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Combustion of low melting point alkane particles under dc electric field

Combustion of low melting point alkanes (n-Octadecane, n-Docosane) is studied experimentally under dc electric field (EF). Nearly two-fold rise of ignition delay time is observed as a result of melting retardation under EF strength E > 60 kV/m. A burning rate constant increases within the range 10÷20 % depending on a droplet initial diameter under. E> 82 kV/m. Droplet combustion intensification is explained by an increase of heat flux from flame luminous zone to the droplet surface as a result of flame deformation. In so way the ignition delay time of alkane particles increases and burning time decreases under dc EF.

Introduction. The electric field (EF) influence on gaseous fuels combustion has been studied extensively for a long time. It is well known that hydrocarbons flames are characterized by high degree of ionization in reaction zone due to formation of radical ions CH_3^+ , H_3O^+ , $C_3H_3^+$, CHO^+ and electrons, so the application of EF can strongly influence the flame front behavior and combustion characteristics [1].

A pronounced effect of dc EF on the burning characteristics of gaseous alkanes was confirmed by many experiments. To get an idea about the state of the art one can read a comprehensive review by Tretyakov et al. [2]. It is established that under EF the flammability limits of fuel-air mixtures expanded, the burning rate changed, flame stabilization shifted toward lean mixtures.

At the same time combustion behavior of solid and liquid fuels under EF is studied quite insufficiently. In particular, there are very few data on low melting point solid fuels (higher alkanes, paraffin wax) combustion under dc EF. The application of the mechanisms elaborated for combustion of gaseous mixtures does not explain the peculiarities of condensed fuel burning under dc EF, because combustion behavior depends appreciably on kinetics of phase transitions (melting and gasification) and soot formation during the combustion. So the influence of EF on alkanes melting and evaporation is to be clarified in view of the new promising space applications of alkanes melting and combustion: environment friendly hybrid paraffin propellants, micro-combustors and micro-actuators.

First of all we are to mention the most interesting results of other researchers. Ilchenko and Shevchuk used the stationary droplet method [3] to study the influence of EF (0.5 ÷ 2 kV/cm) on combustion rate of methanol, hexane and benzene in relation to their sooting tendencies. They found that dc EF affected significantly on smoky flames, so the mass burning rate of benzene increased linearly with rising field strength (the total gain reaches 15%). EF effect on hexane burning was relatively weak and the burning rate of methanol didn't change visibly. In all cases the flame was deflected towards the negatively charged plate of the capacitor. The deviation value increased with EF strength rising, and was more pronounced for luminous flames. The methanol flame was bent in the case of incomplete combustion (the appearance of a yellow glow). The authors considered the EF influence on the burning processes and concluded that the ion wind through charged soot particles was dominant.

The investigations of liquid hydrocarbons (decane, undecane, dodecane, tridecane, tetradecane) combustion under electrostatic field E=10÷60 kV/m [4] indicated a sharp increase of the fuel burning rate as a result of explosive boiling. The flame height increased by 5÷10 times. The pulsations and oscillations of flame were observed in the vertical and horizontal directions.

A comprehensive review of studies on liquid hydrocarbons combustion under EF is presented in [5]. The authors marked the effect of EF on physical properties of fuel and phase change characteristics. They showed that EF application usually increased burning rate,

So, as a rule, application of dc EF led to a significant increase in hydrocarbons burning rate. The effect is more pronounced in diffusion flames, whose propagation velocities are much lower than those of premixed flames. But there are some exceptions. Authors of [6] studied the EF effect on the combustion behavior of solid propellants. They observed that application of external EF result to extinguishment of paraffin strands burning in opposed flow of oxygen over a broad range of operating conditions. In addition, the combustion behavior of two composite propellants was studied under external EF. Both propellants were based on HTPB/AP combinations, with one propellant containing aluminum and the other being non-aluminized. Application of an EF to the composite solid rocket propellant strands demonstrated decreases in propellant burning rate under all operating conditions for both propellants including changes in polarity.

It should be marked some attempts to use plasma for fuel ignition and effective burning. For example, the using of non-equilibrium low temperature plasma for paraffin ignition and combustion stabilization is proposed by professor V.Ya. Chernyak [7]. The plasma assisted combustion of paraffin and stearin was studied experimentally under transverse and rotational gliding arc. The voltage-current characteristics of discharge were measured at the different operating conditions. The flame temperature profiles were calculated.

The present study is aimed at detailed investigation of the dc electric field effect on the burning characteristics of n-Octadecane and n-Docosane.

Experiment. To study combustion of Octadecane and Docosane droplets under EF we equipped our experimental setup with flat capacitor (two copper plates 17cm x10 cm located vertically at the distance 6 cm). The plates are connected to a high voltage source BC-23 (Fig.1). As these alkanes are solid at room temperature, at first a sample is to be melted in a water bath, then a droplet is formed with a syringe needle and suspended on a tungsten filament loop (=114 mcm). Solidified droplet on suspension is inserted into heated air, and the its heating and burning history is recorded by camera through microscope objective (x32). After the droplet ignition its flame is recorded by another camera. The movies obtained are split into separate

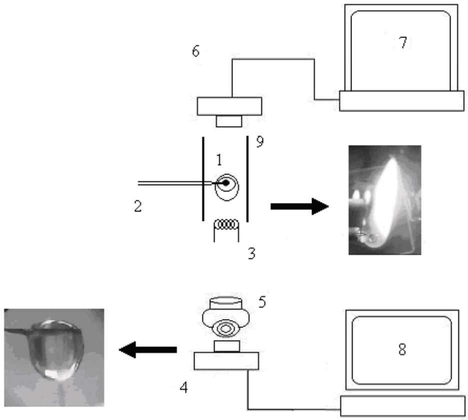

Fig.1. The scheme of the experimental setup: 1 – a droplet; 2 – tungsten filament; 3 – the heating element; 4, 6 –video-cameras; 5 – microscope objective; 8 –computer, 9- the plane capacitor.

frames and processed by Image Processing Toolbox of MatLab. The droplet equivalent diameter values at successive instants of time are determined by specially elaborated correct method. At first we find a semi-perimeter of the droplet projection. Then the droplet surface area is calculated by formula for surface of revolution of corresponding function, and determine the value of the droplet equivalent diameter as a diameter of circle with equal area. Then we plot the graph of droplet diameter squared versus time $d_{eq}^2(t)$. A burning rate constant is defined as a slope of linear part of the curve.

It is found that the burning rate constant significantly increases under dc electric field (Fig.2). For octadecane droplet burning rate rises by 10÷20% depending on the droplet initial diameter. It is also observed that the flame deflects to the negatively charged plate and its height diminishes. The intensification of the droplet combustion is explained by significant increase of heat flux from the luminous flame zone to the droplet surface due to flame shape deformation. As a result the evaporation process accelerates, and the burning rate increases accordingly. It should be noted that the electric field effect on burning rate is noticeable starting with E = 33 kV/m.

The pre-ignition stage of solid alkane particle includes its heating and melting. The substances under consideration have low melting points: n-Octadecane 28.1°C and n-Docosane (44°C), so the droplets begin to melt almost immediately after putting into hot air.

The droplet size histories are analyzed and compared with the characteristics of solid-liquid phase transition in alkanes. It is found that the droplet equivalent diameter increases significantly due to thermal expansion and melting, and after ignition it decreases rapidly. So we can easily determine droplet ignition delay time as its diameter rise duration.

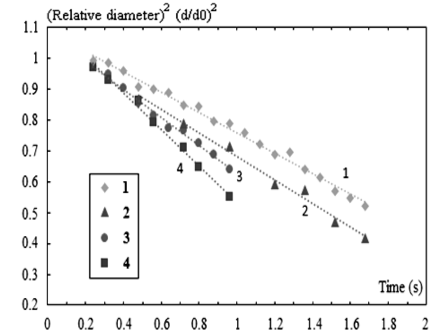

Fig. 2. The effect of dc electric field on burning rate of Octadecane droplet: 1-2. d_0=1.96 mm, E = 0 (1), E =82 kV/m (2); 3-4. d_0=1.64 mm, E = 0 (3), E =82 kV/m (4).

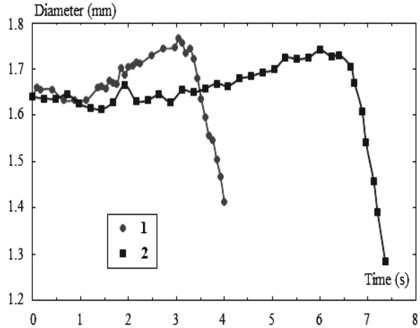

Fig. 3. Octadecane droplet size history: d_0=1.64 mm, 1. E=0; 2. E=82 kV/m, T_g = 720 K

The melting of Octadecane and Docosane droplets is studied under dc electric field in the range from 33 ÷117 kV/m. It is found that melting rate decreases distinctly starting with EF strength E~ 80 kV/m (Fig.3). The effect of EF is more pronounced at high gas temperatures, when the melting time is about a few seconds. Also the Quincke effect was observed, namely a solid residue rotation inside melt under electric field.

Conclusions. Combustion of low melting point alkane particles has been studied experimentally under dc electric field in the range E =33 ÷117 kV/m. It is found that melting time rises nearly two-fold starting with E ~ 60 kV/m. It is found that burning rate constants increase by 10÷20 % under dc electric field E >80 kV/m. This fact is explained by significant rise of radiation heat flow from the flame luminous zone to the droplet surface due to flame deformation. So if an alkane droplet is solid initially (the melting point exceeds ambient gas temperature) its pre-ignition time increases almost two-fold as a result of melting retardation by electric field. This fact should be taken into account when developing devices of electric field assisted combustion.

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Горение частиц легкоплавких алканов в электрическом поле

Аннотация

Экспериментально изучено горение частиц легкоплавких алканов (октадекан, докозан) в постоянном электрическом поле. Установлено, что при напряженности поля выше 60 кВ/м время задержки воспламенения существенно возрастает (примерно вдвое) за счет замедления процесса плавления. Константа скорости горения капель увеличивается на 10÷20% в зависимости от начального диаметра при напряженности поля E > 82 кВ/м. Интенсификация горения капель алканов при наложении электрического поля обусловлена возрастанием теплового потока из реакционной зоны пламени к поверхности капли вследствие деформации пламени. В результате возрастает период индукции воспламенения частиц легкоплавких алканов, зато уменьшается время горения в постоянном электрическом поле.

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Горіння частинок легкоплавких алканів в електричному полі

Анотація

Горіння частинок легкоплавких алканів (октадекан, докозан) в постійному електричному полі вивчено експериментально. Встановлено, що час затримки займання зростає майже вдвічі при напруженості поля вище 60 кВ/м внаслідок гальмування процесу плавлення. Константа швидкості горіння крапель збільшується на 10÷20% залежно від початкового діаметру при напруженості поля E > 82 кВ/м. Інтенсифікація горіння крапель алканів в електричному полі обумовлено збільшенням теплового потоку із реакційної зони полум'я до поверхні краплі унаслідок деформації факела. В результаті в постійному електричному полі зростає період індукції займання частинок легкоплавких алканів, зате зменшується час горіння.