Combustion of a liquid fuel droplet

Introduction

Liquid fuel droplet combustion is characterized by two interrelated processes:

- fuel evaporation by heat supplied from the flame (heat from the flame is transferred to the droplet surface)
- combustion in the zone distant from the droplet surface supported by diffusion of the vapor (volatiles) and ambient oxygen

In case heavy fuels combustion, additionally thermal decomposition of liquid droplet occurs. Intensity of this process increases with increasing temperature. Thermal decomposition products diffuse together with volatiles to the combustion zone.

In general the rate of evaporation of fuel is limiting the combusting process. In case of light fuel, the diameter of the drop decreases during combustion according to the d^2 law described by the following relation [1]:

$$d^2(\tau) = d_0^2 - k\tau \quad (1)$$

where: d_0 - initial diameter of the droplet, d - diameter of the drop at time τ, τ - current time of the phenomenon, k - characteristic rate constant called the evaporation constant or combustion characteristic.

Time required to burn the droplet completely τ_c corresponds to the droplet diameter $d(\tau_c) = 0$, thus

$$\tau_c = \frac{d_0^2}{k} \quad (2)$$

We can see that there is a linear relation between the square of the initial droplet diameter and droplet combustion time. Relation (2) holds for both light and heavy liquid fuels. The evaporation constant can be determined from equation (2) as:

$$k = \frac{d_0^2}{\tau_c} \quad (3)$$

Aim of the exercise

The aim of this exercise is to get acquainted with the phenomenon of burning of the liquid fuel droplets. Fuels of various volatility will be examined and their evaporation constants will be determined.

Experimental setup

As shown in Fig. 1 the test rig consists of four main elements:

- stand for slinging of the fuel drop

- spark igniter
- time measurement stopwatch
- optical device for measurements of the initial droplet diameter

Selected fuel drop should be placed on the loop of a platinum wire. The droplet is illuminated by a light source and its picture is mapped by the telephoto lens and camera system on the monitor. Magnification of the droplet allows more accurate measurement of the diameter. The droplet is then ignited by the electric spark generator and the measurement of time is started. The system with the photodiode controlling the stopwatch serves as the time measurement shutdown. Irrespective of the electronic measurement of the combustion time, this measurement should be also done with the stopwatch [2].

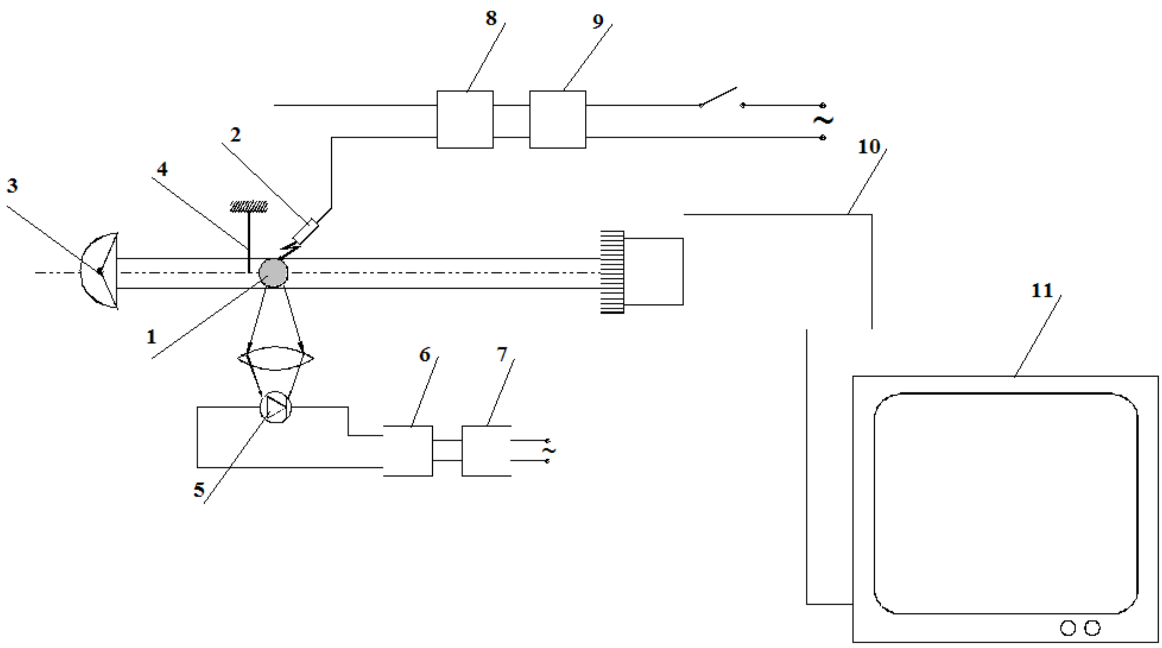

Fig. 1. Scheme for the liquid fuel drop combustion measurement. 1- drop of fuel; 2- spark electrode 3- light source; 4- dimension scale; 5- photodiode; 6- amplifier; 7-electronic timer; 8- spark generator; 9- regulator of the spark transition time; 10- camera with the telephoto lens; 11- monitor

As a model of the dimension for the magnifying system a nickel-chrome wire of 0.5 mm diameter is used. Measurement of the wire diameter on the display allows determining linear magnification of the system mapping of the drop diameter. Other equipment used during the measurements are a caliper for dimension measurements and syringes for placing the drops on the loop.

Methodology of measurements

The combustion time measurements of liquid fuel drops should be carried out in the following order:

1. Plug in all the necessary equipment, check the sharpness of the image on the monitor
2. Determine the enlarging mapping the drop by the measurement of the model wire diameter on the monitor

3. Fill the syringes (about 1/4 of their volumes) with the first of the test liquid fuels and then place a drop at a wire loop
4. Measure with the caliper the diameter of the droplet image on the monitor in two perpendicular directions
5. Ignite the drop with spark and measure electronically and with stopwatch the burning time of the drop
6. Observe the combustion process and if there are any problems (a drop falls down or burns unevenly, e.g. the flame clearly covers both the drop and the wire) the measurement must be repeated
7. Repeat steps 3-6 measuring from 7 to 10 droplet diameters for each fuel

Analysis of the results

The results of measurements for different fuels should be noted down in tables as shown in Table 1 (p - linear magnification factor).

The measured values of d_0^2 versus τ_c should be drawn on a plot and an estimate of the correlation coefficient r between the combustion time τ_c and square of the initial diameter d_0^2 should be calculated according to Eq. (4).

$$r = \frac{n \cdot \sum_{i=1}^{n} \tau_{ci} d_{0i}^2 - \sum_{i=1}^{n} \tau_{ci} \cdot \sum_{i=1}^{n} d_{0i}^2}{\left[\left(n \cdot \sum_{i=1}^{n} \tau_{ci}^2 - \left(\sum_{i=1}^{n} \tau_{ci}\right)^2\right) \cdot \left(n \cdot \sum_{i=1}^{n} d_{0i}^4 - \left(\sum_{i=1}^{n} d_{0i}^2\right)^2\right)\right]^{1/2}} \quad (4)$$

where: n - number of measurements, τ_{ci}, d_{0i} – i-th values of the measured combustion time and the drop initial diameter.

Calculate the combustion constant for each of the tested fuels using the least squares method applying the following equation:

$$k = \frac{\sum_{i=1}^{n} d_{0i}^2 \tau_{ci}}{\sum_{i=1}^{n} \tau_{ci}^2} \quad (5)$$

On the graph (d_0^2 vs. τ_c) plot additionally the relationships $d_0^2 = k\tau_c$ using the calculated combustion constants k for all fuels. Draw conclusions.

Table 1. The measurement results of drop diameter and the combustion time

No.	d_0', d_0'' mm	$d_{0i}' = (d_0' + d_0'')/2$ mm	$d_{0i} = d_{0i}'/p$ mm	d_{0i}^2 mm^2	τ_{ci} s
1					
2					

Literature

[1] Fossil Fuel Combustion. A Source Book (Eds. - Bartok W., Sarofim A.F), John Wiley and Sons Inc., New York, Chichester, Brisbane, Toronto, Singapore, 1991

[2] Paliwa i ich spalanie. Część V Laboratorium (R. Petela - red.), Skrypt Politechniki Śląskiej Nr 1191, 1984

[3] Paliwa i spalanie (W. Kordylewski - red.), Oficyna Wydawnicza Politechniki Wrocławskiej, II wyd., Wrocław, 1999