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ФИЗИКА ГОРЕНИЯ

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Combustion characteristics of alkane two-droplet array. Part 1. Two droplet array of n-Octadecane

Characteristics of ignition and combustion of two n-Octadecane droplets placed vertically are studied by videomicroscopy. Upper droplet burning histories are obtained for different droplet spacing, burning rate constants are determined. To clarify flame spread along fuel droplet array ignition delay is measured at different droplet spacing.

Introduction. In our previous works the experimental data were presented on burning characteristics of single alkane droplet [1, 2]. But as we know, spray combustion is a main way of liquid fuels burning – it is widely used from diesel engines to space rockets. So droplet array burning characteristics are of particular interest for researchers.

Spray combustion is a complex phenomenon, which includes different physical processes starting with atomization of liquid, following by droplets vaporization and ignition, flame spread and extinction. All these processes are complicated by heat and mass transfer, droplet-air and vapor-air mixing, formation of premixed or diffusion flames. So different regimes of spray combustion are possible depending on physical-chemical properties of fuel, size and concentration of droplets, pressure and temperature of ambient gas. In case of fast chemical reactions combustion is diffusion controlled, then its regime is defined by ratio of three characteristic times:

- time of heat diffusion into droplet cloud $t_c = a_c^2 / D_T$;
- droplet vaporization time $t_v = (\rho_d / \rho) \cdot (a^2 / D_T)$;
- characteristic time of the mass and temperature change in surrounding gas due to fuel vaporization $t_g = \left(4\pi D_T a n / 3\right)^{-1}$.

Chiu [2] introduced so called group-combustion number G to predict combustion regime of droplet cloud:

$$G = \frac{t_c}{t_g} = \frac{4\pi a_c^2 a n}{3} = \left(\frac{a_c}{a_g}\right)^2,$$

here a_c – radius of a cloud, m; a – droplet radius, m; a_g – characteristic length of thermal diffusion in the spray cloud, m ; n – droplets concentration, m^{-3}.

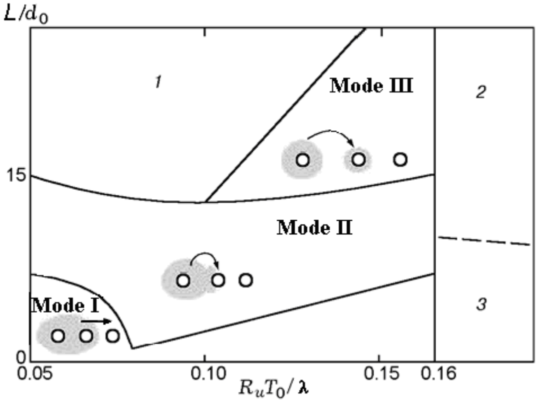


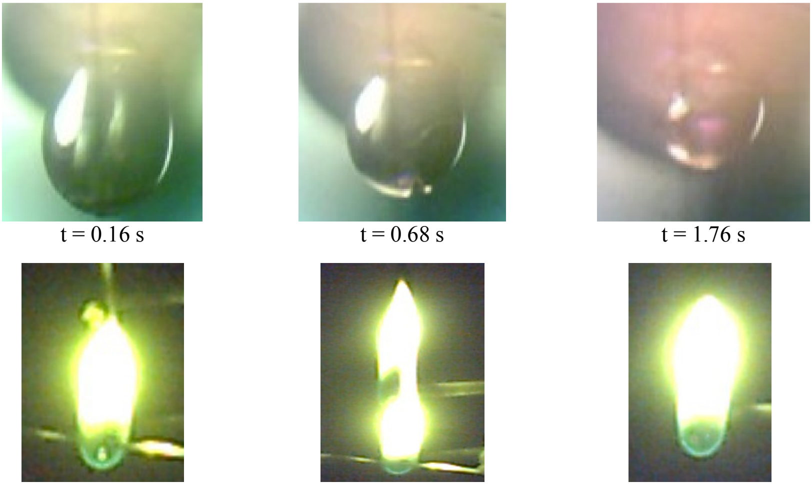
Fig.1 Diagram of flame spread modes: I – flame propagation in premixed fuel vapor-air mixture; II– flame propagation with simultaneous ignition; III – flame propagation by discontinuous ignition, 1 – evaporation without burning; 2 – spontaneous combustion of isolated droplets; 3 – spontaneous combustion of the whole cloud.

Flame spread rate along droplet cloud influences substantially combustion stability and efficiency, so it is a basic burning characteristic, which depends on fuel properties, dimensionless spacing and ambient temperature[3]. As a rule two basic modes of flame spread are considered (Fig.1) – premixed propagation (I) and propagation with discontinuous ignition (III). In addition we can mark out some intermediate flame propagation regime (II): the unburned droplet ahead of the flame front is ignited before the front arrives at his premixed layer. The ignited region is immediately combined with the propagating flame. Hence, this process can be considered as intermediate between premixed propagation and propagation with discontinuous ignition. The flame spread modes are presented in Fig.1 [4]. Here R_uT_0/λ – dimensionless ambient temperature, L/d_0– dimensionless droplet spacing.

Burning characteristics of a single droplet could be used to describe group droplet combustion with some empirical coefficients. These coefficients depend on droplet spacing and convection currents. At atmospheric and super atmospheric pressure interdroplet distance exceeds flame front thickness, so spray combustion is controlled by fuel evaporation rate.

The presented paper focuses on experimental study of droplet burning characteristics depending on spacing, and flame spread from droplet to droplet.

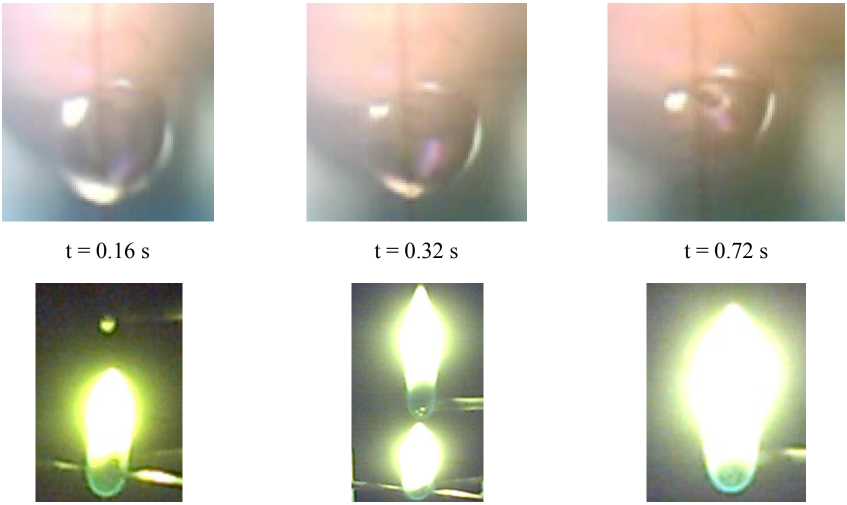
Experiment and results. Experimental setup to investigate droplet combustion is described in our previous paper [1]. To study two-droplet array it is supplied by additional tungsten filament loop (d = 0.58 mm) for second droplet. Inter-droplet spacing is adjusted by a micrometer screw with accuracy higher than 0.1 mm. The upper droplet is registered by camera Trust WB-1400T through microscope objective (x16). Flames of both droplets are imaged by the second camera Genius iSlim 1300



t = 0.16 s t = 0.68 s t = 1.76 s

t = 0.48 s t = 1.28 s t = 2.46 s

Fig. 2. Images of upper burning droplet and total flame, $d_0 = 2.4$ mm.(spacing L=15 mm)



t = 0.16 s t = 0.32 s t = 0.72 s

t = 0.48 s t = 1.20 s t = 2.56 s

Fig.3. Successive images of upper burning droplet and total flame, $d_0 = 2.17$ mm (spacing L=21 mm).

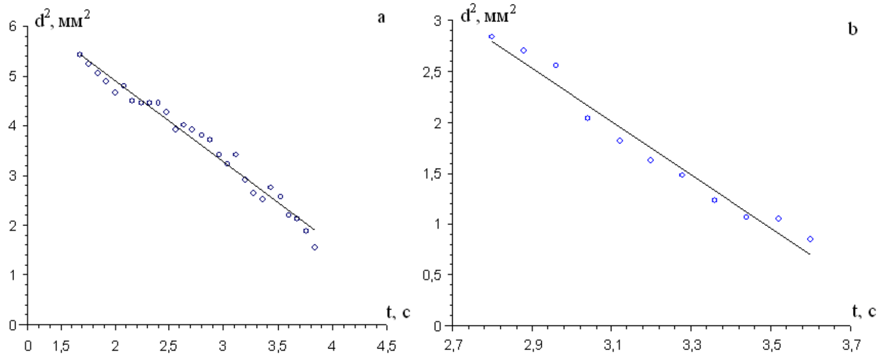


Fig. 4 Squared diameter of burning Octadecane droplet, a) d_0 = 2.4 mm; b) d_0 = 2.17 mm.

Table. *The burning characteristics of upper Octadecane droplet* $<d_0>$*=2,26 mm.*

L, mm	d_0,mm	h_{max}, mm	t_{bur}, s	L/d_0	K_{bur}, mm²/s
7	2.09	35.6	3.60	3.3	1.46
9	2.43	40.4	4.48	3.7	1.69
11	2.30	55.3	4.72	4.8	1.98
15	2.40	31.3	4.80	6.3	1.63
21	2,17	35.1	4.08	11.6	2.61
25	2,15	21.7	4.48	11.6	0.98

[5]. The video-files then are transferred to computers, decoded and processed by useImage Processing Toolbox of MatLab 7.0 [6]. Two illustrative examples are presented in Fig.2-4 below.

It is shown, that burning history of upper droplet is described by d^2–law, so we can determine burning rate constant K_{bur} by the slope of the straight-line approximation. Simultaneously we define its burning time t_{bur}.

As well we measure flame height of lower droplet and the total flame height. The results obtained are presented in the Table below. Since the initial diameters of droplets are nearly equal, we calculate average value to be equal 2.26 ± 0.17 mm.

As well we determine ignition delay time of upper droplet versus inter droplet spacing (Fig. 5). We can see that ignition delay increases slowly at short distance and then rises abruptly when spacing exceeds 20 mm. The critical value of dimensionless spacing (L/d_0) above which the flame doesn’t spread is about 12.

In Fig.6 the dependence of burning rate constant versus inter droplet spacing is presented. We can see it is non-monotonous and decreases abruptly at $L/d_0 > 10$.

Flame images analysis allows us to conclude that total flame height is maximum at inter droplet spacing ~ 11 mm. When spacing equals 25 mm, upper droplet is beyond the flame of lower droplet.

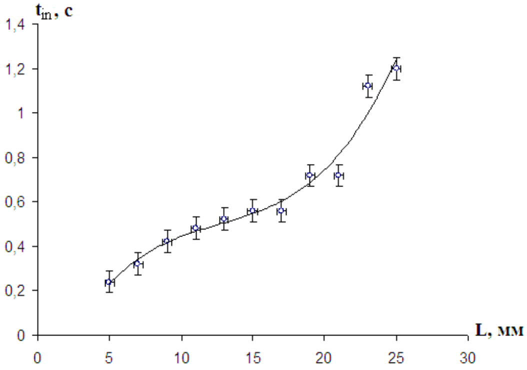


Fig.5 Ignition delay of upper droplet versus inter droplet spacing, d_0=2.1 mm.

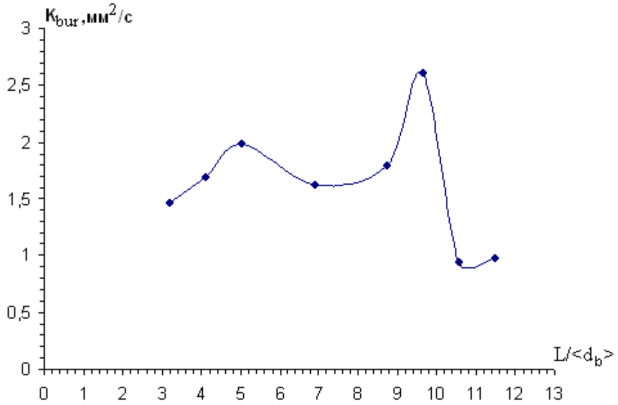


Fig.6 Burning rate constant of upper droplet versus dimensionless spacing.

Conclusions. Combustion of two-droplet array of n-Octadecane is studied experimentally. Applicability of d^2-law for upper droplet burning history is shown. Burning rate constant is determined to be in range 1,4÷2.5 mm^2/s depending on spacing. It is shown, that burning rate of upper droplet is lower than one of isolated droplet due to decrease of oxygen concentration in air. It is shown that ignition delay of upper droplet rises with inter droplet spacing increase, critical value of spacing is found, above which flame doesn’t spread.

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Характеристики горіння системи двох крапель алканів
Частина 1. Система з двох крапель октадекану

АНОТАЦІЯ

Експериментально вивчено характеристики спалахування та горіння системи з двох однакових крапель октадекану. Визначено час затримки спалахування верхньої краплі в залежності від міжкрапельної відстані, та отримано часові залежності квадрату її діаметру. Знайдено час горіння та константи швидкості горіння крапель різних розмірів та при різних міжкрапельних відстанях.

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Характеристики горения системы двух капель алканов
Часть 1. Система двух капель октадекана

АННОТАЦИЯ

Экспериментально изучены характеристики воспламенения и горения системы двух одинаковых капель октадекана. Найдено время задержки воспламенения верхней капли в зависимости от межкапельного расстояния, получены зависимости квадрата ее диаметра от времени. Определены времена горения и константы скорости горения капель разных размеров при разных межкапельных расстояниях.