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Ignition of Hydrocarbon Films by a Pulsed Discharge Propagating above a Water Surface

A. F. Aleksandrov, D. N. Vaulin*, and V. A. Chernikov

Faculty of Physics, Department of Physical Electronics, Moscow State University, Moscow, 119991 Russia
**e-mail: vaud@yandex.ru*

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Abstract—We present the results of experimental investigations into the ignition and combustion of hydrocarbon films deposited on a water surface by a pulsed discharge propagating above the liquid in motionless air under atmospheric pressure.

Key words: pulsed discharge, liquid surface, hydrocarbon ignition, propagation rate.

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1. INTRODUCTION

Pulsed high-voltage electrical discharges created in the atmosphere between two electrodes—one of which is located above the surface of a weakly conducting liquid and the other is in contact with it [1–4]—may be efficient for a whole series of technological applications, such as water purification by electric discharge [2] and treatment of solid electrode material [3]. At the same time, pulsed discharges are widely used for igniting high-velocity flows of both gas- and liquid hydrocarbons; in particular, in [4], the combustion of thin hydrocarbon films in the plasma of a surface pulsed SHF discharge was studied. In the present work, we study the character of the ignition and combustion of thin hydrocarbon films (gasoline, kerosene, and alcohol) under the action of a pulsed discharge propagating above the surface of a weakly conducting liquid. For the most part, we conducted experiments for the case of deposition of gasoline on the surface of industrial water.

2. EXPERIMENTAL

In the study, we used a setup similar to that described in [5]. Industrial water was poured into a dielectric cuvette above which a spike-shaped negative electrode (cathode) was placed. A flat grounded electrode (anode) was placed in the water at the opposite side of the cuvette. On the water surface, a thin film of gasoline or other hydrocarbon was deposited, the quantity of which could be regulated from 0.1 g to 5 g with an accuracy of 0.05 g. In this way, the thickness of the gasoline film on the water surface varied from 0.1 mm to 5 mm. To initiate combustion, we used a pulsed discharge propagating along the water surface from the cathode to the anode; the duration of the pulse changed within the range of 100–300 μs; the initial voltage of the power source varied from 10 to 25 kV. The distance between the cathode and the anode and the height at which the cathode was raised above the water surface were fixed constants (L = 50 mm, H = 5 mm). To limit the current continuously with the discharge, a ballast resistor was switched on. To detect ignition and combustion of gasoline, we used a photomultiplier placed perpendicular to the discharge axis at a distance of 20 cm from it. Note that the photomultiplier recorded the emission intensity and the spectral range, which was determined by its characteristics.

3. RESULTS

Figure 1a shows the typical oscillograms of the discharge current and the glow intensity over the duration of the pulse. As follows from these oscillograms, the glow intensity of the discharge increases sharply at the moment of its closing on the cathode, independently of whether gasoline is added or not; then it either remains constant or increases by the end of the pulse. At the same time, the addition of even so small an amount of gasoline as 0.2 g to the water surface (the minimum mass of gasoline in the experiments was 0.1 g) leads to significant growth in the glow intensity. Figure 1b shows the dependences of the maximum glow intensity on the magnitude of the discharge current. It is clear that the glow intensity grows with increasing discharge current independently of the addition of gasoline, but the deposition of gasoline on the water surface leads to an increase in intensity by a factor of 2–2.5.

As gasoline is deposited on the water, not only does the glow intensity increase, but the character of its temporal evolution also changes substantially. As an example, Fig. 2 shows the glow oscillograms obtained

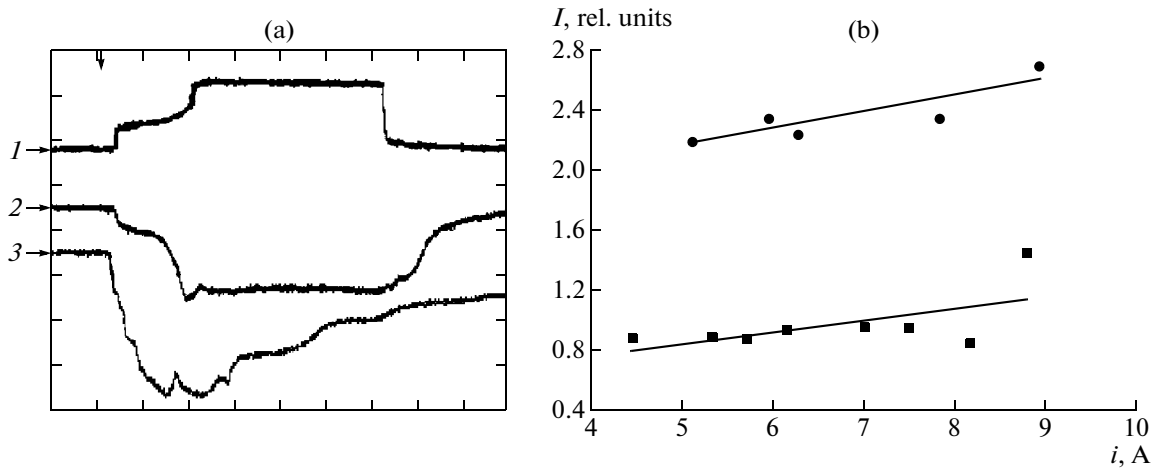

Fig. 1. (a) Oscillograms of discharge current (*1*) and discharge glow without (*2*) and with the addition of 0.2 g of gasoline (*3*)—the photomultiplier is situated at the anode; (b) dependence of the glow intensity of the discharge on current without (●) with the addition (■) of 0.1 g of gasoline. $R_b = 2$ kΩ, $U_0 = 14$ kV.

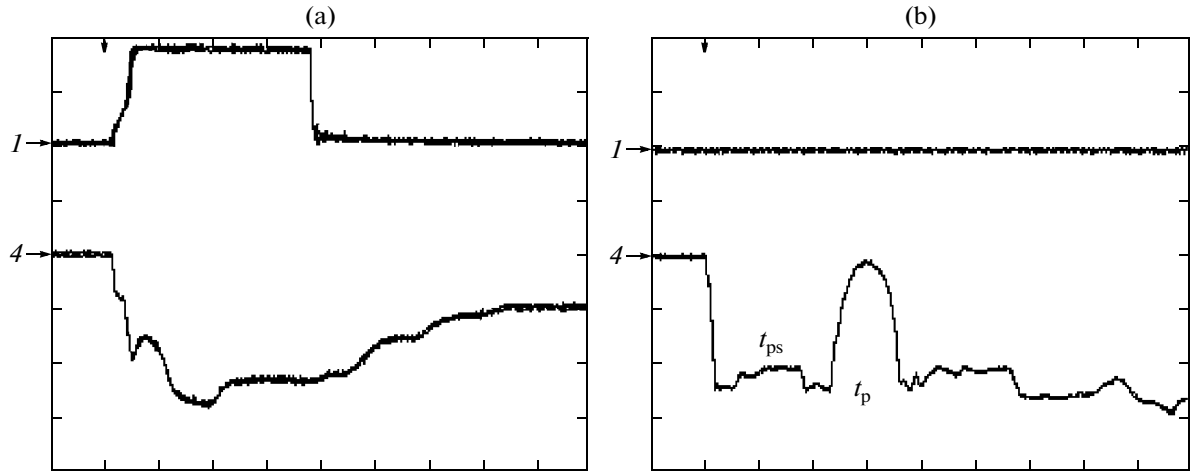

Fig. 2. Oscillograms of current (*1*) and discharge glow (*4*) at $R_b = 1$ kΩ, $U_0 = 20$ kV with the addition of 0.9 g of gasoline. (a) Fast sweep, sensitivity over glow channel (*4*) is 2 W/div; (b) slow sweep, sensitivity over glow channel (*4*) is 500 mW/div.

with various time sweeps. Figure 2a corresponds to time juxtaposed with pulse duration ($\tau \sim 100$ μs); Fig. 2b, to much larger time intervals after the end of the pulse.

As follows from these oscillograms, the glow intensity at the discharge stage exceeds by a factor of many (in the given case, by a factor of 4) the combustion intensity of gasoline after the pulse. We examine in more detail the time dependence of the glow of the combustion products in Fig. 2b. We emphasize that owing to the large difference in the time sweeps, the pulse of the discharge in Fig. 2b looks like a sharp vertical line, indicated by an arrow. Further, in this oscillogram, we can distinguish three time phases. The first corresponds to the time interval t_{ps}, which we can define as some time of preliminary glow or the time of preliminary combustion. On the other hand, in the time interval t_p (the pause time), glow is not detected and, consequently, combustion does not take place (second phase). Finally, after pause t_p, the third phase is achieved, which corresponds to the regime of independent combustion, which continues after the pulse until the gasoline is fully burned out. Note that the time of preliminary glow when there are small additions of gasoline significantly depends on the amount thereof. So, we have experimentally established that when 0.1 g of gasoline is added, independent combustion does not occur. In this case, without the addition of more gasoline, we determined the time of afterglow after conducting a specific number of discharges. We established that this time decreases exponentially with an increasing number of discharges and in the limit drops to a quantity characteristic of a discharge in pure water, i.e., to a value on the order of 200–500 μs. The

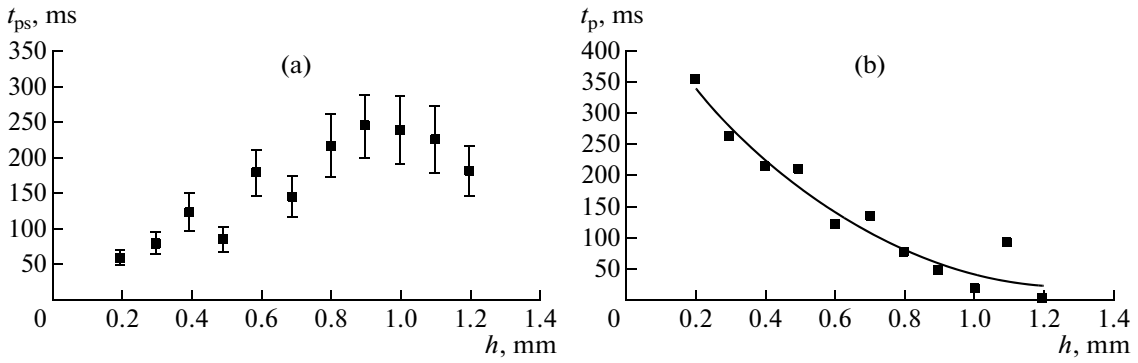

Fig. 3. Dependences of time of preliminary combustion (a) and time of pause (b) on the thickness of the gasoline film at R_b = 1 kΩ, U_0 = 20 kW.

experiments showed that both the process of discharge propagation over a liquid surface and the process of gasoline combustion have a non-steady-state character. Therefore, it is quite difficult to determine any dependences, characterizing the combustion process, on external parameters of the discharge. Under these conditions, we can only speak about determining certain tendencies observed in the combustion process. One of these trends, which can be traced from statistical processing of a large number of experiments, is the conclusion that with an increase in the mass of gasoline deposited on the water surface, the time of preliminary glow increases and the time of the pause decreases. As an example, Fig. 3 shows the averaged time dependences on the thickness (and, consequently, on the mass) of the gasoline film.

As follows from Fig. 3a, the time of preliminary glow increases with increasing mass of added gasoline. In contrast, an increase in the time of preliminary glow is accompanied by a corresponding decrease in the time of the pause (Fig. 3b). Note that the tendency toward an increase in the time of preliminary glow is somewhat retarded and it even begins to decrease when there are large amounts of gasoline added. However, if this is the case, it is quite difficult to accurately determine both the time of preliminary glow and the time of the pause, because under these conditions, independent combustion of gasoline begins almost simultaneously with the end of the pulse and it is impossible to determine the difference between interim glow and combustion.

4. CONCLUSIONS

From our experimental results it follows that addition of gasoline leads to a significant increase in the glow intensity of discharge during the pulse. After the end of the pulse, combustion of gasoline can occur in three stages: the preliminary combustion phase, the pause phase, and the independent combustion phase; as well, with increasing mass of added gasoline, the time of the pause decreases and the independent combustion stage begins immediately after the end of the discharge pulse.

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