The gas mixture was ejected into water with the conductivity ≈1 $\Omega^{-1}\cdot m^{-1}$ through the tube-electrode with the outer diameter d_c = 2.1 mm and inner diameter d_{in} = 1.5 mm. The bubble diameter was $d \approx d_c$, and the voltage of 350–500 V was supplied to the electrode. To prevent flame propagation in the gas pipe, a fire barrier was mounted in the tube.

Hydrodynamic modeling of experimental set-up 2. Hydrodynamic modeling of pulse ejection of hot acetylene combustion products into water was worked out. Pulse burning acetylene-oxygen mixture was performed in the shock tube of the multifunctional pulse detonation device CCDS-2000 developed in LIH SB RAS [2].

Experimental results. Figure 1 shows the typical frames and oscillogram of the process for one cycle of gas ignition and burning in a bubble. In this arrangement of experiments, the electric breakdown in the gas occurs inside the bubble, between the tubeelectrode and electrolyte, which ignites the gas mixture in the bubble. The bubble expands during the time of 0.3 msec and then starts to collapse approximately back to its initial diameter losing its symmetry. The collapse and subsequent motion are accompanied by formation of a toroidal vortical bubble cluster. The velocity of separation of the first bubble cluster from the electrode is $v_b \approx$ 10–15 m/sec. In the course of motion of the toroidal bubble cluster, it is broken to the size d_i = 0.1–0.3 mm. It follows from the records obtained that the second bubble is formed at the instant when the bubble with the burnt gas collapses. In this arrangement of experiments, the second bubble is generated by the electric discharge energy.

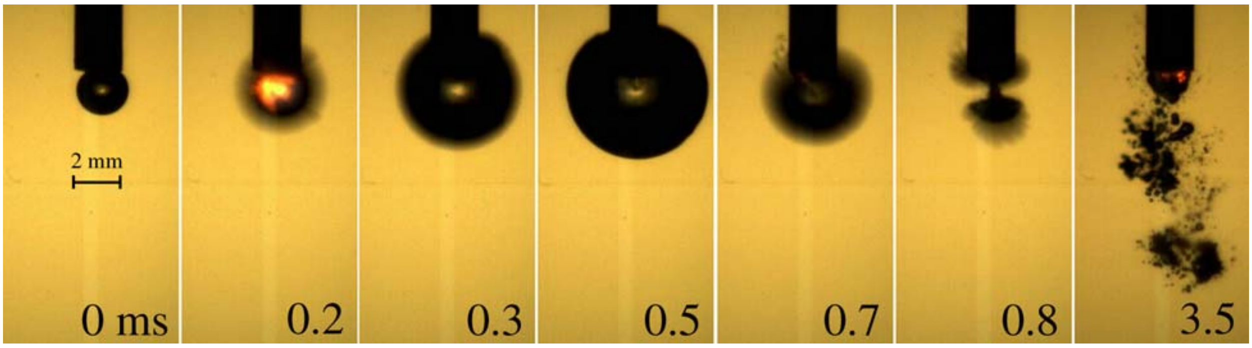

Fig. 1

Figure 2 demonstrates the typical frames of pulse ejecting the detonation combustion products of acetylene-oxygen mixture (T ~3000K^o) from the slot-like hole, h=2mm, l=15mm.

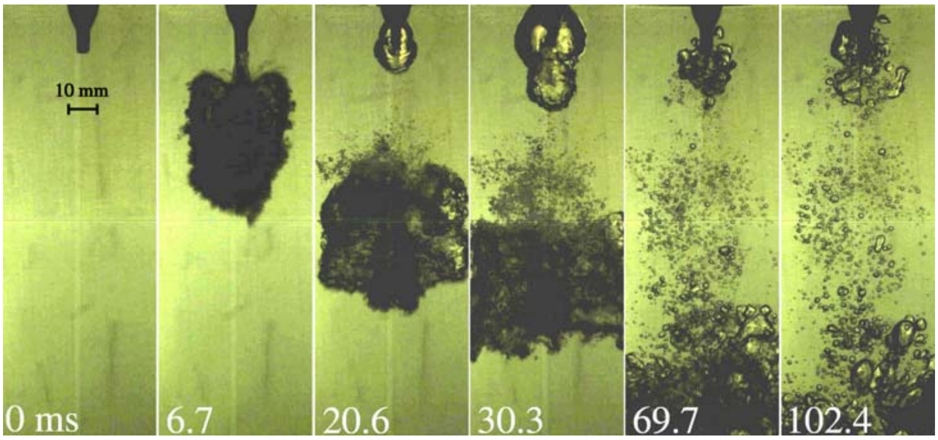

Fig. 2

The analysis of results. For the experimental set-up 1, the approximate calculation of time of gas burning in the bubble was performed. At the effective adiabat index of 1.1, the maximum bubble diameter is approximately 3.9 times greater than the initial diameter, whereas the experimental value is D/d = 3. The difference is partly associated with heat transfer to water in the course of expansion and also with departure of some part of the burnt gas to the input tube. If the bubble were not destroyed, it would cool down during the time $t_1 \approx 10^{-2}$ sec. In our case, the broken bubbles transfer the heat during the time $t_2 < 10^{-4}$ sec. The degree of bubble fragmentation can be estimated on the basis of the Weber number. For the relative velocity of ≈10 m/sec, the Weber number is We ≈ 10^3, which is two orders greater than its critical value. The bubble is broken into smaller bubbles with the mean size $d_i \approx$ 0.3 mm. It is fragmentation of the initial bubbles in our experimental arrangement that leads to drastic enhancement of heat transfer. Simultaneous ignition of the gas in N bubbles can occur in the regime of electrohydrodynamic selfsynchronization of breakdowns in these bubbles [3, 4]. Here the upper limit of the generator power is constrained only by the frequency of fuel ejection into water. For instance, if the frequency of burning of the bubbles is 1 kHz and 25,600 tubes-electrodes are placed on the area of 1 m^2, the mean specific power of such a generator is ≈25 MW/m^2. All thermal energy remains in water. Note that this estimate was made for a particular case with the test conditions used in our experiments. Structurally, more powerful and compact devices with pulsed burning of fuels in a water-based heat carrier are possible.

As powerful experimental device one may consider existing pulse gas-detonation device CCDS-2000 [2], which was used to perform preliminary experiments in experimental set-up 2. These experiments show that a hot gas bubble ejected into water with the velocity of 20 m/sec is effectively desintegrated (Fig.2) that provides high-performance heat transfer from desintegrating bubbles to water.

CONCLUSIONS

A principal possibility of pulsed burning of hydrocarbon fuels directly in the water-based heat carrier in an automatic regime, aimed at creating heat generators of a new type, is experimentally demonstrated.

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