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THE NITROGEN OXIDE AND SOOT REDUCTION USING WATER/HEAVY FUEL OIL EMULSION

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Abstract: *The soot and oxides of nitrogen (NO_x) emissions from marine engines are significant on a global level. Soot and oxides of nitrogen emissions participate in the formation of photochemical smog and acid rain. The challenge is to control soot and O_x emissions without increasing fuel consumption and smoke. There is much interest in the potential of utilizing oil/water emulsion in liquid-fueled combustors for pollutant reduction and enhanced fuel economy. In this work it is preferred to emulsify by using an ultrasonic method in a hydrodynamic generator, because the fuel and water produce a very finely dispersed emulsion. The graphic transposition of the processes of fuels and oil/water combustion is defined by the combustion graphology, developed in a simulator. 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".*
Key words: *water/heavy fuel soot nitrogen oxide reduction*

INTRODUCTION

Every year approximately 10 million tons of nitrogen oxide (NO_x) are produced by ships. The world fleet include 55% slow speed diesel, 40% medium speed diesel and 5% other engines. Slow speed diesel engines produce higher NO_x emissions. The photochemical smog and acid rain are also produced by NO_x emissions. Introducing water into the combustion chamber the temperature of burning is reduced due to the vaporations process. There are two ways to introduce water. The first way is through air intake, using humidification and the latter way is by water/fuel emulsion. The latter way mentioned above reduces smoke, while humidification increases it. Water/fuel emulsion and direct water injection have the maximum effect on NO_x reduction. This paper presents the resultants of burning the emulsified and non-emulsified fuel droplet on the laboratory condition (simulator). The emulsification of the water with oil was performed by means hydrodynamic liquid generator.

THE WATER/FUEL EMULSIONS GENERATION USING ULTRASOUNDS

The high intensity ultrasound generation in liquid is realized using a hydrodynamic whistle. The hydrodynamic whistle for liquids, Fig.1, consists on a tapered nozzle (1), with a segment (2) placed in front of it at 0.3 – 1 mm. The segment is fixed in one or two nodal points (Jinescu, G. 1983).

Passing through the nozzle, the liquid flow hits the segment fixed on one end on the bracket. At about 12-15 bar pressure it resonates at frequency (Popa&Iscrulescu, 1983):

$$f = \frac{22.4 \cdot d}{4 \cdot \sqrt{3}} \cdot \frac{1}{l^2} \cdot \sqrt{\frac{E}{\rho}} \text{ [Hz]} \qquad (1)$$

where

l – is the segment length [m]; d – segment thickness [m]; E – Young's modulus [N/m^2]; ρ - density.

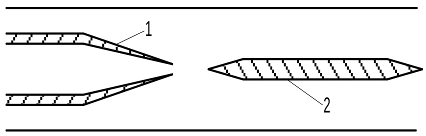

Fig.1. The hydrodynamic generator for liquids; 1– snout, 2– flexible segment.

If the resonating segment is made of, the resonance frequency is:

$$f = 5.4 \cdot 10^5 \cdot \frac{d}{l^2} \text{ [Hz]} \qquad (2)$$

The ultrasound frequency depends on the flow pressure. The hydrodynamic generator irradiates ultrasounds in the working environment as the following relation reveals:

$$f = \frac{v}{h} \cdot 0.5, \text{[Hz]} \qquad (3)$$

where

v – is the flow rate in the nozzle [m/s]; h – the distance between the nozzle and resonating flexible segment [m].

The nozzle and the vibrator segment are situated in a resonant chamber with an acoustic form (Jianu C. 1996).

THE EXPERIMENTAL APPROACH

The experimental approach has two stages: in the former stage is the combustion of non-emulsified fuel and the latter one is the combustion process of oil/water emulsion (for the lock of space I didn't write the combustion oscillogram of non-emulsified fuel).The emulsions have different water mass fractions in fuel. The analyses have been performed in special laboratories. The fuel drops bathing at pre-established diameters was realized using a special device. The same temperature and air conditions were used for emulsified and non-emulsified fuel drop combustion. The process was realized in free convection (Law, 1997). The remarks were directly made with the naked eye, and the processes were registered using a special camera.

THE WATER/FUEL EMULSION FUNDAMENTAL CHARACTERISTICS

In order to state the quality and the steadiness of an ultrasound emulsion its properties will be compared to those of a non-emulsified fuel shown in Table 1. The water/fuel emulsion has been stored for 45 days. The determinations revealed a good stability in time. There is no separation of liquid components danger. We also performed tests in order to determine the water/fuel emulsion behavior in heat-proof vessels. Emulsions were stored for 60 and 150 days at 50^0, 60^0 and 80^{0}C temperatures. The water drop dimensions and the percentage analyses were also performed.

THE WATER/HEAVY FUEL EMULSIONS COMBUSTION OSCILOGRAMS

Fuel combustion graphology is a new technical and scientific field (Ghia 1991). It transposes the fuel combustion processes in a simulator using graphics. It is an easy way to establish the ignition and combustion characteristics and relations between combustion conditions and fuel specifications. The combustion oscillogram is a graphic of combustion process development for a liquid droplet. This diagram shows the time variation t of radiation intensity I of volatile substances caused as a result of combustion changed into an electric signal by means of an optical-electronically system equipped with a photoelectrical cell. On a standard condition, the oscillogram establishes self-ignition delay τ_i, the combustion time of volatile matters τ_v, the cenosphere combustion time τ_c, the maximum radiation intensity for cenosphere combustion I_c, the maximum radiation intensity for volatile matter combustion I_v, the energy radiation resulting from cenosphere burning, transformed by photocell into electric energy E_c, etc The standard condition of the combustion tests are mainly specified by the combustion chamber geometry, the temperature, the pressure inside chamber, the emulsion temperature, the fuel admission system, the air flow conditions around droplet and the initial and average diameters of the droplet.

Fuel characteristics	Non emulsified fuel	Water/fuel emulsion
Lower thermal power (kJ/kg).	38650 ± 845	36920 ± 845
Water content (%)	0 – 1	7.5 – 10.5
Sulphur content (%)	2.5 – 3.5	2.2 – 3.3
Conradson coke content (%)	12 - 20	11.5 - 19
Density (kg/m^3).	960 - 980	960 - 985
Viscosity at 80^{0}C (^{0}E)	14 - 26	14 – 25.5
Average diameter of water drops (μm)	-	3 – 4.4
Water drops with smaller than 4.8μm diameter content	-	80 – 90.6
Viscosity at injection nozles (^{0}E)	2.5 - 3	3.2 – 5.8

Table 1. Fuel characteristics.

The propulsion systems for ships and the steam generators fitted up on the oil tankers run with residual heavy fuel RME 25, RMF 25, RMG 35 range according to ISO 8217/1995. Fig.2 shows the combustion oscillogram for a water emulsified RMG 35. Fuel drop having the following characteristics:

– water content 3.4%; lower thermal power 39950 kJ/kg.

The results for a drop with a D_0=1.9 mm diameter ignited at T_{fo}=1023 K temperature, T_a=293 K ambient temperature, T_c=300 K fuel temperature and Re=135 are:

– self-ignition delay τ_I = 260 ms; volatile matters burning time τ_v=1070 ms; cenosphere burning time τ_c=1150 ms; volatile matters radiated power E_v=700620 u.c.*; cenosphere radiated power E_c=33870 u.c.* (*u.c-conventional units).

Fig. 3 presents the combustion oscillogram for a water emulsified droplet RMG 35having the following characteristics:
– water content 7.5 %; lower thermal power 39050 kJ/kg.

The results for a drop with a D_0=1.9 mm diameter ignited at T_{fo}=1023 K temperature, T_a=293 K ambient temperature, T_c=300 K fuel temperature and Re=135 are:

- self-ignition delay τ_I = 288 ms; - volatile matters burning time τ_v=720 ms; - cenosphere burning time τ_c=732

ms;- volatile matters radiated power E_v=549000 u.c.*; - cenosphere radiated power E_c=2530 u.c.*.

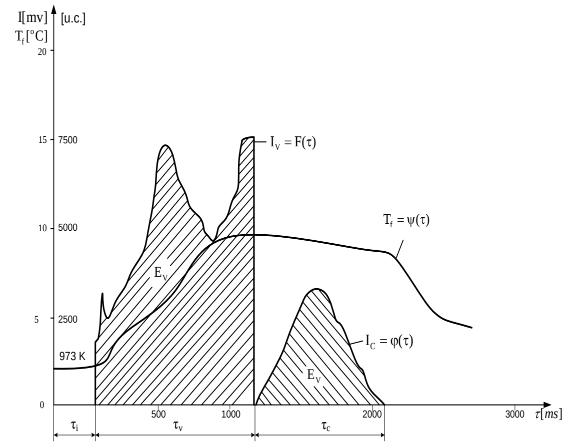

Fig.2. The combustion oscillogram for a RMG 35 fuel drop/ water emulsion w = 3.4(%).

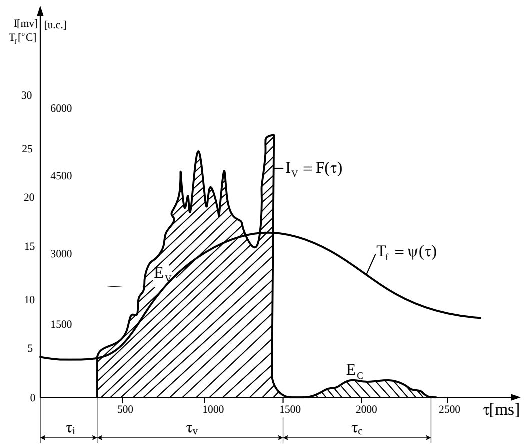

Fig.3. The combustion oscillogram for a RMG 35 fuel drop/water emulsion w = 7.5%.

In both cases the curve $I_v = f(\tau)$ has a gap in the middle part. It is due to water vaporization wich leads to the decrease of combustion temperature. (a potential factor of NO_x reduction). Testing the 3.4 % emulsified fuel the $I_v = f(\tau)$ volatile matters radiated power is bigger than E_c cenosphere radiating power.
By testing the 7.5 % emulsified fuel the radiated power Iv = f(τ) of volatile matters is a little smaller and the radiating power E_c of cenosphere is much reduced. The reason is the secondary vaporization.
The explanation relies on the fast heating of water dispersed inside individual fuel droplets. The internal water droplets undergo a spontaneous vaporization of water, causing a violent change of water droplets into steam.
On the other side, the vaporization causes a rapid expansion of surrounding oil droplets, bathing the oil into a large number of small fuel droplets. This process is secondary atomization.
Experiments show that a 7.5% water/residual RMG 35 fuel emulsion has better combustion properties than a 3.4% water/residual RMG 35 fuel emulsion. The explanation relies on secondary atomization effect.

Conclusions

The initial droplet strain subjected to water vapors action breaks into smaller droplets. The I_c low values of E_c and T_c lead to reduced unborn carbon losses and to decreasing of carbon black (soot) quantity. The increasing of cenosphere burning performance as result of secondary atomization. The introduction of water into the combustion chamber reduces the combustion temperature due to the absorption of energy for vaporization. Humidification can reduce the NO_x emissions.

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