Combustion of Water Emulsion - Marine Diesel Oil Droplet

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The vaporization and combustion characteristics of an heavy oil-water emulsion droplet are investigated with graphological method. The combustion graphology of fuel oils is defined as a new technical and scientific field which deals with the graphic transposition of the processes of fuels combustion development in a simulator. Thus, it is easy to establish the ignition-combustion characteristics, including the laws that govern their changes depending on the combustion conditions and fuel specifications.

Keywords: oil-water emulsion, vaporization, graphological method

Theoretical criteria on the boil-up and combustion rate of liquid fuel droplet

The need for increasing the degree of marine fuel combustion with and without researches, through which can be mentioned that of applying the water emulsion to the atomized fuel combustion. This paper deals with finding new methods and means for improving the combustion processes of marine liquid fuel. It tries to make evident the effects of water emulsion on the marine liquid fuel during combustion. The assessment of emulsification influence was made by comparing the combustion performance and the results with those obtained in the absence of emulsification under the same test conditions. The laboratory researches developed on the isolated droplet burning had in view to state the measure in which the emulsification would interfere for carrying on the secondary atomization [1]. It was also tried to determine the characteristics of induced flames following their configuration and radiation and to assess the igniting and burning behavior of droplets by laying down comparison criteria of the following times:

τ_i - self-igniting delay time;
τ_v - burning time of volatile matters old;
τ_c - burning time of cenosphere.

The combustion graphology of fuel oils is defined as a new technical and scientific field which deals with the graphic transposition of the processes of fuels combustion development in a simulator [2]. Thus, it is easy to establish the ignition-combustion characteristics, including the laws that govern their changes depending on the combustion conditions and fuel specifications. The graphic representation of the combustion processes development for a droplet of liquid fuel used in the industrial combustion may be made by means of the so-called "combustion oscillogram" (fig. 1).

This graph specifies the time variation *t* of the light-thermal energy radiation intensity *I*, for a burning droplet, transformed into electric signals by means of an optical-electronical system, equipped with a photoelectrical cell (fig.2).

Thus for a heavy fuel oil, this ignition and combustion graph establishes, in standard conditions: the self-ignition delay τ_i, the volatile matters combustion time τ_v, the cenosphere combustion time τ_c^m, the maximum radiation intensity obtained at the combustion of the cenosphere I_c^m, the maximum radiation intensity obtained at the combustion of the volatile matter I_v^m, the energy radiated

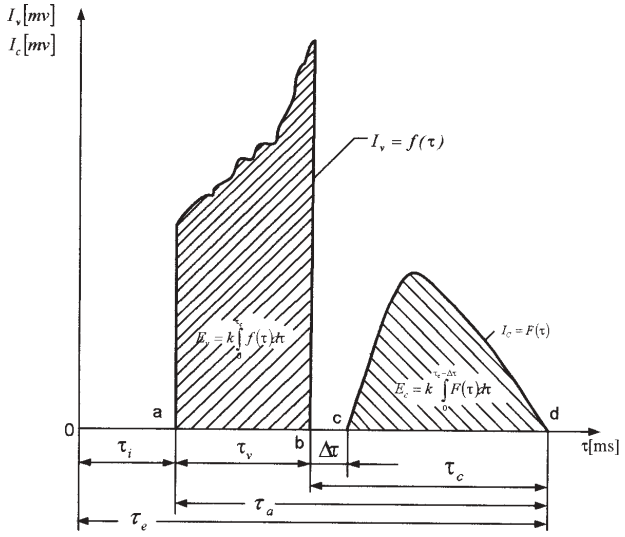

Fig. 1

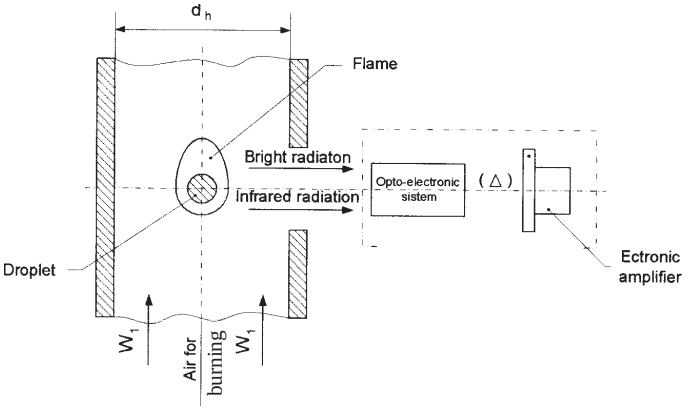

Fig. 2

by the burning cenosphere transformed by the photocell into electric energy *Ec*, etc.

Self-igniting delay time τ_i

The physical model for theoretical calculation of self-igniting time [1]:

$$\tau_i = \frac{\rho L_v (r_0 + r_i)}{\varphi_r C_r \left[\left(\frac{T_m}{100}\right)^4 - \left(\frac{T_0}{100}\right)^4\right] + \alpha_c (T_m - T_0) + \gamma C_a Q} \qquad (1)$$

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The theoretical expression of time τ_i shows that its value can be decreased by increasing the ambient temperature of droplet, the coefficient of heat-transfer from the gas flowing around the droplet to its surface, the oxygen concentration of droplet environment, the constant of reaction rate, the quantity of heat released up to flame ignition and by decreasing of the droplet starting diameter as well, the latent heat of vaporization and the liquid fuel density.

Burning time of droplet τ_a

The burning of residual fuel droplet is achieved in a period of time given by [1]:

$$\tau_a = \tau_v + \tau_c, [s] \quad (2)$$

where:

τ_v is burning time of volatile matters;

τ_c is burning time of cenosphere.

The life of droplet τ_e is longer than the burning time because it also includes the self-igniting delay time τ_i.

$$\tau_c = \tau_i + \tau_a, [s] \quad (3)$$

The liquid fuel droplet is considered a porous sphere in the middle of which the liquid volatile matters are concentrated. By vaporization and porous mass diffusion the volatile matters get out of lattice and burn. After consuming of volatile matters, the carbon porous lattice also burns due to the oxygen diffusion from the environment to its surface.

Burning time of volatile matters τ_v

Based on the used physical model, the theoretical relation for calculating the burning time of volatile matters was determined [1]:

$$\tau_v = \frac{\rho_v \left(\frac{M_v}{100}\right)}{8C_0 \frac{P_0}{\mu_v}} d_o^2 = \frac{d_0^2}{K_v} \quad (4)$$

where:

p_v is the density of liquid volatile matters [kg/m^3];

M_v - the content of volatile matters [%];

μ_v - coefficient of dynamical viscosity of volatile matters [kJ/kgK];

d_v - starting diameter of droplet;

C_v - on the surface of porous lattice where $r=r_o$ the volatile matter concentration is zero $c=0$ and for $r=r_v$ the concentration is $c=c_o$;

K_v - vaporization constant of volatile matters, depending on the chemical analysis of liquid heavy fuel and the characteristics of oxygen carrier medium as well. Decreasing the time τ_v is made by reducing the starting diameter of droplet and by increasing the ambient temperature as well and the starting diameter of droplet decreases by increasing the content of volatile matters in the fuel.

Burning time of cenosphere τ_c

After burning of volatile matters the carbon spherical porous lattice with diameter d_c remains which burns at the surface due to the oxygen diffusion from the environment to it [1]:

$$\tau_c = \frac{\rho_c \left(1 - \frac{M_v}{100}\right)}{3\rho_0 D_0 C_a \left(\frac{T_m}{T_0}\right)^{0,75}} d_c^2 = \frac{d_0^2}{K_c} \quad (5)$$

where:

ρ_c - density of cenosphere [kg/m^3];

ρ_o - density of gaseous fluid;

D_o - diffusion coefficient of nitrogen at $T_o=273$ [K], [m^3/s];

T_m - absolute average temperature of gaseous fluid surrounding the droplet [K].

The burning time of cenosphere τ_c decreases with temperature rise and concentration increase in oxygen of the environment around the droplet and with the increase of the diffusion coefficient of oxygen as well [1]. The self-igniting delay time of cenosphere τ_{ic} was experimentally perceived by time elapsed from the flame vanishing of volatile matters to the self-igniting of carbon residues.

$$\tau_c = \tau_1 + \tau_v + \tau_{ic} + \tau_c. \quad (6)$$

Experimental part

Oscillogram for burning a marine heavy fuel droplet

In figure 3 it is presented the oscillogram for burning a marine heavy fuel droplet RMD which ignites and burns in the symmetry centre of the combustion chamber simulator [2]. The oscillograms for burning of three marine heavy fuel droplets with different starting diameters D_o(d_1=2.4mm, d_2=2mm, d_3=1.6mm) are shown in figure 4. After the burning of the three droplets d_1, d_2, d_3 we can come to the conclusion that together with increasing the starting diameter of droplet, the self-igniting delay time τ_1, the T burning time of volatile matters τ_v, the burning time of cenosphere τ_c and the intensity I of a burning droplet radiation are increased.

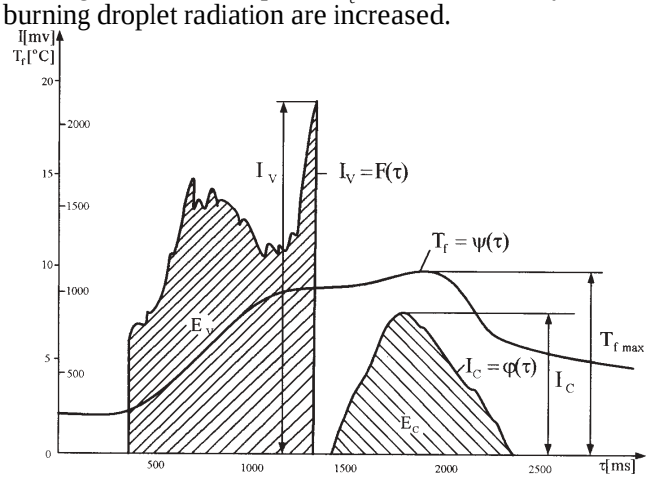

Fig. 3

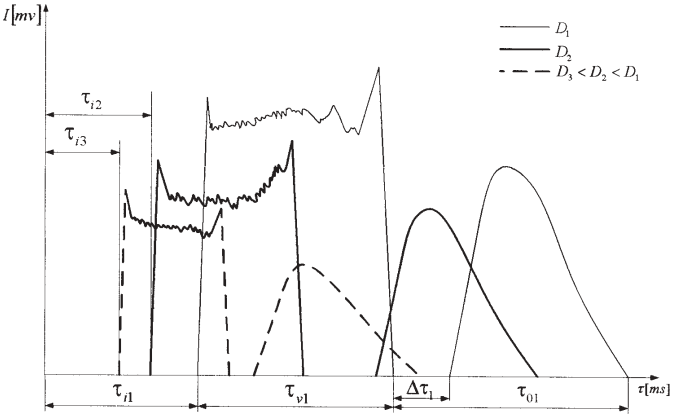

Fig. 4

Results and discussions

From figure 2 we can see that the energy (power) radiated by the volatile matters $I_v = f(\tau)$ is much higher than the energy of cenosphere represented on scale by the area under the curve $I_c = f(\tau)$.

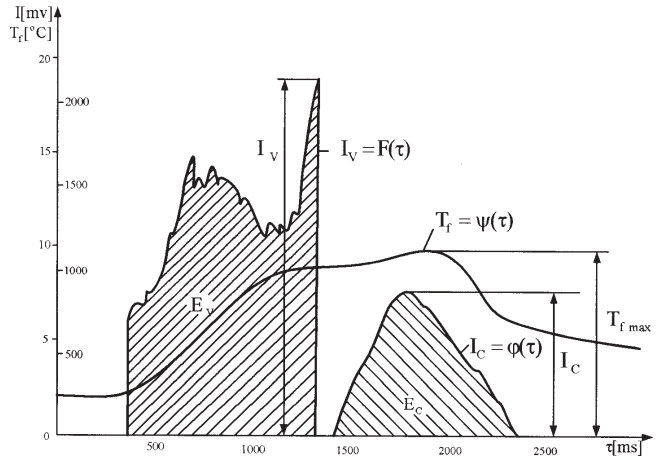

Fig. 5

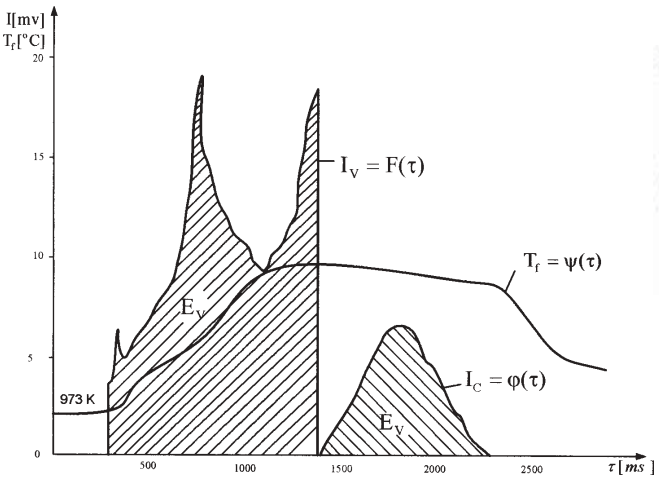

Fig. 6

Also, the smaller the droplet diameter the lower the intensity of radiated energy. We can state that the smaller the droplet diameter the more will be the chances that the cenosphere burns entirely. The droplet diameter can be decreased up to the limit of mechanical fuel-atomizers, following that beyond this limit its decrease should be achieved by fuel emulsification resulting in secondary atomization.

The experiments with simulator aimed at the igniting and burning behavior of a high-quality marine fuel. I used the marine fuel DMB. From this fuel four samples (C_1, C_2, C_3) were taken analyzing the igniting and burning behavior of a droplet from each of the them. The content of sample C_1 was non-emulsified and the other samples have the following quantities of emulsion water:C_2 - 4%, C_3 - 8%;.

Figure 5 presents the oscillogram for burning non-emulsified fuel droplet C_1 having a diameter d_o=2mm ignited at the initial temperature in the combustion chamber T_{fo} = 973 [K] for the ambient temperature T_a = 295 [K], the fuel temperature T_c= 300[K] and the criterion R_c = 140.

Figure 6 represents the oscillogram for burning a droplet of 4% emulsified-water fuel C_2 having a diameter d_o = 2mm.

By comparing the characteristics values obtained for emulsified fuel sample C_2 with the values obtained for non-emulsified fuel sample, it has been found a decrease of powers (energies) E_c , I_c and of τ_c at the emulsified fuel droplet, and so, a decrease of radiated power (energy) by burning the cenosphere. This way are created the premises

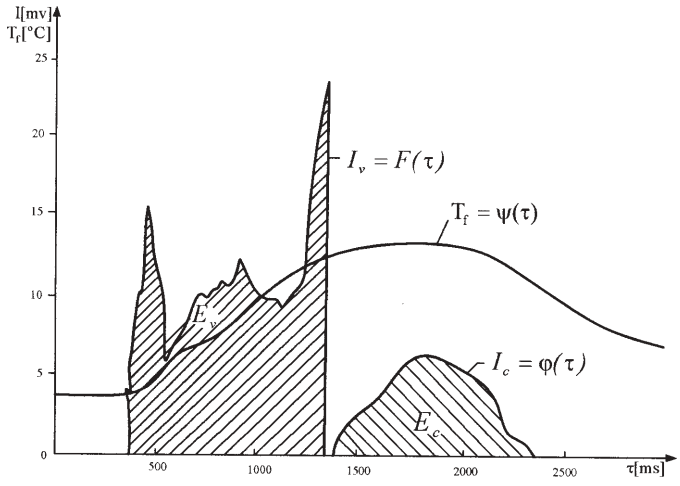

Fig. 7

Fig. 8

of decreasing the losses by unburned carbon, therefore, the quantity of soot (carbon black) released in eloquent flame is smaller. Figure 7 presents the oscillogram for burning a droplet of 8% emulsified-water fuel C_3.

In order to exemplify the occurrence of micro explosion and therefore, of secondary vaporization it is eloquent the behavior of a droplet of 8% emulsified-water fuel C_3 (fig. 8) [1, 4].

Conclusions

The initial strain of the droplet under the action of water vapors contained in emulsion is followed by its breaking in more droplets of smaller diameters.

The smaller values of I_c, E_c and for C_3 fuel droplet as compared to the samples C_1, C_2 and the sudden variation in temperature T_f, make evident the possibility of reducing the losses by unburned carbon, therefore the decrease of carbon black (soot) quantity released in flame due to the increase in burning performance of cenosphere, as a result of secondary atomization.

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