COMBUSTION CHARACTERISTICS OF A MARINE HEAVY OIL-WATER EMULSION DROPLET

Corneliu MOROIANU
Associate Professor, Naval Academy, Constanţa

Abstract: The vaporization and combustion characteristics of a marine 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.
Key words: marine oil-water emulsion, vaporization, combustion, graphological method.

INTRODUCTION

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 [Ghia, 1991]. 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).
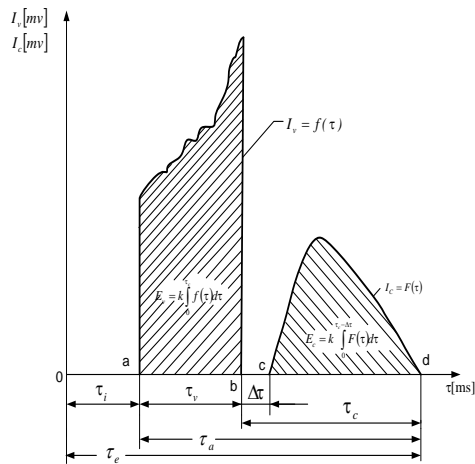

Fig. 1. Graphic representation of the combustion processes development for a heavy oil droplet.

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-electronically system, equipped with a photoelectrical cell [Jianu, 1996], [Popa & Iscrulescu 1983]. Thus for a marine 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, 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 by the burning cenosphere transformed by the photocell into electric energy E_c, etc. 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.

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 I can mention 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]. I 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.

Self-igniting delay time τ_i

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

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

(1)

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]   (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]   (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]:

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

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_0 - starting diameter of droplet;

C_0 - on the surface of porous lattice where $r = r_0$ the volatile matter concentration is zero $c = 0$ and for $r = r_v$ the concentration is $c = c_0$;

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]:

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

where: ρ_c - density of cenosphere $[kg/m^3]$;

ρ_0 - density of gaseous fluid;

D_0 - diffusion coefficient of nitrogen at $T_0 = 273\ [K]$, $[m^3/s]$;

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.

$$\tau_c = \tau_l + \tau_v + \tau_{ic} + \tau_c. \qquad (6)$$

2. THE WATER/HEAVY FUEL EMULSIONS COMBUSTION OSCILOGRAMS

I have made the combustion oscillograms for marine heavy fuel RMF25 with its characteristics mentioned in table 1, at which the water emulsification included four determination tests for water – marine fuel emulsion in proportions of 5[%], 10[%], 15[%] and 20[%]. At the combustion of water – marine fuel emulsion with a water percent of 40[%], the combustion becomes unstable.

In figures 2 and 3, there are synthetically presented the experimental results. Each point marked in diagrams represents the arithmetic mean of six determination tests.

CARACTERISTICA	RMF 25
Volumetric mass at 15[C], [kg/m^3], max.	991,0
Kinematic viscousity at la 100^{0}C, [mm^2/s], max.	25,0
Ignition point [C], min.	60
Flow point in [C] - winter, max. -summer, max.	30 30
Coked residue,[%g/g], max.	20
Ash, % [g/g], max.	0,15
Water , % [v/v], max.	1,0
Sulphur , % [g/g], max.	5,0
Vanadium , [mg/kg], max.	500
Aluminium plus silicon, [mg/kg], max.	80
Existing total sediment, % [g/g], max.	0,10

Tab. 1. The characteristics of marine heavy fuel RMF25.

Based on the data obtained it results that by emulsifing the RMF25 fuel with water from 0 to 20%, we obtain:
- the increase of self–ignition delay τ_i from 525[ms] to 1170[ms];
- the decrease of lower heating power Q_i;
- the maximum temperature variation T_f during the ignition processes;
- from the rate of curves $\tau_v = f(w)$ and $\tau_c = F(w)$ it results that in the emulsifing range 0 – 10[%] water the fastest decrease of times τ_v and τ_c appears; so it is recommended an average emulsifing value of 5 – 8[%];
- as the substitution of a fuel part for water reduces the combustion temperature once the vaporization of emulsified water needs an additional energy consumption, it is recommended that we should have an average value.
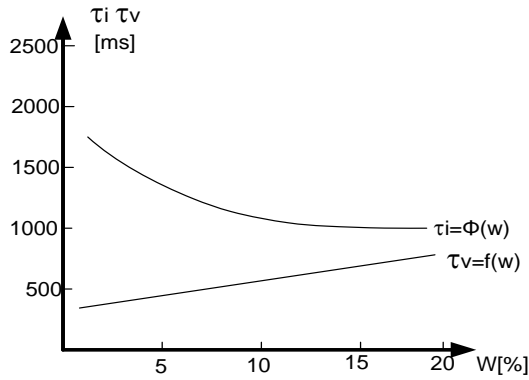
Fig. 2. The influence of water content in water – RMF25 marine heavy fuel emulsion on the quantities τ_i and τ_v.
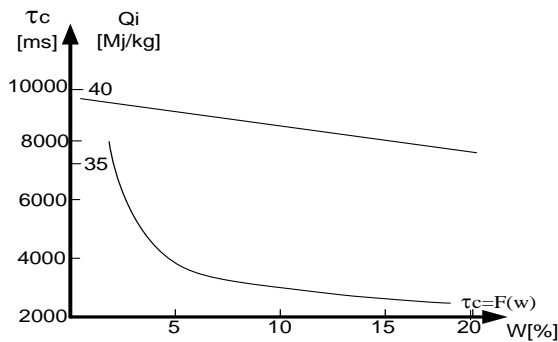

Fig. 3. The influence of water content in water RMF25 marine heavy fuel emulsion on the quantities Q_i and τ_c.

The decrease velocities of times τ_v and τ_c , respectively, that is the ratios $d\tau_v/dw$ and $d\tau_c/dw$ depend on the characteristic of emulsifing system used, namely, the smaller diameter of water drops in the resulted emulsion and more homogeneous distributed, the more sudden the decrease of times; as a result, for the same effect of reducing the nitrogen oxide generation, it will be necessary a smaller percentage of water for emulsification. For a systematical differentiation of fuels, from the three points of interest, namely, of ignition, of combustion and of luminous drop energy, the following specific indices and global quality indices of combustion have been defined:
-        the expression of combustion quality S_a (its value is reduced according to the damage of fuel quality);

$$S_a = \frac{\tau_c}{\tau_v} \qquad (7)$$

To state the weight of ignition process to the combustion processes of volatile matters and cenosphere,

the ignitionratio ψ has been defined, increasing with the rise of τ_i value:

$$\Psi = \frac{\tau_i}{\tau_i + \tau_v + \tau_c} \qquad (8)$$

The weight of the energy radiated by burning the volatile matters E_v to the total energy $E_v + E_c$ has been stated by the radiation index (ratio) B, of which the value decreases with the damage of fuel quality:

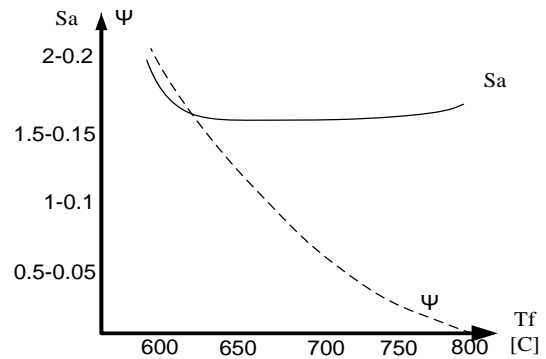$$B = \frac{E_v}{E_v + E_c} \qquad (9)$$

Fig.4. The variation according to the temperature of combustion simplex S_a and ignition ratio ψ.

The global combustion quality index G = f(A,0) decreases by damaging the composition of heavy liquid fuels:
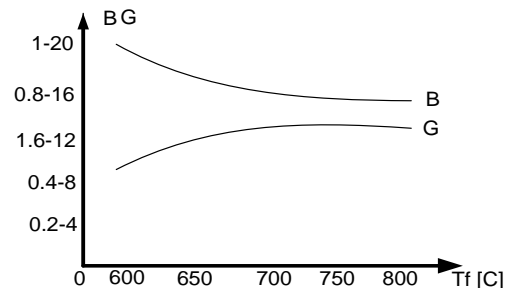
$$G = C\frac{\tau_v}{\tau_i + \tau_c} \qquad (4)$$

Fig. 5. Variation of B and G indices depending on the temperature T_f.

CONCLUSIONS
The test results of the isolated water/heavy fuel emulsion droplet burning presented, lead to the following conclusions:
- the increase of S_a value together with the increase of cenosphere content of fuel;
- the decrease of ignition index ψ by increasing the temperature T_f;
- the ignition index (ratio) ψ, increases with the rise of τ_i value;
- the decrease of radiation index B, by damaging the content in cenosphere of fuel.
The introduction of water into the combustion chamber reduces the combustion temperature due to the absorption of energy for vaporization. Thus, the humidification can reduce the NO_x emissions.

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