Bulletin of the *Transilvania* University of Braşov • Vol. 2 (51) – 2009
Series I: Engineering Sciences

THE INCREASE OF HEAT EXCHANGE BY BURNING THE HEAVY LIQUID FUELS IN THE MARINE THERMAL SYSTEMS

C. MOROIANU[1] **I. PATRICHI**[1] **F. TULEI**[1]

Abstract: *The increase of burning efficiency of liquid fuels used in the marine thermal systems is possible by their burning in sound fields of variable intensities and frequencies. This method can lead to change the characteristics, the structure of droplet life time and burning time of volatile matters and cenosphere. The increase of burning processes mainly due to the gasodynamic effects induced by the sound energy propagation in fuel mixture, with implication on the turbulent heat and mass exchanges facilitating the forming processes of fuel mixture.*

Key words: *burning, liquid, heavy fuels, sound, field .*

1. Introduction

In the operation of marine thermal systems which use for burning only intermediary and heavy liquid fuels, it appears a series of major disadvantages, such as:

- imperfect burning with improper air excesses that generate unburnt suspended mechanical particles (soot);
- clogging up of heat exchange surfaces with mineral and carbon deposits leading to the reduction of thermal efficiency and to load limitations, implicitly;
- corrosion of metallic heat exchange surfaces and specially, the low temperature corrosion;
- environment pollution with soot, carbon oxides, nitrogen oxides, sulphur oxides;
- high prices for maintenance and repairs.

It is of first importance the application of some methods for increasing the efficiency of liquid fuel burning for preventing and reducing as far as possible the disadvantages mentioned above, not to disturb the operation of boilers and at the same time, to ensure the protection of the heat exchange surfaces and the environment by observing the standards of international legislations, with low expenses.

The practical conventional methods of combustion of increasing the burning related to the rise of relative speed between the gas flow which takes part in the reaction and the fuel particle, the flame turbulence, the hot gases recirculation, the jet turbulence etc. aren't enough, in many cases. Some technologies have been approached having in view the following possibilities of application. A first technology refers to the, burning of intermediary and heavy fuels in the sound field by using a variable frequency ultrasound generator, in the combustion process, a method which induced the change of flame characteristics, the change of life time structure of the drop and the burning time of volatile matters and cenosphere. The increase of combustion processes is mainly due to the

---

[1] Dept. of Naval Machinery and Equipment, Naval Academy "Mircea cel Batran", Constantza.

gasodynamic effects caused by the propagation of sound energy in the mixture with implications over the turbulent mass and the heat exchange which facilitate the forming processes of combustible mixture.

The homogenization of the mixture and the oxygenation in the middle of the flame activate the burning in all its volume. The micro turbulence caused by the sound field interferes between the oxidizer and the drop by a constant relative motion and by reducing the diffusion resistance of hydrodynamic boundary layer. So, the prevalent gasodynamic effect is equivalent to the great increase of total heat exchange factor (vapors–oxygen fuel) by turbulent diffusion and by increasing the local heat transfer to the drop. At the same time, it is also possible an improvement of atomization quality due to the liquid particle disintegration, both as a result of amplifying the initial free oscillations under the influence of a sound oscillation field and the non-steady state of relative drop–gas motion as well as due to the impact caused by the cavitations phenomenon.

2. The Increase of Mass and Heat Exchange

The sound vibrations are one of the factors which allow the increase of mass and heat exchange. The mechanism is determined enough, the hypotheses explain only partially the experimental results obtained. Most studies performed assign the increase of mass and heat exchange in the sound field to the changes appearing in the limit structure, namely, the turbulence which, for one reason or another, occurs under these conditions. The periodical variations of pressure and density induced by the sound field generate the anabatic (convective) micro currents near the solid limits and lead to the reduction of thickness and the change of hydrodynamic flow lines in the boundary layer. Experimentally, it was noted the increase of heat transfer factor value with the increase of turbulence intensity.

It is clear that the increase of heat exchange in sound field can’t be entirely caused by the turbulence increase appeared under these conditions. The fluid mass transfer under the action of vibrations is performed both by a “forced” diffusion intensified by the relative motion effect between the specific mass particles – the orthokinetic effect – and by acoustical currents appeared in the intermodal spaces of stationary waves or they are generated by the progressive waves. The orthokinetic effect can be estimated from the relative amplitude of suspended particle motion in a fluid:

$$\frac{A_p}{A_f} = \frac{1}{\sqrt{1+\frac{\pi.\rho.f.d^2}{9\eta}}} \tag{1}$$

in which:

A_p – the amplitude of particle motion

A_f - the amplitude of fluid motion

ρ – the particle density

f – the frequency

d – the particle diameter

η - the dynamical viscosity factor of air.

Accordingly, an important scavenging of the particle is set at small values of the ratio A_p/A_f. The curves plotted for atomized fuel-air suspension show the necessity of a reduced fine atomization of fuels in sound field. The mass transfer in sound field is strongly influenced by the micro currents induced in the boundary layer near the bubble surface. Experimentally, this process has been found during the study of growth speed of air bubbles induced by dissolving air in water. The micro currents around the air bubble transport the fresh material to its surface supporting the acceleration of mass transfer. In this case, the mass variation speed of a bubble is given by the relation:

$$\frac{dm}{d\sigma} = 24.\pi.D.c_\infty\rho.(\frac{W_\xi}{\omega.r_0}).r_0 \tag{2}$$

in which:

D – the molecular diffusion factor;

c_∞ - the concentration of air dissolved in water;

ρ – the air density;

ω – the acoustical pulsation/variation;

W_ξ – the amplitude of oscillation speed of bubble surface;

r_o – the initial radius of bubble;

r – the current radius of bubble.

The value W_ξ has the following expression:

$$W_\xi = \frac{P^{ac}}{\omega . r_0 . \rho_l . \sqrt{[(\frac{\omega_{rez}}{\omega})^2 - 1] + \delta^2}} \qquad (3)$$

where:

P^{ac} – the amplitude of sound pressure;

ρ_l – the liquid density;

ω_{rez} – the resonance frequency of bubble;

δ – the acoustical damping constant.

At high values of frequency and oscillation speed of bubble surface, the forced diffusion becomes prevalent with the mass flow due to the micro currents.

3. The Overall Heat Exchange

The heat transfer is characterized both by a so-called thermal conductibility factor and by the thermal component corresponding to the convective micro currents acoustically induced in the liquid mass, on the contact surface with the end plates. From the differential equation for the non-steady one-dimensional heat transfer through a body with internal uniform heat sources:

$$\rho \cdot c_p \cdot \frac{T(x,\tau)}{\partial \tau} = \lambda \frac{\partial^2 T(x,\tau)}{\partial x^2} + Q \qquad (4)$$

where:

ρ – the body density;

c_p – the specific heat at constant pressure

T – the local temperature;

X – the coordinate of temperature point;

τ – the time;

λ – the thermal conductibility;

Q – the speed of reducing the internal heat:

$$T\left(\frac{L}{2},\tau\right) = \frac{Q \cdot l^2}{8 \cdot \lambda}\left[1 - \frac{32}{\pi^3} \cdot e^{-\frac{\pi^2 \cdot \lambda \tau}{l^2 \cdot \rho c_p}} + \frac{32}{27 \cdot \pi^3} \cdot e^{-\frac{9\pi^2 \lambda \tau}{l^2 \rho c_p}}\right] + \frac{\Delta T}{2}\left[1 + \frac{4}{\pi} e^{-\frac{\pi^2 \lambda \tau}{l^2 \rho c_p}} - \frac{4}{3\pi} e^{-\frac{9\pi^2 \lambda \tau}{l^2 \rho c_p}} + \ldots\ldots\right]. \qquad (5)$$

in which:

ΔT – the temperature difference between the plates;

λ = λ' – in the presence of sound vibrations.

If we neglect, in each series, the terms higher than 2 and if ΔT = 0, then:

$$T\left(\frac{l}{2}\right) = \frac{\rho \cdot l^2}{\rho \cdot \lambda}; \qquad Q = \frac{8 \cdot \lambda \cdot T\left(\frac{l}{2}\right)}{l^2} \qquad (6)$$

The relation for determining the temperature of equidistant point to the edges is deduced in the presence of a uniform acoustic absorptivity:

$$T\left(\frac{l}{2}\right) = \frac{Q \cdot l^2}{16 \cdot \lambda}; \quad Q = \frac{16 \cdot \lambda \cdot T\left(\frac{l}{2}\right)}{l^2} \qquad (7)$$

and in non-steady state

$$T\left(\frac{l}{2},\tau\right)=\frac{\Delta T}{2}+\frac{7Ql^2}{64\lambda}+\sum_{n=1}\left\{\frac{12Ql^2}{\lambda n^5\pi^5}\left[1-(-1)^n\right]-\frac{6Ql^2}{\lambda n^3\pi^3}+\frac{2\cdot\Delta T}{n\pi}\right\}\cdot\sin\frac{n\pi}{2}\cdot\frac{n^2\pi^2\lambda\tau}{l^2\rho c_p}. \tag{8}$$

Actually, due to the temperature gradient, a diffraction of sound wave takes place leading to a non-uniform acoustic absorptivity. If the sound waves will be deflected to the minimum and maximum limits, and the input power will have a parabolic distribution, then, considering $\Delta T = 0$, it results that:

$$r=\sum_{i=1}^{n+2} r_i=\frac{1}{\alpha_1}+\sum_{j=1}^{n}\frac{\sigma_j}{\lambda_j}+\frac{1}{\alpha_2} \tag{9}$$

where:

r_i – the partial thermal resistances;

α_1, α_2 – the convective factors of heat transfer;

λ – the thermal conductibility;

δ – the thickness of material layer;

n – the number of layers.

The overall heat exchange factor is:

$$k=\frac{1}{r}\ ;\ \text{so:}\ \ k<\alpha_1;\frac{\lambda_j}{\sigma_j};\alpha_2 \tag{10}$$

The diffraction of sound waves in the presence of a temperature gradient establishes a concentration of sound waves on the tube periphery. In the case of water stream flow through the tube, this will determine an increase of heat transfer in the boundary layer. At the heating of water flowing through the tube, the sound waves will be deflected to the tube axis, so, their action in the boundary layer is much reduced. In the overall heat exchange, the value of heat transfer factor is determined by the minimum term. In the case of total heat resistance related to the unit exchange area.

4. Conclusion

For the performance of a controlled increase of heat exchange is rationally to act on the minimum factor of heat transfer. The convective heat factors, specially, those on the gas side, have the most reduced values. On the other hand, the sound field acts strongly just in the convective range of heat and mass transfer, reducing the most important partial thermal resistance.

As a result, the overall heat exchange is increased. The experimental results show the positive influence of acoustic vibrations over the power efficiency of thermal system. The increased sound fields determine the reduction of total and monochromatic emission factor, as well as an increase of flame power intensity, followed by an emission homogenization and a temperature balance in the combustion enclosure.

References

1. Boyd, R., Kent, J.: *21 Symp. on Combust*, p. 265-258, 1986.
2. Clayton, R.: *The Theory of Emulsion and Their Tehnical Treatment*. London. J.A.Churcill Ltd., 1981.p 4-8.
3. Drăgan, O.: *Ultrasunetele de mari energii*. Bucureşti. Ed. Academiei, 1983.
4. Jinescu, G.: *Procese hidrodinamice şi utilaje specifice*. Bucureşti. Ed. Didactică şi Pedagogică, 1983.
5. Popa, B., Iscrulescu, V.: *Procese de ardere în câmp sonor*, Ed. Acad.