THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI.
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^{0}. 2 – 2007, ISSN 1453 – 083X

THE ACTION OF THE ULTRASONIC VIBRATIONS OVER THE DIFFUSION PROCESS IN GASES AND LIQUIDS

Aurel CIUREA, Marian BORDEI
Universitatea "Dunarea de Jos" din Galati
email: ciurea.aurel@ugal.ro

ABSTRACT

Among the new method of studying the properties of the substance and the influence over the most various physical and chemical processes, used in different industrial domains, the main place is occupied by the usage of sound and ultrasound oscillations. Of course, nowadays we consider the acceleration of the diffusion processes, the degassing of the liquids under the action of the sound field, in melt, over the crystallisation process as being very important.

KEYWORDS: ultrasonic vibrations, diffusion, liquides, gases

1. The kinetics diffusion in gases and liquids

Numerous experiments demonstrated that the rate of the heterogeneous reaction taking place according to the kinetics diffusion are defined through the diffusion which appears as a result of the presence of different concentrations of the substance among the adhered substance layers directly at the surface and the liquid thickness.

Mathematically, this confirmation is expressed by Fick's law:

$$I = D\int_S \frac{\delta c}{\delta n}\Big|_{S=0} dS \qquad (1)$$

where: is the flux of the substance towards the surface; D - the molecular coefficient of diffusion; $\frac{\delta c}{\delta n}\Big|_{S=0}$ - the concentration gradient at the surface;

S - surface.

For the practical calculus Nusselt coefficient is used:

$$N_u = \frac{J_e}{\Delta CSD} = \left(\frac{\delta c}{\delta n}\right)_{S=0} \frac{e}{\Delta C} \qquad (2)$$

where: e is a characteristic value of the surface; ΔC - the concentration difference between the surface layers and the liquid thickness.

According to a series of experiments [1] and [2] it follows that the flux of the substance, y, increases in the presence of the sound field, in other words, the heterogeneous reaction accelerates, the reaction taking place according to the diffusion kinetics.

In conformity with the relation (1), this is possible when the ultrasonic field leads to the Δ of the diffusion coefficient, or of the concentration gradient at the surface ∂c/∂n.

2. The diffusion coefficient in the sonic field

According to Einstein the diffusion coefficient has the following relation:

$$\Delta = K_0 T D \qquad (3)$$

where: K_0 is the Boltzman coefficient; T - absolute temperature; D – mobility.

For the spherical parts:

$$b = \frac{1}{6}\pi\eta r \qquad (4)$$

where: η is viscosity; r - particle radius.

From relation (3) it result that D = f(T), and the environment temperature (T) can be changed into ultrasounds field from three reasons. An important fact is that the sound wave is absorbed and the loss of its energy will lead to the change of the surrounding temperature, T_1. The temperature increase can be determined from the relation of the thermal balance.

$$Q = C_v \rho_0 \Delta T_1 \chi \qquad (5)$$

where:

$$Q = I_0\left(1 - e^{-\alpha|\chi}\right)$$

$$A' = \frac{\left(\frac{4}{3}\eta + \xi\right) * \omega^2}{2\rho_0 C_0^{\,3}}$$

in which: ρ_0 is the density; C_v – specific heat of the medium; x – distance covered by the sonic wave; I_0 – sonic intensity; ξ – viscosity coefficient of the second medium; C_0 – the sonic rate in the middle; ω – frequency of the sonic waves.

If we take as example 1 cm^3 of water, I_0=1W/cm^2, $\omega=2\pi$ MHz (In such a way that the cavitations cannot in water) from (5) rezults $\Delta T=10^{-5}\,^0C$. For 1 cm^3 of air, I_0=4W/cm^2, $\omega=2\pi*18$KHz, results $\Delta T=10^{-2}\,^0C$.

In conclusion the heating of the two medium as a result of the sound absorption is proved to be insignificant. An other reason which might generated the heating would be a adiabatic compression of the middle in sonic field (ΔT):

$$\Delta T_2 = \frac{C_0\beta^* T}{C_p} V_0 \qquad (6)$$

where: C_p - specific heat at the constant pressure; V_0 - amplitude; β^* - coefficient of the middle thermal expansion.

Using the same data of calculus it results that the change of the temperature in water $\Delta T_2=10^{-3}\,^0C$ and in air $\Delta T_2=0,3\,^0C$.

Neither this variation of temperature will not significantly influence the diffusion coefficient in sonic field. An important consequence of sonic wave absorption is the heating of the middle in capillaries and at surfaces of the phases separation.

The energy of the sounds absorbed in the capillaries can be expressed by the relation:

$$Q = E_0 \frac{\sqrt{\omega}}{\sqrt{2rc_0}}\left[\sqrt{\upsilon} + \left(\frac{c_p}{c_v} - 1\right) * \sqrt{\chi}\right] \qquad (7)$$

where: r is capillary radius; υ-cinematic viscosity; χ-thermal conductibility; E_0-energy of the sonic wave in the capillary.

For a tube having radius of 1 cm an the length of 1 cm using the some parameters of the sonic wave the change of the temperature in capillary owing to the sound absorption in water will be $\Delta T_3=10^{-3}\,^0C$ and for the air $\Delta T_3=10^{-2}\,^0C$.

With diminish of the radius the energy inside the capillary has a sudden decreases in such a way in a thin capillary will be also small. For the real ferrous pieces, where the influence of the area unoccupied by pores in comparison with total area of the pores is equal of g the energy inside the coefficient is determined with Reily relation:

$$E_0 = \frac{4M}{2M^2 + 2M + 1} \qquad (8)$$

Supposing that g = 1, meaning that the pores area is equal to the area occupied by the pores, r = 10^{-4}cm; $\omega=2\pi*10^6$Hz'. It results that in the case of liquid that fills the capillaries, almost the whole energy will penetrate in them and according to the relations (5) and (7), $\Delta T_3'=1^0C$. For the air, $\omega=2\pi*18$KHz, r=10^{-4}cm, the part of energy that passes (penetrates) reach 3.5%, and the heating of the air in the capillaries will not surpass 4^0C. Another case of heating the middle part is possible an the condition of a normal fall of the sonic wave on a plane surface. The cause of this phenomenon is the fact that close to the rigid wall, there are transfers. However, at the surface, the temperatures that have contact with the core must be equal. In conclusion, in the thin layer close to the wall, it appears a temperature gradient which leads to an important energy dissipation.

The absorption of a sonic energy in the wall is equal to:

$$Q = \frac{2I_0\sqrt{2\omega}}{C_0}\left[\sqrt{\chi}\left(\frac{C_P}{C_V} - 1\right)\right] \qquad (9)$$

Using this relation and that of the thermal balance (5) it results that the variation of middle temperature as following the absorption in the wall, $\Delta T_4=0,1^0C$ for water and $\Delta T_4 \approx 1^0C$ for air. From the analysed data it results that the changes of temperature in ultrasonic field do not surpass several degrees Celsius. According to the relation (3) the ratio between the diffusion coefficient in sonic field D_{zv} and the diffusion coefficient in its absence is equal to:

$$\frac{D_{ZV}}{D} = \frac{T + \Delta T}{T} \approx 0,1\% \qquad (10)$$

Consequently, the diffusion coefficient in the free middle and in the presence of the limited surfaces, practically does not change in the sonic field. Taking into account the fundamental relation (1) and the practical observations, it results that in the sonic field the gradient of the reactive substances concentrations must increase at the surface the phases separation.

3. The influence of the sonic vibrations aver the diffusion current

In order to find the concentration gradient in the most general form it is necessary to solve the consecutive diffusion equation:

$$\frac{\delta C}{\delta T} + (V\text{grad})C = D\Delta C \qquad (11)$$

where: V-the moving rate of the particles of the middle.

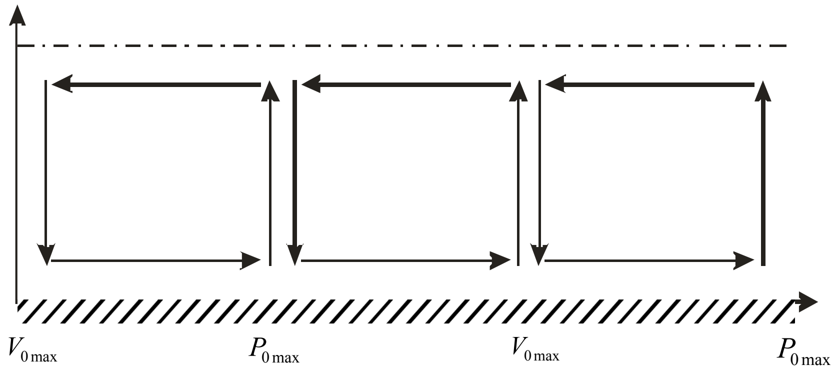

Fig.1. *The acoustic currents in the tube (current configuration), V_{0max} - oscillatory rate; P_{max} - pressure.*

We shall limit to the simplest condition:

$C = C_r$ (surface) (12)
$C = C_\infty$ (middle)

In the sonic field, the movement rate of the middle particles consists in the rate of consecutive movement, V_k^*, which always exists in the absence of the sound, the movement rate of the oscillations, V_{zv}, and the rate of the acoustic flows.

Because the influence of the sonic sound V_k^*, does not interest, it can be reflected, and the influence V_{zv} over the diffusion process in insignificant.

Therefore, the progress of the calculus of the diffusion processes acceleration in the sonic field consists in the necessity of solving (11) under the condition (12), understanding (concluding) that the movement rate of the middle particles is the rate of the acoustic flows. In the static sonic wave, in the rigid wall on a plane surface which is situated on the propagation direction of the wave, the turbionar acoustic currents are produced, currents that are periodically repeated. The tangent at U_x and the U_y that form (compose) the currents rate are given through the following equations:

$$U_x = -\frac{V_0^2 \sin 2kx}{8C_0}\left[e^{-\beta y}\left(4\sin\beta y + 2\sin\beta y + 1\right) - 3\right]$$

$$U_y = -\frac{2kV_0^2 \cos 2kx}{8C_0}\left[e^{-\beta y}\left(\sin\beta y + 3\cos\beta y + \frac{1}{2}e^{-\beta y}\right) + 3\beta y\right] \qquad (13)$$

where: K – wave number, equal with ω/Co; β=√ω/2ν; x,y – the tangential and normal coordinates of the phases separation surface.

The rate of the acoustic currents, according to Reily corresponds to the experimental data for the small comparative levels of the sonic pressure.

If they are big, meaning:

$$V_0 > \sqrt{\nu\omega} \qquad (14)$$

then the rate of the acoustic flows will be one level bigger and can be expressed:

$$U_x = 2{,}7 \cdot 10^{-4} V_0^2 \sin 2Kx\,(1 - e^{-\beta y}) \qquad (15)$$

The acoustic flows, appeared in the cylinder and sphere with radius a, namely, over them the sonic wave falls, are given by the following relations:

$$U_0 = \frac{3}{2}\frac{V_0^2}{\omega a}\sin 2\theta\left[e^{-\beta y}\left(\frac{2\beta y}{11}\sin\beta y - e^{-\beta y}\right) + 1\right] \qquad (16)$$

for $y \to \infty$ $\quad U_0 = 3/2 \cdot V_0^2/\omega_a \cdot \sin 2\theta$ (17)

where the signification of the θ and y are presented in fig.2.

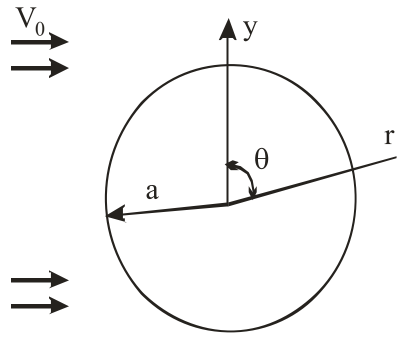

Fig.2. *The signification of the θ and y.*

4. Conclusions

Using the above data we can solve the mass transfer of the substance with the sphere radius, a, in sonic field.

In order to solve this problem, the diffusion equation is to be resolving (9) with condition (10), where we can consider as a movement rate of the middle the rate of the acoustic flows. Which appear around the middle.

The results can be written as follows:

$$N_{U_a} = \frac{BV_0}{\sqrt{\omega D}} \quad (18)$$

where: B-is a constant, B = 1.7 or 2.4;

The value 2.4 gives a better concordance with the experimental results.

At the same time, the influence of the ultrasounds over the diffusion process of the gas from liquid is used at the acoustic release. The release mechanism means that under the influence of the ultrasounds over the liquid, the dissolved gas dissipates in gas and this rise at the surface and in this way the liquid is relieved.

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