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ФІЗИКА ГОРІННЯ

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Combustion characteristics of alkane two-droplet array Part 2. Two droplet array of n-Docosane

Combustion of two n-Docosane droplets in air at room temperature is studied experimentally. The droplets are disposed vertically one above another and burning history of upper droplet is registered. A new accurate method for measuring an equivalent diameter of burning droplet is developed. As a result, burning rate constants of Docosane and Octadecane droplets are measured more accurately. The dependence of upper droplet burning rate on interdroplet spacing is analyzed.

Introduction. Higher hydrocarbons, which are liquid or solid at room temperature, constitute the significant part of fossil fuels, as well as new alternative fuels. Thus, paraffin wax is considered to be a promising hybrid propellant [1]. So characteristics of higher alkanes combustion is in the focus of researches. As we know, physical properties of normal alkanes change as number of carbon atoms increases. For example, melting and boiling temperatures increase with molecular weight rise. At the same time heat of combustion decreases slightly from 49.1 MJ/kg (Pentane) till 47.6 MJ/kg (Octadecane). Heat of combustion on volume basis on the contrary increases from 30.7 MJ/l to 37.1 MJ/l. So if fuel volume is limited higher alkanes are preferable due to their higher volumetric heat of combustion. Unfortunately, there is lack of experimental data on burning characteristics of pure higher alkanes starting with heptadecane.

In the first part of this paper [2] we present the experimental results of two Octadecane droplets combustion. The second part of the paper is aimed at investigation of two Docosane droplets combustion, namely burning characteristics of upper droplet rate versus interdroplet spacing.

Experiments and results. Experimental setup to study droplet combustion is adapted for two droplet array study and described in Part 1 [2]. In our previous studies we determined an equivalent diameter of a droplet by conventional procedure based on supposition that equivalent diameter of a droplet is equal to that of its projection onto the image plane [3]. But this approach leads to an essential systematic error in a droplet diameter if $d > 1$ mcm, because coarse droplets are evidently nonspherical. This error doubles when we calculate burning rate constant because it is proportional to squared diameter.

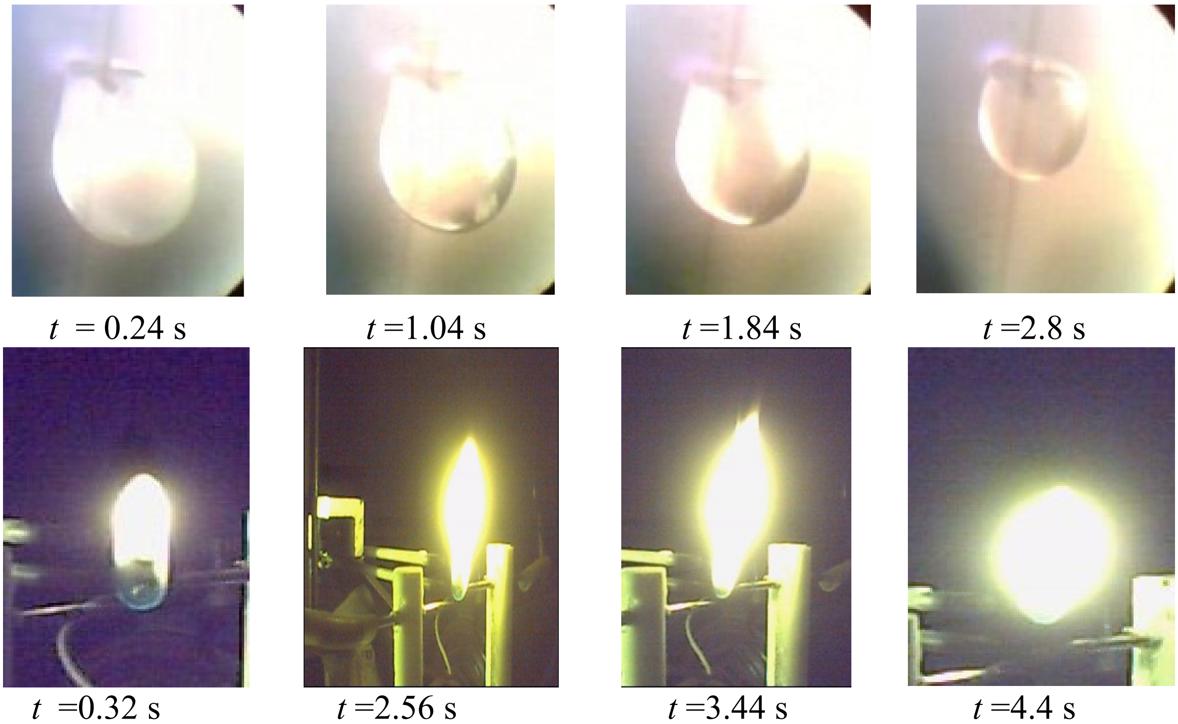

Fig. 1. Images of upper droplet and group flame, d_0 = 2.62 mm, L = 7mm

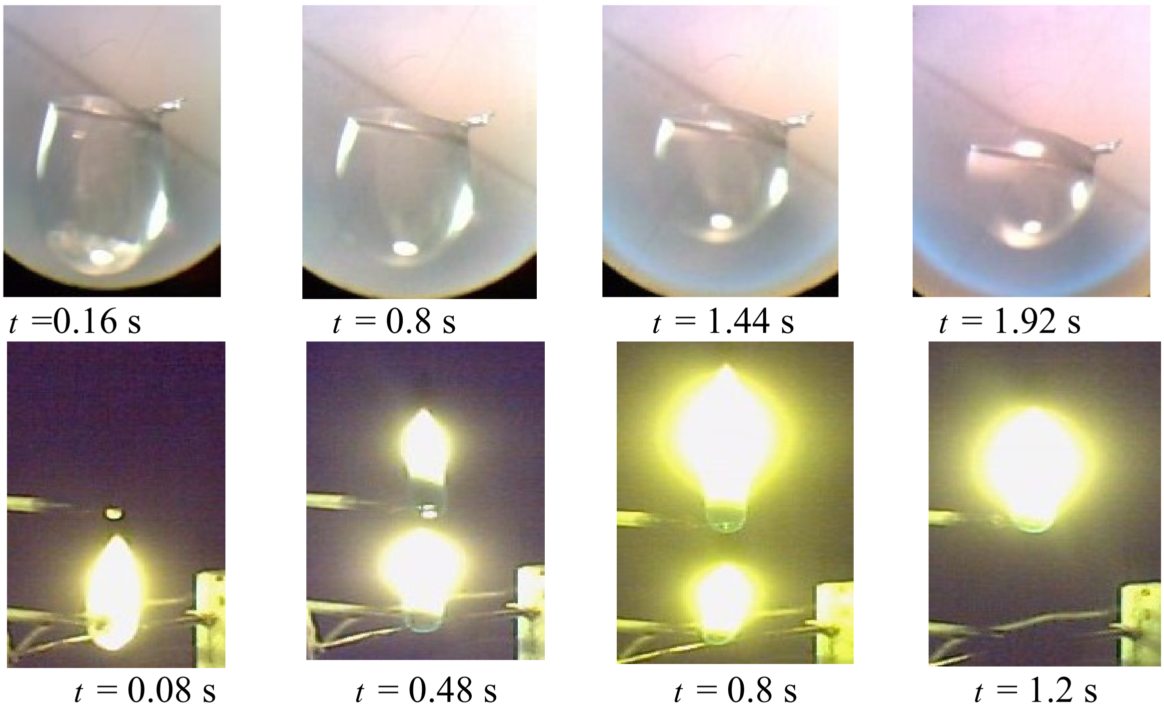

Fig. 2. Images of upper droplet and group flame, d_0 = 3,12 mm. L = 26 mm

So to determine an equivalent diameter of a droplet more accurately we proceed from definition of this term – "the diameter of a spherical particle which will give identical geometric, optical, electrical or aerodynamic behaviour to that of the particle (non-spherical) being examined; sometimes referred to as the Stokes diameter for particles in non-turbulent flows" [4]. The burning rate is proportional to droplet surface area, so we have to find a droplet surface area and then calculate its equivalent diameter.

Table 1. Burning characteristics of upper Docosane droplet

L, mm	d_0, mm	h_{fl}, mm	t_b, s	L/d_0	K_b, mm^2/s
5	2.2	12.3	1.12	2.3	1.3
7	2.4	13.7	1.28	2.95	1.36
9	2. 7	16.3	1.54	3.37	1.3
11	2.4	26.2	1.76	4.6	1.34
15	2.6	28.6	1.84	5.75	1.4
23	3.2	40.3	2.48	7.14	1.55
26	3.1	38.7	2.16	8.33	1.67

Suspended droplet has axisymmetric shape, so we should use the formula for a surface of revolution to calculate the droplet surface area. This method has been used earlier to find a surface area of a laminar flame front [4]. We consider droplet as a solid obtained by rotating its semi-perimeter around a vertical axis. Then its surface area equals to an appropriate integral.

So we process burning histories of many droplets in so way. Equivalent diameter value obtained using this procedure is distinctly smaller than one obtained using conventional method. We estimate error of measurement of burning rate constant and determine that it significantly depends on droplet initial diameter: For example, for small droplets (initial diameter less than 1.5mm) the error is small: $\delta K < 0.1$ too, but in case of coarse droplets ($d_0 \approx 2.5 \div 3$ mm) systematic error is excessive: $\delta K \approx 0.4$. At the same time fine droplets are practically spherical, and both methods give equal results. So we must take into account this systematic error while studying coarse droplets, especially when investigating dependence of burning rate on initial droplet diameter.

There are pictures of upper burning droplet and two droplets flame shown in the Figures below. Images of burning droplet are processed with Image Processing Toolbox of MatLab. The successive values of equivalent diameter are obtained, and graph of squared diameter versus time is plotted. Then a linear approximation of $d^2(t)$ dependence is determined and a burning rate constant K_b is found.

The results obtained are presented in Table. Here L is a distance between the centers of droplets; d_0 - initial diameter of upper droplet; L/d_0 – dimensionless spacing; h_{fl} – a height of total flame; t_b – a burning time of upper droplet; and at last, K_b – a burning rate constant.

We can conclude that flame height increases with inter-droplet distance. Burning time of upper droplet depends on spacing too. Burning rate constant also increases with interdroplet space and droplet initial diameter. These facts could be explained by diffusion-controlled burning regime of Docosane droplet. So the oxygen content in surrounding gas affects greatly on burning rate. But at the same time the gas temperature is to exceed ignition temperature. In case the inter-droplet distance exceeds 27 mm, the upper droplet melts but not ignites.

In Fig. 3 we present dependences of burning rate constant versus interdroplet distance for Octadecane and Docosane. We can see that burning rate of Docosane

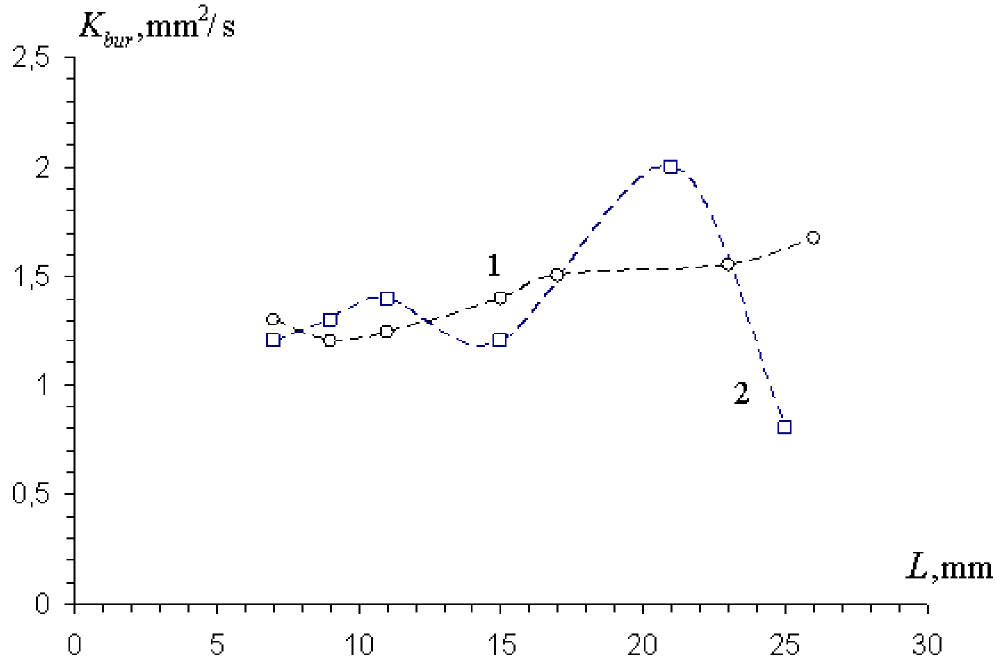

Fig. 3. Burning rate constants versus interdroplet distance: 1. Docosane; 2. Octadecane.

rises monotonically with spacing. The burning rate of Octadecane depends on interdroplet distance more complexly. Additional experiments are necessary to draw reliable conclusions.

Conclusions

Combustion of two droplets array of Docosane is studied. The droplets are disposed vertically one above another and burning history of upper droplet is studied. A new method to determine accurately an equivalent diameter of burning droplet is developed. In so way more precise data on burning constants of Docosane droplet are obtained, and burning rate constant of Octadecane droplet is determined more precise.

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Орловська С.Г., Карімова Ф.Ф., Шкоропадо М.С.

Характеристики горіння системи двох крапель алканів.
Частина 2. Система двох крапель н-докозана

АНОТАЦІЯ

Експериментально досліджено процес горіння двох крапель докозану у повітрі при кімнатній температурі. Краплі розміщувались на підвісах вертикально – одна під іншої. За допомогою двох камер реєстрували окремо верхню краплю та загальне полум'я. Розроблено нову методику визначення еквівалентного діаметру краплі по площі її поверхні, що дало змогу точніше виміряти стали швидкості горіння крапель докозану та октадекану. Побудовано і проаналізовано графіки залежності сталої швидкості горіння від міжкрапельної відстані.

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АННОТАЦИЯ

Экспериментально исследовано горение системы двух капель докозана в воздухе комнатной температуры. Капли размещались вертикально – одна под другой. С помощью двух камер регистрировалось горение верхней капли и общий факел. Разработан новый метод определения эквивалентного диаметра капли по площади поверхности, что позволило более точно измерить константы скорости горения докозана и октадекана. Построена и проанализирована зависимость скорости горения верхней капли от межкапельного расстояния.