"Mircea cel Batran" Naval Academy Scientific Bulletin, Volume XIV – 2011 – Issue 1
Published by "Mircea cel Batran" Naval Academy Press, Constanta, Romania

THE PRODUCTION OF WATER-RESIDUAL HEAVY FUEL EMULSIONS BY ULTRASOUNDS

Corneliu MOROIANU[1]
[1] Associate Professor, Ph.D., Naval Academy, Constanta, Romania

Abstract: *Nitrogen oxides are known to be immediately dangerous to human and environmental health. Mobile and stationary diesel and residual fuel engines are contributing largely to the worldwide NO_x emissions. Emulsification of the fuel with water is a way to reduce the NO_x emissions of engines. The ultrasonic emulsification is an effective means for generating fine-size fuel/water-emulsions. This paper presents a possibility of producing the water-heavy fuel emulsions by means of ultrasounds.*
***Keywords**: emulsion, ultrasonic vibration, NO_x emissions, heavy fuel emulsions.*

1. INTRODUCTION

The emulsion is an heterogeneous system consisted of, at least, an immiscible liquid intimately dispersed in another one under the form of some drops with a diameter over 0.1mm. These systems have a minimum stability which can be increased by additives like surface-active agents, finely powdered solid particles, etc. The reference to the particle dimensions of dispersed phase makes a distinction between the emulsify phenomenon and the solubilization one. The emulsions are considered heterogeneous systems which belong to the pseudo colloid cathegory. In the analysis of emulsions it is necessary to differentiate the emulsion phases. The phase that is under the form of some fine drops is named the disperse phase or the internal phase. The phase that forms the matrix in which these drops are suspended, is called the continuous phase or the external phase. Also, the internal phase is named the discontinuous phase while the external phase is called the non-disperse phase. Classically, there are two types of emulsions, starting from the known case of water-oil emulsions. When the disperse phase is oil, then it is the oil-water emulsion and it is noted with the symbol O/W. When the disperse phase is water, it is the water-oil emulsion noted with the symbol W/O. This terminology is conveniently applied even in the case in which the emulsion phases are not, strictly speaking, oil or water.

2. THE ULTRASOUND ACTION IN LIQUID MEDIA

To understand the ultrasonic vibration phenomenon, it is analyzed the simple case in which the oscillation source is a pulsating piston placed in front of a pipe. It has been found the propagation of plane waves in the pipe and the existence of a series of normal planes on the pipe axis, in which the substance is, at one time, in a state of compression or dilatation. Two states of maximum (minimum) compression are separated by an equal distance with a wavelength, λ, and we have the relation:

$$T = \frac{1}{\nu} \qquad (1)$$

where:

T – the period of time [s];

ν - the frequency of oscillation [1/s].

The common phenomena of reflection, refraction and diffraction are produced as in the case of light vibrations. If we place a reflecting plane at the pipe end, the reflected waves interfere with the incident waves to form a stationary wave system in which double amplitude modular oscillations take place; if the reflector is perfect, the oscillations are generated on the both sides of the planes placed at the distance of λ/4 named nodal planes and vertical planes. Each of the two planes with the same name are separated by a distance λ/2. We can consider instead of a vibratory piston, a pulsating sheer similar to a punctiform light source generating spherical waves. This case is nearer to the practice and leads to the same arguments generated by optics. The molecular vibration corresponding to the acoustical phenomenon is accompanied by a dissipation of thermal energy. A decrease of amplitude takes place depending on the vibration frequency and the nature of the vibratory body. When the vibration falls over a surface, a radiation pressure is developed, as in the case of the light but with a different order of magnitude. To describe the state of vibratory medium particles, we take:

- the motion amplitude, A – the maximum deflection on the propagation axis;
- the pressure amplitude, P;
- the velocity amplitude, ν, as these particles vibrate with a certain frequency (sinusoidal time function);
- the acceleration amplitude, t.

In the medium, there is a certain density of energy, w, which is the energy contained in the volume unit of the medium. When the vibration is propagated under the form of traveling plane waves, at the crossing the surface unit, a certain quantity of energy passing in a second is given by:

$$w = \frac{I}{\nu}; \quad [\frac{J}{m^3}] \qquad (2)$$

The vibration amplitude is related to the acoustic intensity, I, by the following relations:

$$I = \frac{1}{2}\cdot\rho\cdot\nu\cdot A^2\cdot\omega^2 = \frac{1}{2} - \frac{p^2}{\nu\cdot\rho} = \frac{1}{2}\cdot\rho\cdot\nu\cdot\gamma^2 \quad (W/m^2) \qquad (3)$$

where:

ρ - the medium density [kg/m^3];

ω - the pulsation $\omega = 2\cdot\pi\cdot\nu$.

To simplify, we shall use the following notations:

$$\gamma = \omega\cdot A, \quad \Gamma = \omega\cdot\gamma, \quad P = \rho\cdot\nu\cdot\gamma .$$

The ultrasonic activation process of the liquids is based on the cavitations phenomenon. When an acoustic pressure changing from positive values to negative values acts on a liquid, the liquid volume is put to compression and dilatation, at the same time. When a maximum pressure is reached, in the points where the cohesion is weak, a liquid breakage is produced. This breakage is followed by an overpressure in the point where it has occurred, finding the presence of some cavities. In these hollows, the liquid-dissolved gases, under the form of bubbles which blow up after a short time, generate local pressures of tens of bars. As on the surface and inside the bubbles there are contrary electric charges, with the explosion, the lightning discharges are generated. These produce an ionization of surrounding particles and an emission of ultraviolet rays.

The cavitations process is influenced by the frequency and the intensity of ultrasounds. The appearance of cavitations in a liquid depends, to a great extent, on the existence of liquid-suspended undissolved gases. The cavitations can be obtained with acoustic pressures lower than 20 [bar] and in this case, the well-differentiated points appear in the liquid, named nuclear centers. These inhomogenities localized in a liquid form the place of cavitations process. If in a liquid there are introduced particles from another liquid which is immiscible with the first one, the liquid resistance is reduced, being possible that the included gas molecules to separate the liquid from the particles introduced on their surface. The presence of gas seems to play the role of a real catalytic agent of cavitations formation. The cavity bubble is developed up to a certain extent which, at a certain pressure, depends on the developing time and the ultrasound frequency. The time, t, necessary for the development of spherical cavity bubble from the initial radius R_0 to R is given by the relation:

$$t = \sqrt{\frac{3}{2} \cdot \rho \cdot R_0^2} \cdot \int_{\frac{R_o}{R}}^{1} \frac{d\left(\frac{R_o}{R}\right)}{\left(\frac{R_o}{R}\right)^2 \cdot \sqrt{\left(1 - \frac{R_o}{R}\right) \cdot \left[\left(\frac{R_o^2}{R^2} + \frac{R_o}{R}\right) \cdot (R_0 \cdot P + 3 \cdot \tau) - R_0 \cdot P\right]}}; \quad (4)$$

where:

ρ - the liquid density [kg/m^3];

P – the hydrostatic pressure [daN/mm^2];

τ - the surface liquid pressure [N/m].

In the following phase, after the relative slow dilatation of the cavity bubble, its sudden compression and its quick destruction are produced. The compression time of the bubble from a radius R_m to a radius R can be calculated by the relation:

$$\tau = R_m \cdot \sqrt{\frac{3 \cdot \tau}{2 \cdot P}} \cdot \int \frac{\left(\frac{R}{R_m}\right)^{\frac{3}{2}} \cdot d\left(\frac{R}{R_m}\right)}{\sqrt{\left(1 - \frac{R}{R_m}\right) \cdot \left[\left(\frac{R}{R_m}\right)^2 + \left(\frac{R}{R_m} + 1\right) \cdot \left(1 + \frac{3 \cdot \tau}{R_m \cdot P}\right)\right]}}; \quad (5)$$

As a result of the cavity bubble destruction, the gas or the existing vapors inside it are adiabatically compressed, the temperature can reach 1000^{0}C and a shock wave is generated of which intensity increases with the increase of acoustic pressure. The generation of acoustic cavitation in a liquid causes a series of mechanical, acoustical, optical and chemical effects.

3. THE ULTRASOUND PROPAGATION IN INHOMOGENEOUS LIQUID MEDIA SPECIFIC TO THE RESIDUAL HEAVY FUELS

The actual media of propagation are not homogeneous which leads to some changes in the wave propagation. This situation often appeared in the ultrasonic techniques consists of the propagation of longitudinal plane wave beam to a normal direction on the interface of two infinite media with the characteristic impedances ρ_1 c_1 and ρ_2 c_2 where:

ρ - the liquid density [kg/m^3];

c – the propagation velocity of the ultrasonic wave [m/s].

On the interface, the wave undergoes a reflection and a partial transmission of energy in the latter medium, the acoustic intensities proper to the two fractions being dependent on the acoustic parameters of the two media. The reflection and the transmission are evaluated by means of the reflection and transmission factors, respectively. The acoustic reflection factor is defined by the ratio of reflected wave intensity to incident wave intensity:

$$r_a = \frac{I_r}{I_i} = \frac{(\rho_1 \cdot c_1 - \rho_2 \cdot c_2)^2}{(\rho_1 \cdot c_1 + \rho_2 \cdot c_2)^2}; \quad (6)$$

The acoustic transmission factor is defined by the ratio of transmitted wave intensity to incident wave intensity:

$$t_a = \frac{I_t}{I_i} = \left[\frac{(4 \cdot \rho_1 \cdot c_1 - \rho_2 \cdot c_2)}{(\rho_1 \cdot c_1 + \rho_2 \cdot c_2)^2}\right]^2; \quad (7)$$

The two factors are correlated to the relation:

$$r_a + t_a = 1. \quad (8)$$

From this relation, it results that for two equal impedance mechanisms $r_a = 0, t_a = 1$, the entire acoustic energy is transmitted in the latter medium. On the other hand, the more different the impedances of the two media are, the higher the reflection factor and the lower the transmission factor. The propagation velocity of longitudinal waves depends on the temperature and the speed, decreasing according as the liquid temperature increases. Also, the propagation velocity of wave varies with the pressure applied on the liquid, that is, up to 500 [daN/mm^2], the speed linearly increases with the pressure and at high pressures of 104 [daN/mm^2]it reaches the limit value specific to the liquid. The ultrasound energy, as a result of passing through a liquid, besides the generation of cavitation phenomena, interface friction, acoustic pressure and radiation, it is also the reason for ultrasound absorptivity.

4. THE ULTRASONIC EMULSIFICATION PROCESS

The formation of emulsions by means of ultrasounds is due to the cavitation phenomenon. An ultrasound wave passing through a liquid puts it to a compression and a dilatation, successively. When the dilatation is moderate and the liquid doesn’t contain any gas, nothing is happened. If the liquid is gas-saturated, there are bubbles of that gas. The liquid disrupts under the action of ultrasound vibrations resulting cavities in the liquid. Rayleight has calculated the pressure appeared at a bubble implosion in a liquid; it can be of some thousands of bars. These forces can be able to generate any mechanical effects, including dispersion. On the other hand, this intense agitation which is determined by these effects, can lead to the increase of number of collisions of dispersed particles, and in this case, the emergence probability of coalescence increases.

In fact, from this point of view, the ultrasonic emulsification process represents a competition between opposing forces and for that reason, it is necessary to choose the working conditions and the frequencies, so that the disruptive effect should be prevailing. To prepare an emulsion, the limit value of ultrasound intensity must be exceeded, specific to the type of emulsion. So, to produce an emulsion of O/W type, the limit acoustic intensity is more reduced than that necessary to prepare an emulsion of W/O type. The type of acoustic field influences the emulsification process, that is, by applying some traveling ultrasonic waves, the process efficiency is increased as compared to the application of some stationary waves. This is explained by the fact that in a field of stationary waves, the process opposed to dispersion, namely, coagulation prevails. In the case of stationary waves, the emulsification process is of low quality than that in the case of traveling waves. Unlike the case of stationary waves where in the emulsification process the coagulation phenomena prevail, in the case of traveling waves, the small particles (0.5 - 1.0[µm]) are relevant. The ultrasound frequency determines the type of emulsion. As a rule, at low frequencies (15 – 25 [KHz]) the emulsions of O/W type are obtained and at high frequencies (200 – 300[KHz]) the emulsions of W/O type are produced.

The ultrasonic treatment time conditions the emulsification process which takes place after a certain period of time, longer in the case of emulsions of W/O type than that of emulsions of O/W type, and the moment of emulsion formation coincides with that in which the emulsion reaches a certain concentration. The duration of ultrasound application influences the dispersion degree and the emulsion homogeneity has a great importance for the emulsion quality; a too short time or a too long time can endanger the mean diameter value of the particles. In the first stage of the process (5–15 [min]) the coagulation phenomena prevail and then, the dispersion becomes prevalent (after 25–30 [min]), most of particles obtaining dimensions between 1.0 and 1.65 [µm]. By extending the time of ultrasonic process over 30 [min], new instability phenomena occur beginning again the coagulation enhancement.

5. THE HYDRODYNAMIC WHISTLE FOR LIQUIDS

The generation of high intensity ultrasounds in liquids was performed by means of hydrodynamic whistle for liquids. The hydrodynamic whistle for liquids, Fig. 1, is formed of a tapered nozzle (1) provided with a nipple which has in front of it, at a distance of 0,3 – 1 mm, a vibrator segment (2) fixed in one or two nodal points. Passing through the nozzle, the liquid jet hits the segment (fixed at an end on the bracket) which at a certain jet pressure (about 12-15 bar) resonating with its own frequency:

$$f = \frac{22{,}4 \cdot d}{4 \cdot \sqrt{3}} \cdot \frac{1}{l^2} \cdot \sqrt{\frac{E}{\rho}}, \quad [Hz] \qquad (9)$$

where:
l – the segment length [m];
d – the segment thickness [m];
E – Young's elasticity modulus [N/m^2];
ρ - density of segment material [kg/m^2].

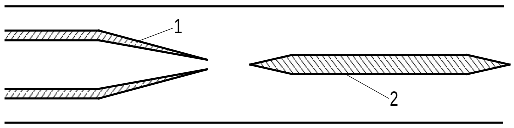

Figure 1 Hydrodynamic generator for liquids:
1- snout, 2- elastic lamella**.**

When the resonator segment is made of steel, its resonance frequency is given by:

$$f = 5{,}4 \cdot 10^5 \cdot \frac{d}{l^2}, \quad [Hz]; \qquad (10)$$

The ultrasound frequency is a function of liquid jet pressure and so, the hydrodynamic generator effectively irradiates the ultrasounds in the working environment as long as the following relation is observed:

$$f = \frac{v}{h} \cdot 0{,}5 \quad [Hz]; \qquad (11)$$

where:
v – is the flow rate in the nozzle [m/s];
h – distance from the nozzle to the resonator segment [m].

The whole system formed of a nozzle and a vibrator segment is enclosed in a resonant chamber having an acoustical form, namely, dimensioned.

REFERENCES:

[1] B. Popa, V. Iscrulescu**,** *Procese de ardere în câmp sonor*, Ed. Acad., 1983.
[2] Drăgan, O. şi colab., *Ultrasunetele de mari energii*, Ed. Academiei, Bucureşti, 1983.
[3] Jinescu, G.,*Procese hidrodinamice şi utilaje specifice* ,Ed. Didactică şi Pedagogică, Bucureşti, 1983.
[4] Boyd R. and Kent J., *21 Symp. on Combust*, p. 265, 1986.
[5] Clayton, R., *The Theory of Emulsion and Their Tehnical Treatment*, J.A.Churcill Ltd., London, 1981.