

**R.A.Vadov**

## **LOW FREQUENCY RELAXATION AND SOUND ATTENUATION IN A MARINE ENVIRONMENT**

*N. Andreyev Acoustic Institute,  
ul. Shvernika 4, Moscow, 117036 Russia,  
Ph.: (095) 126-9947, Fax: (095) 126-8411;  
E-mail: [bvp@akin.ru](mailto:bvp@akin.ru)*

The experimental data on sound absorption and attenuation in a marine environment obtained by Acoustic institute for World ocean locales distinguishing temperature, salinity of waters, pH-value are analyzed. By taking into consideration of the data on low frequency attenuation, published in the literature, and relaxation time of boron complexes, inclusive in seawater, and also functional connection, earlier obtained in laboratory conditions, of high frequency dissipation from temperature and salinity (bound with a structural relaxation of molecules of water and relaxation of a degree of dissociation of magnesium sulfate), it is concluded a ratio for the description of a frequency dependence of a sound attenuation in ocean, which is recommended for evaluation of an absorption coefficient on frequencies of 200-400 Hz and above.

For experimental researches of a sound attenuation in a marine environment (in their development) there are characteristic a gradual decrease of investigated frequencies, transition from laboratory methods of measurement to ocean experiment, and also constant looking up of physical explanation of "heightened" values of an absorption coefficient. So in 30-40 years by the main problem was to explain triple excess of experimental values of a sound absorption coefficient in fresh water above outcomes of calculation on the Kirchhoff - Stokes. This problem was resolved by consideration of the mechanism of a structural relaxation of molecules of water (with relaxation frequency  $10^{10} - 10^{11}$  Hz), introducing of concept of volumetric viscosity. On frequencies 1 MHz and lower a sound attenuation in fresh water vary proportionally to square of frequency and ratio of proportionality can be described by expression:  $K = 1.42 \cdot 10^{-8} \cdot 10^{1240/T}$  dB/km·kHz<sup>2</sup> (1), where  $\hat{O}$  - absolute temperature, °Ê.

At the end of 40 - beginning of 50 years there were necessary to explained by tenfold excess of a sound attenuation in seawater on frequencies about 100 kHz above absorption in fresh water. The mechanism of such excess was found, the theory of a relaxation of magnesium sulfate dissociation degree has appeared. As a result of series of laboratory experiments carried out at the end of 50 - beginning of 60 years in Acoustic institute, and also considering of experimental materials published in the literature, for the description of a sound attenuation in seawater on frequencies 5-10 kHz and above expression was concluded: (2),

$$b = \frac{A_{MgSO_4} \cdot f}{\frac{f}{f_{rMgSO_4}} + \frac{f}{f_{rMgSO_4}}} + K \cdot f^2$$

where the parameters of relaxation absorption conditioned by magnesium sulfate are determined as:

$$f_{rMgSO_4} = 1.125 \cdot 10^{(9-2038/T)} \text{ , kHz , } A_{MgSO_4} = 62.5 \cdot S \cdot T \cdot 10^{-6} \text{ , dB/km·kHz.}$$

The second term in the right part of a ratio (2) describes sound absorption in fresh water, value of factor  $K$  is determined by expression (1),  $S$  - salinity of sea water, ‰.

In 60-70 years the heightened sound attenuation in a marine environment on low (< 3-5 kHz) frequencies became a reason of consideration and profound analysis of a number of physical processes - potential sources of an observed phenomenon. Most close to authentic explanation of observed attenuation has appeared a low frequency relaxation, conditioned with presence of boron at seawater (1972-74). The main reason in its benefit was and is remained till now the result of measurement of a relaxation time executed by method of a temperature jump for sea water which contained and not contained a boron. The experimental data on sound attenuation coefficients in range of frequencies 0.2-5 kHz outcomes of full-scale measurements executed in a underwater sound channel (USC) consider as unique reliable.

From stands of a hypothesis of low frequency relaxation absorption conditioned by boron, we reviewed experimental data obtained in five locales of World Ocean, much distinguishing in such parameters, as temperature, salinity of waters (northwest (deep water) part of Pacific and Mediterranean, Black, Japanese, Baltic seas). Some characteristics of these locales are listed in table 1.

**The table 1**

Region:	N-w. Pacific	Mediterranean sea	Black sea	Japan sea	Baltic sea
Min. C(z) depth	50-100 m	150-250 m	40-60 m	120-180 m	40-50 m
t° near axes USC	1-2°Ñ	12.5-13°Ñ	8.5-9°Ñ	0.5-1°Ñ	4-5°Ñ
S‰ near ax.USC	33-33.5‰	38-39‰	18-20‰	34-34.5‰	6-10‰
Ph̄ near ax.USC	8.1-8.25	8.0-8.17	8.15-8.25	8.1-8.25	7.8-8.0
Pheff	8.2	8.1	8.17	8.22	7.85
Parameters of a frequency dependence of attenuation, defined on experimental data:					
p,dB/kmkHz <sup>n</sup>	0.0275	0.071	0.035	0.04	0.04
N	1.35	1.1	1.25	1.28	0.65
f <sub>rB</sub> , kHz	0.844	1.230	0.640 - 0.683	0.848	0.290
A <sub>B</sub> , dB/kmkHz	0.044	0.147	0.06	0.058	0.120
A <sub>B</sub> /S	0.00132	0.00382	0.00316	0.00169	0.015
A <sub>B</sub> /S·10 <sup>(0.78pH-5)</sup>	0.000053	0.000184	0.000133	0.000065	0.00123

For all these locales superficial axes of USC (50-250 m) and large difference on a salinity (6-39 ‰) and temperature (0.5-13°Ñ) of waters are characteristically. One of these locales (Baltic sea) is shallow-water. These locales well enough inspected - for them the representative enough material on a sound attenuation in frequency band 0.2-5 kHz is obtained. For each of these locales the frequency relation of a decay coefficient in range 0.2-5 kHz can be well enough described both power law

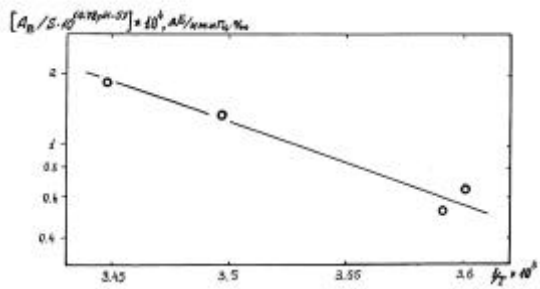
$$\mathbf{b} = p \cdot f^n, \text{ and expression (2), supplemented by a function } \Delta \mathbf{b} = \frac{A_B \cdot f}{f_{rB} + f} \quad (3),$$

depicting low frequency relaxation process by the applicable selection of parameters  $A_B$  and  $f_{rB}$ . Both a relaxation expression, and exponential function (by the applicable selection of parameters  $A_B$ ,  $f_{rB}$ ,  $p$  and  $n$ ) equally well describe (quantitative) a frequency dependence of a low frequency sound attenuation in these locales. However relaxation expression claims for the description of physical processes, accountable for attenuation. It is possible to neglect by relation of absorption to hydrostatic pressure at the analysis of experimental data obtained for these locales, because of superficial axis of USC. The values of a factor  $p$  and degree  $n$ , and also parameters  $A_B$  and  $f_{rB}$ , definite by us for each of selected locales, also are listed in table 1.

Grounding on measuring of a relaxation time by a method of a temperature jump under two temperatures (9.7°Ñ and 25.5°Ñ) and three values of a salinity of standard seawater (35 ‰, 17.5 ‰, and 7 ‰), undifficultly to receive a ratio:

$$f_{rB} = 37.9 \cdot S^{0.8} \cdot e^{-1800/T}, \text{ kHz} \quad (4).$$

Values of  $f_{rB}$  resulting in the table are counted by this expression, values of  $A_B$  are estimated on attenuation experimentally observed in USC.



surpass values definite for other locales.

In aqueous solutions of electrolytes the proportionality of parameter A to concentration was established by theoretical and experimental researches of relaxation absorption. Would be reasonable to admit the validity of such regularity for a low frequency relaxation conditioned by presence of a boron in sea water. Values of  $A_B$  normalized to a salinity are shown in the table. This normalization has resulted in a conclusion: Baltic sea leave out of the common. Really, the value, definite for Baltic sea, at 5-10 times

On the basis of the analysis of correlation between low frequency attenuation and values of pH the foreign explorers offered expression:  $A \approx 10^{(0.78pH-5)}$ . The strong variability pH on depth is known. For the Black sea, for example, the limits of change pH with increase of depth reach 0.8. Such difference results in change of parameter  $A_B$  (and, therefore, a factor of dissipation  $\Delta\beta$ ) in 3-4 times. At the registration of a pH value it is necessary to use its virtual value, mean on a beam (on its complete cycle), intersecting miscellaneous layers of ocean. For those regions, where experiments were conducted, on the basis of the archive data on relation pH from depth and observed data of a profile C (z) the calculations for main energy-formation beams, restricted axis cross-section angles  $\pm 6^\circ$  were made. Thus the range of changes has compounded 0.04 - 0.07 for all four locales, that results in change of parameter  $A_B$  within the limits of 10 -15 %. Using updated values pH, the values  $A_B/S \cdot 10^{(0.78pH-5)}$  for all of locales are listed in table. Undifficulty to note the definite tendency of change these values from locale to locale. Practically not distinguishing for the Japanese sea and Pacific (temperature of its water near axis of USC is identical), these values are augmented with temperature rise. The similar relation of parameter A from temperature (but not so strong) was marked at realization of researches on frequencies of ten - hundred kHz.

In a figure the values  $A_B/S \cdot 10^{(0.78pH-5)}$  for four deepwater locales are shown depending on reverse value of absolute temperature of waters (1/T). Undifficulty to determine on a slope of regression line the best form of temperature relation of parameter  $A_B$ :

$A_B/S \cdot 10^{(0.78pH-5)} = 1.65 \cdot 10^{(9-3696/T)}$ . Thus it is possible completely to agree experimental data on a sound attenuation among themselves for four locales essentially distinguishing in temperature and a salinity of waters.

Thus, the final ratio for calculation of low frequency dissipation can be written to a following view:

$$a = \frac{A_B \cdot f}{f_{rB} + f_{rB}/f} + \frac{A_{MgSO_4} \cdot f}{f_{rMgSO_4} + f_{rMgSO_4}/f} + K \cdot f^2 \quad (5),$$

The first term in a right member characterizes relaxation absorption, bound with a boron.,  $f_{rB} = 37.9 \cdot S^{0.8} \cdot 10^{-780/T}$ , kHz,  $A_B = 1.65 \cdot S \cdot 10^{(4+0.78 \cdot pH - 3696/T)}$ , dB/kmHz. The second and third terms describe relaxation absorption, bound with magnesium sulphate, and sound absorption in fresh water (the parameters are determined by ratio (1) and (2)).

The obtained ratio was checked up on experimental data on Atlantic, Pacific, Bay of Aden and Mediterranean sea, reduced in of Fisher and Simmons papers (1977). In table 2 for these locales are shown temperature, salinity,  $\delta \dot{I}$  and value  $\dot{A}_B$ , estimated from experimental materials, and also value  $\dot{A}_B$ , counted on the formulas (5). The values  $\delta \dot{I}$  were determined in conformity to our performances. So, for Pacific the value 8.1 was accepted, applicable to depth of an axis of USC equalled 50-80 m in one of two Lovett experience (1975).

**The table 2**

Region:	Temperature, °N	Salinity, ‰	$\delta \dot{I}$	$\dot{A}_B$ , dB/kmHz (experiment)	$\dot{A}_B$ , dB/kmHz (calculation)
Atlantic ocean	4	35	8.09	0.110	0.055
Pacific	4	34	8.1	0.055	0.054
Bay of Aden	15	36	7.7	0.078	0.09
Mediterranean sea	13	38	8.1	0.150	0.158

The counted values  $\dot{A}_B$  are agreed well with experiment for all four locales except for Atlantic, where the experiment was conducted along a route Eljutera - Bermudas, intersecting a vast coverage of the Antilles flow, that apparently was by a reason of heightened values of attenuation coefficient. To similar locales, for which the low frequency attenuation notably exceeds values, predictable on expression (5), necessarily to attribute water areas of the deepwater seas arranged near to powerful flows, zones of mixing of waters distinguishing in temperature, salinity. In such locales the sound attenuation is determined not only its absorption, but also sound scattering on heterogeneities of a water environment. To such locales also necessarily to attribute shallow seas, for which outflow of a sound energy in bottom is essential even in conditions of USC well formed.