INFLUENCE OF PLASMA ON SURFACE TENSION OF HYDROCARBONS

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The results of studying of plasma influence on the surface tension of liquid hydrocarbons and distilled water during experiments with corona discharge are presented. The charged particles influence on the surface tension of fluids with different electrical conductivity is demonstrated. Current-voltage characteristics of corona discharge are measured. It is shown that the flow of charged particles leads to fragmentation of liquids with low conductivity into small droplets. The effect of corona discharge on the stearin combustion rate is investigated.

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INTRODUCTION

An active part of modern plasma chemistry consists of a development of various plasma-liquid systems. Among those systems are discharges with liquid electrodes, discharges in aerosols or vapors of liquids. Such systems are widely used in reforming and combustion of hydrocarbons, plasma medicine, plasma treatment of fluids, and in number of other applications. That is why special attention must be paid to the interaction between the charged particles generated in plasma and the surface of liquid in such systems. An active gassing was observed in water near the surface of the submerged electrode during the experiments in plasma-liquid system with reverse vortex gas flow of tornado type with liquid electrode [1-3]. Gas bubbles rose to the surface of the liquid and disappeared at plasma-liquid contact area.

The electrolysis of the same fluid with the same current value as during discharge was accompanied by the accumulation of gas bubbles at the surface of liquid [2]. This fact leads to an assumption that particles with electric charge can affect the surface tension value upon their interaction with fluid. However, the usage of discharges with capacity of 500…800 W has large possibility that surface tension changes are due to thermal heating of the liquid surface by discharge plasma. The possibility to regulate the surface tension by means of charges can be useful in hydrocarbon reforming and combustion of various solid hydrocarbon fuels that have prospects in the aerospace industry. Stearin and paraffin are among the most promising fuels for hybrid rocket motors. Stearin is melting first during burning, after that it is sprayed and forms into an aerosol or vapor which are ignited. Intensity of stearin burning can be increased by increasing its evaporation rate. This characteristic is closely associated with the surface tension phenomenon: the lower the surface tension, the weaker the interaction between molecules in liquid is and the higher evaporation rate becomes. This approach will simplify the creation of working substances aerosols in plasma-chemical systems, which will result in a more effective interaction with plasma. For the first time, the interaction between the charged particles and fluids in association with electrical phenomena in an atmosphere was considered by Gaston Plante in 1891 [4]. Interest to this question reappeared due to intensive development of plasma chemistry at the beginning of XXI century and resulted in MSU carrying out the investigation [5], whose aim was to study corona discharge and liquid surface interaction.

1. EXPERIMENTAL SET-UP

The experimental system with corona discharge was used for investigation of this problem. The advantage of this discharge lies in creation of ion flow (ion wind) with a temperature which is approximately equal to the ambient temperature. This feature, combined with relatively low discharge power, allows to neglect the heating of samples during the study, and to exclude the temperature dependence of surface tension from consideration. Several modifications of the basic system that were used during an experiment are shown at Fig. 1. The system for liquid research consists of cathode tip (1) and a grounded anode plate (3), on which lies a test liquid drop (2). The liquids with different specific electric conductivity were used during the experiment: vacuum and vegetable oils (15 $p\mathrm{S\cdot m^{-1}}$), distilled water (50 $n\mathrm{S\cdot m^{-1}}$) and bioglycerol (80 $\mu\mathrm{S\cdot m^{-1}}$). Discharge current-voltage characteristics were measured by a voltmeter (5) and an ammeter (6). Discharge was supported by DC power source (4). The average power of discharge was 40 mW. Drops of liquids were deposited on the anode plate by syringe and had the same volume (7 $\mathrm{mm^3}$). The system on Fig. 1,b. was used for investigation of the corona discharge influence on solid hydrocarbon fuels. This system has anode surface (3) which is completely covered with stearin (9) instead of a liquid droplet. Anode was preheated in order to keep stearin layer in a molten state. The metal plate (2) was inserted between stearin surface and cathode tip (1). Its purpose was to shield hydrocarbon from charged particles that were generated in corona discharge.

The system had the third modification for study of stearin combustion rate under charged particles flow. This system modification is showed at Fig. 1,b, where stearin pieces were placed on the thermocouple (8) between the corona discharge electrodes instead of a metal plate (2). Stearin pieces were ignited using a gas lighter.

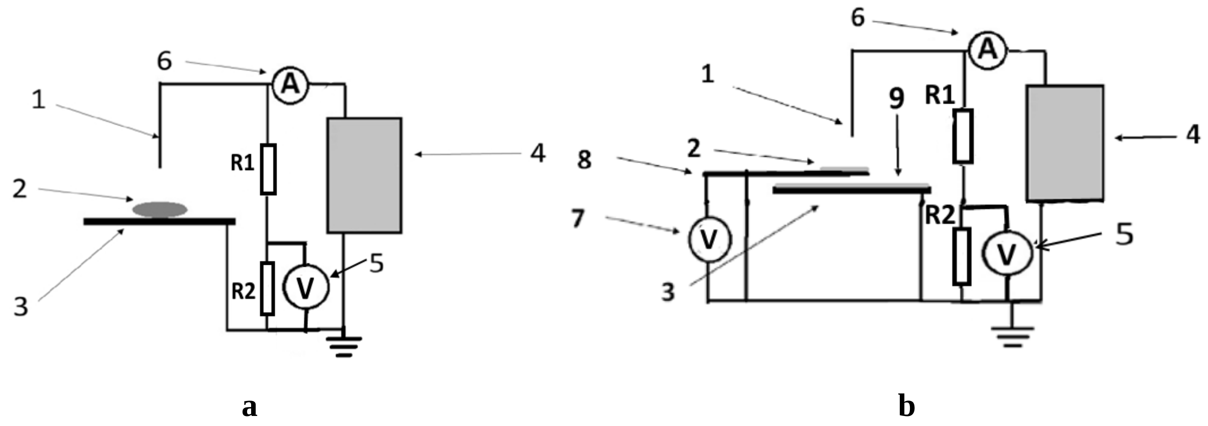

Fig. 1. Experimental setup for studying the influence of charged particles on the surface tension of the liquid (a), stearin (b) and burning rate of stearin

2. RESULTS AND DISCUSSION

The discharge current-voltage characteristics are shown at Fig. 2. They were measured in absence and in presence of drops of the working fluids (distilled water, bioglycerol, vegetable oil, vacuum oil).

The investigations of the influence of charged particles flow on liquid showed that its strength depends on the electrical conductivity of a substance. In bioglycerol case, the liquid showed no response to charged particles. When a distilled water droplet was processed, depression appeared on the surface of water droplet. It was located under the tip of the discharge; this phenomenon coincides well with the results of similar experiments [4].

The time of complete evaporation of water droplets was several times shorter with the discharge influence than without it. Calculations demonstrated that the increased evaporation rate can't be explained as a result of additional heating of fluid because of the low power of the discharge. The strongest impact on fluids was observed in case of liquids with low electrical conductivity: vacuum oil and vegetable oil. When corona discharge was switched on the liquid drops were dispersed into a large number of droplets (Fig. 3). They spread in directions perpendicular to the cathode.

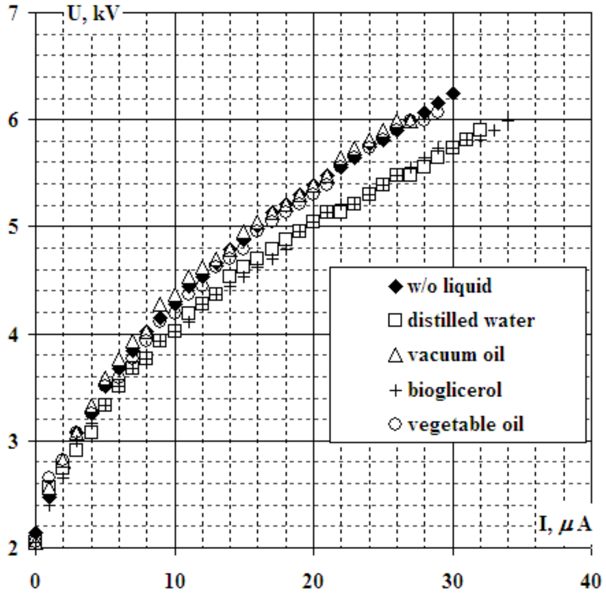

Fig. 2. Current-voltage characteristics of the discharge in absence and in presence of drops of working fluids (vegetable oil, vacuum oil, distilled water, bioglycerol) on the surface of the anode

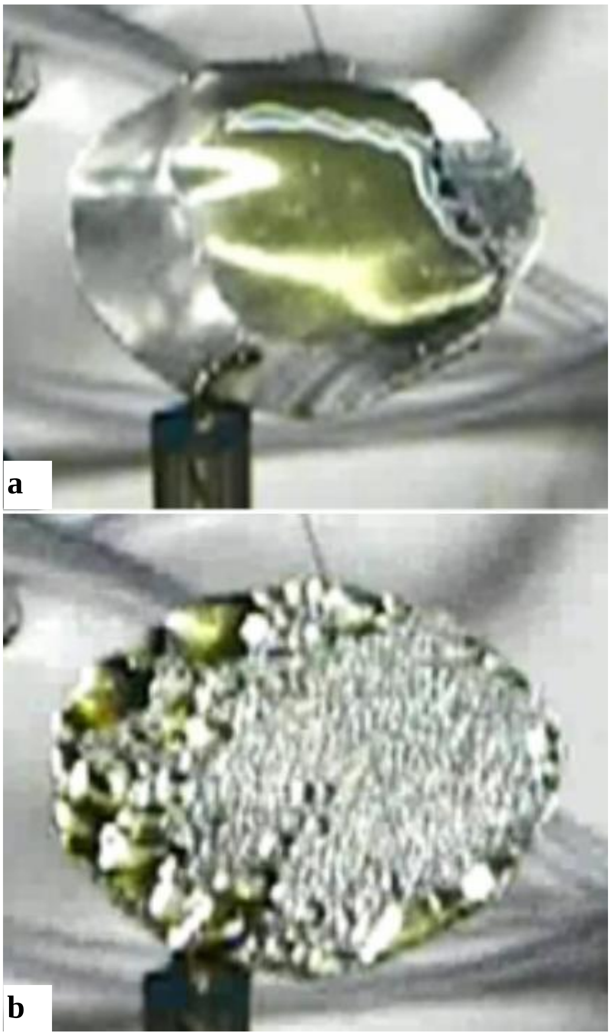

Fig. 3. Reaction of vacuum oil to discharge: a – discharge is "off"; b – discharge is "on"

The liquid droplets size change indicates a decrease of the surface tension value. The experiment with liquid stearin was the confirmation of electric nature of liquid's response to corona discharge. Changes, which are induced in the molted stearin and dielectric liquids in response to discharge, are identical (Fig. 4).

Metal plate installed over the molten stearin provides shielding from the charged particles stream generated by cathode tip. A shielded part of stearin did not disperse during the experiment (Fig. 5). This is confirmed by the patterns formed by cooled down stearin during the experiment. The area previously shielded by plate was clearly marked out by the large concentration of stearin.

The study of plasma assisted combustion of paraffin and its mixtures [6-8] has shown that plasma increases the flame temperature during combustion. Therefore, it was decided to examine the effects of low power electrical discharge on the burning process of stearin. The investigations of burning rate of stearin depending on charged particles flow was conducted using stearin pieces with an average weight of 4.0 ± 0.5 mg. Combustion process was recorded on video. Its analysis allowed to determine the burning substance. The mean time of complete stearin combustion with switched off corona was 4.5 ± 0.5 s (Fig. 6,a). When corona discharge was engaged full combustion time changed to 3.5 ± 0.5 s (Fig. 6,b). It should be noted that the discharge provided destabilizing effect on the flame, therefore it was more difficult to ignite the samples with gas lighter.

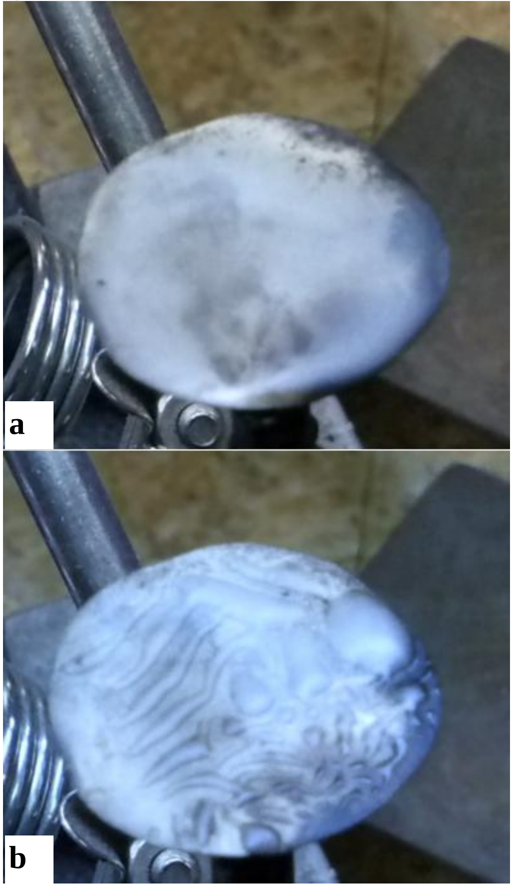

Fig. 4. Stearin: top – frozen without discharge processing and shielding plate; bottom – frozen during discharge processing without shielding plate

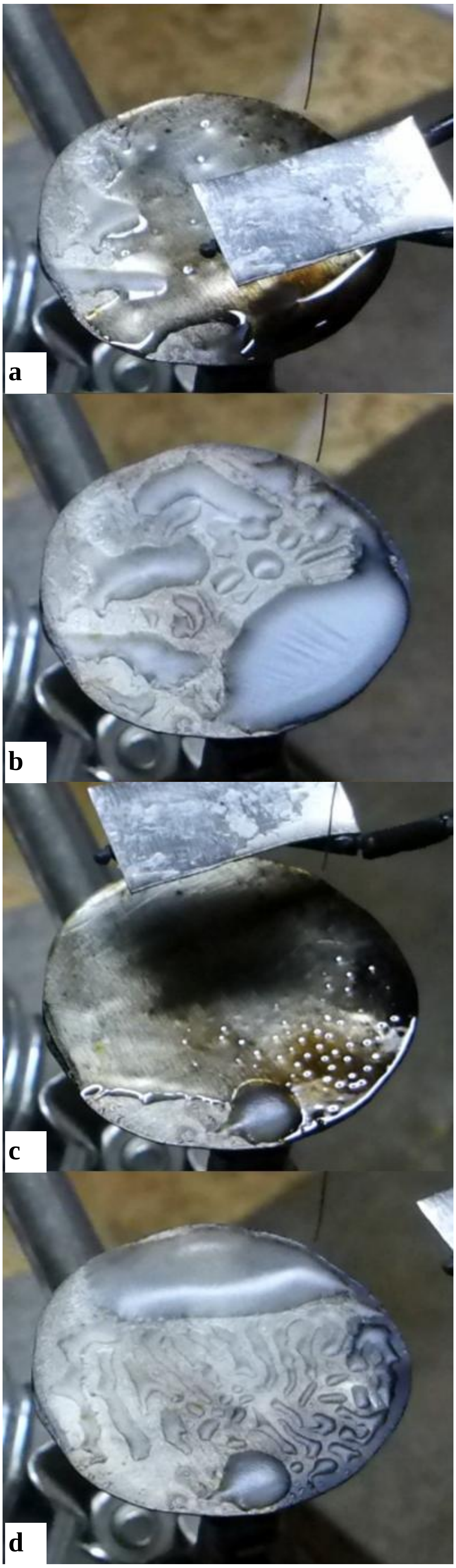

Fig. 5. Stearin with shielded plate: a, c – during the discharge processing; b, d – frozen during the discharge processing

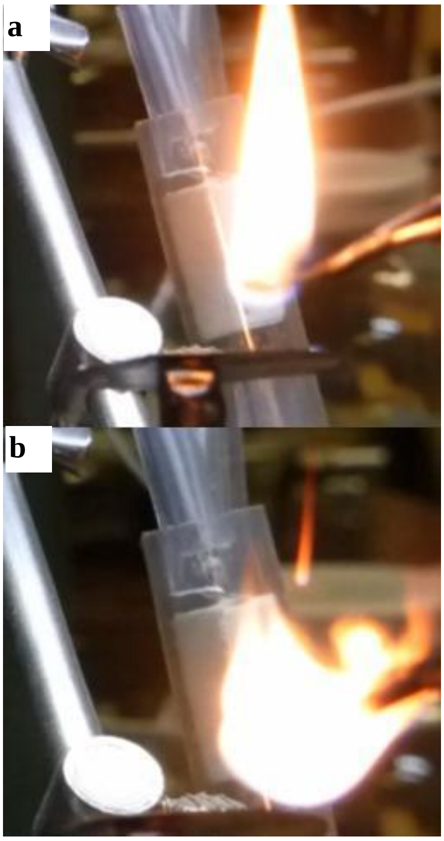

*Fig. 6. Stearin combustion: a – discharge is "off";
b – discharge is "on"*

The flame of stearin had a bigger diameter (see Fig. 6) at the presence of the discharge. It indicates the more effective spraying of stearin.

CONCLUSIONS

The interaction of charged particles with the surface of a liquid affect its surface tension, effectively reducing it in case of liquids with low electrical conductivity. Reduced surface tension of distilled water in response to corona discharge increases water evaporation rate.

The presence of corona discharge reduces the time of stearin combustion by 20% comparing to its absence.

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ВЛИЯНИЕ ПЛАЗМЫ НА ПОВЕРХНОСТНОЕ НАТЯЖЕНИЕ УГЛЕВОДОРОДОВ

И.И. Федирчик, О.А. Недыбалюк, Л.Ю. Вэргун, С.Г. Орловская, М.С. Шкоропадо

Представлены результаты серии экспериментов с коронным разрядом по исследованию влияния плазмы на поверхностное натяжение жидких углеводородов и дистиллированной воды. Показано влияние заряженных частиц на поверхностное натяжение жидкости с различной электропроводностью. Измерены вольт-амперные характеристики коронного разряда. Показано, что поток заряженных частиц приводит к фрагментации жидкости с низкой электропроводностью на мелкие капли. Исследовано влияние коронного разряда на скорость сгорания стеарина.

ВПЛИВ ПЛАЗМИ НА ПОВЕРХНЕВИЙ НАТЯГ ВУГЛЕВОДНІВ

І.І. Федірчик, О.А. Недибалюк, Л.Ю. Вергун, С.Г. Орловська, М.С. Шкоропадо

Представлено результати серії експериментів з коронним розрядом за дослідженнями впливу плазми на поверхневий натяг рідких вуглеводнів та дистильованої води. Показано вплив заряджених частинок на поверхневий натяг рідини з різною електропровідністю. Виміряно вольт-амперні характеристики коронного розряду. Показано, що потік заряджених частинок призводить до фрагментації рідини з низькою електропровідністю на дрібні краплини. Досліджено вплив коронного розряду на швидкість згорання стеарину.