# The Research on Measuring the Coefficient of Sound Absorption in Turbid Seawater

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**Abstract**: When naval mine-hunting sonars and side-scan surveying sonars operating at 20~60 kHz are working in shallow coastal waters, the visco-thermal absorption of sound by suspended mud in the water may greatly decrease their detection properties. This kind of water is also characterized as turbid seawater. However, the research on measuring the coefficient of sound absorption in turbid seawater has little been done. The main difference between turbid seawater and clear seawater is that there are mud particles suspending in turbid seawater. It is also the main reason why sound absorption in turbid seawater is greater than that in clear seawater. In the paper, the coefficient of sound absorption at 20~60 kHz in turbid seawater has been measured by the reverberation technique. Results demonstrate that if the concentration of the mud is bellow 0.11 kg per cubic meters, the mud in turbid seawater doesn't cause additional absorption. When the concentration of the mud is between 0.14 and 0.49 kg per cubic meters, the coefficient of sound absorption in turbid seawater is as twice at least as that in clear seawater.

# 1 Introduction

The working frequency of naval mine-hunting sonar, side-scan surveying sonar and acoustic Doppler current profilers in shallow coastal environments is from tens of kHz to hundreds of kHz. When these sonar works at the domain of turbid seawater, the sound absorption and sound scattering in turbid seawater may decrease their working performance deeply. Sound absorption in turbid seawater is increasing in evidence and sound scattering is enhancing remarkably. It is positive that the performance of normal underwater acoustic detection equipment decreases in turbid seawater. Because sound absorption in the medium has the linear dependence on squared frequency, an efficient way is to decrease the working frequency, so as to increase the detection performance of underwater acoustic equipment in turbid seawater. The relation between the intensity of sound scattering and frequency is complicated. The intensity of sound scattering may be caused by scattering objects' kinds, dimensions and distribution, etc. However, it is not simple or easy to decrease the working frequency of underwater acoustic detection equipment. In order to maintain the power and directivity identically, the dimension of transmitting transducers must be enlarged and the capability of space resolution will be sacrificed with frequency decreased. The decrease extent of the frequency depends on the properties cognition of sound absorption and sound scattering in turbid seawater. Since 1940s, scientists have been doing the research on measuring the properties of sound absorption in water medium. The work has mainly been done on pure water and electrolyte solutions. There are several methods to do the research, such as plane wave method, resonance method and reverberation method [1-6]. But the research on turbid seawater is relatively less. These methods can also be used to study the sound absorption properties of turbid seawater.

# 2 The principles of theory

Generally speaking, there are several reasons why the sound intensity attenuates with increased distance. First, the sound absorption is caused by the viscosity of seawater or other reasons, which transforms sound energy into heat energy. Second, the sound scattering of non-homogeneous objects in seawater. Third, the spreading of wave front. Fourth, because the temperature and salinity of seawater are non-homogeneous, sound ray bends. In shallow water, the reflection of sea surface and sea bottom can also bring the

attenuation. If sound intensity at the distance $r$ can be denoted by $I$, then,

$$I = \frac{I_0}{r^n} e^{-2\alpha r} \qquad (1)$$

Where, $I_0$ is a constant and decided by the intensity of sound source, $n$ is the index number and depends on the condition of ocean propagation, $2\alpha$ is the attenuation coefficient of sound intensity, while $\alpha$ is the attenuation coefficient of the amplitude. If the effect of sea surface and sea bottom doesn't exist, the attenuation coefficient is the summation of sound absorption coefficient and volume scattering coefficient.

The measurements indicate that when the frequency is beyond 1 MHz, the attenuation coefficient of seawater is equal to the viscous absorption coefficient and also equal to measured value of viscous absorption in pure water. However, when the frequency is in the range from 1 kHz to 1 MHz, the measured attenuation coefficient of seawater is much greater than that of pure water. The salinity of clear seawater is from 3.3 to 3.8%. In the seawater, the 99.5% of salts is made up of nine ions. These ions are sodium chloride (NaCl), magnesium chloride (MgCl2), magnesium sulfate (MgSO4), calcium sulfate (CaSO4), potassium sulfate (K2SO4), calcium carbonate (CaCO3), magnesium bromide (MgBr2). Unless the salinity of seawater is much lower, the proportion of the ions is extraordinarily constant. The biology organism makes the component and the solute gas change in local areas only. Although the proportion of magnesium sulfate in the total solute salts weight is only 4.7%, Leonard, Combs and Skidmore have discovered that the main absorption component is not the sodium chloride in seawater, but the special salt magnesium sulfate. Due to the molecule relaxation of magnesium sulfate, the measured attenuation coefficient of seawater is much greater than the viscous absorption coefficient in the frequency range from 1 kHz to 1 MHz.

The listed results demonstrate that when the frequency is beyond 1 kHz, the sound absorption of seawater has crucial effect on the attenuation of sound propagation. The sound attenuation due to sound scattering can be eliminated sometimes. So the measured value of $\alpha$ according to equation (1) can be considered to be the coefficient of sound absorption in seawater. When the frequency is beyond 1 MHz, the coefficient of sound absorption in seawater is equal to the coefficient of viscous absorption in pure water. When the frequency is below 1 MHz, the coefficient of sound absorption in seawater is equal to the sum of chemical relaxation absorption in seawater and viscous absorption in pure water.

At present, the explicit definition of turbid seawater doesn't exist. The difference between turbid seawater and clear seawater is that there exist suspended particles in turbid seawater. The main reason why turbid water is formed is that the soil eroded by rain water pours into the rivers. The gigantic grains and coarse grains are deposited by the function of gravity in the river. The fine clay particles are deposited slowly in the river due to their minute diameter. Even if the fine clay particles can be deposited freely, the suspended clay particles move randomly at the collision of water molecule in the water due to the effect of Brownian movement. When the grain diameter is equal to 2 microns, the Brownian movement is very obvious. When the grain diameter is equal to 1 micron, the velocity of Brownian movement is far greater than that of clay particles' free deposition. So the soil grains suspended in the water for a long time are that the diameter of the particles is at the micron levels, such as the illite, smectite and kaolinite. When the water suspending the particles of micron dimension pours into the sea, the suspended particles are mixed with seawater. There exists not only electrolyte, but also exists suspended particles. The turbid seawater is formed near the shore due to the listed reason. However, two absorption mechanisms are generated due to the existence of suspended particles, viscous absorption and scattering. The mass of suspended particles is greater than that of water molecule, so that the inertia of suspended particles is far greater than that of water molecule surrounding the particles. When the sound wave propagates in turbid seawater, the phase delay exists between the suspended particles and water molecule. The velocity gradient exists near the boundary layer of the particles, so that the friction is generated between the suspended particles and water medium. Heat dissipation is created due to the friction, then the viscous absorption generates. Meanwhile, the sound wave can be scattered in various direction by suspended particles, then, the primary wave generates, which will also induce energy loss. Although the viscous drag expression of Stockes can be used to calculate the viscous absorption of spherical particles and the scattering expression of Sheng and Hay can be used to calculate the sound absorption due to the scattering of spherical particles, the suspended particles are not simply spherical and their shapes is extremely complicated in practical turbid seawater. It is impossible to calculate the sound absorption by the theoretical expression, especially in some special turbid seawater. In order to solve the listed difficulties, the coefficient of sound absorption in turbid seawater is measured by the experimental method in the paper. The law of sound absorption in turbid seawater is also analyzed quantitatively.

The coefficient of sound absorption in turbid seawater is equal to the coefficient of sound absorption in clear seawater and the coefficient of sound absorption due to the viscous and sound scattering effect of suspended particles. It is shown

$$\alpha = \alpha_w + \alpha_v + \alpha_s \qquad (2)$$

where $\alpha_w$ is the coefficient of sound absorption in clear seawater, $\alpha_v$ is the coefficient of sound absorption caused by the viscosity of suspended particles, $\alpha_s$ is the coefficient of sound absorption caused by the scattering of suspended particles.

There are a lot of expressions to calculate the sound absorption in clear seawater. But the best relation between the theoretical calculation values and the experimental data is Francois and Garrison sound absorption calculation expression. Their calculation expression is composed of three parts and shown by the equation (3).

$$\alpha_w = 10^{-3} \left[ \frac{A_1 P_1 f_1 f^2}{f^2 + f_1^2} + \frac{A_2 P_2 f_2 f^2}{f^2 + f_2^2} + A_3 P_3 f^2 \right] \qquad (3)$$

# 3 The principles of experimental measurement

The coefficient of sound absorption in turbid seawater medium is measured by the reverberation technique in the paper. The theory of reverberation had been brought forward by Sabine (W.C.Sabine) in 1900. Sound source radiates energy and get to steady state in the sound diffusing field. Then the sound source stops working. The time taken for the sound pressure level to fall by 60 dB is called reverberation time. It can be signed by $T_{60}$ usually.

The calculation formula of reverberation time is given by

$$T_{60} = \frac{55.26 V}{c(\alpha S + 8 \beta V)} \qquad (4)$$

Reverberation time reflects the speed of sound energy attenuation in a reverberation room (barrel). It also reflects the condition of sound absorption in a reverberation room (barrel) indirectly. The more sound absorbs, the quicker sound energy attenuates and the shorter reverberation time is. So the relation between reverberation time and sound absorption can be utilized. If the reverberation time is measured, the coefficient of sound absorption will be calculated.

The basic principle is as follows. When the reverberation barrel is filled up with pure water or turbid seawater, the energy loss of the container surface and measuring system is considered to be identical, so that pure water can be used to calibrate total energy loss of the reverberation barrel inner surface and the measuring system. The mean sound absorption coefficient of the equivalent reverberation barrel inner surface can be calculated by Sabine formula. If the reverberation time of pure water and turbid seawater is measured respectively, the coefficient of sound absorption in turbid seawater can be calculated by the formula:

$$\beta_0 = \left( \frac{60}{Tc} - \frac{60}{T_0 c_0} \right) + \beta_0' \qquad (5)$$

Where, $\beta_0'$ is the coefficient of sound absorption in pure water, $\beta_0$ is the coefficient of sound absorption in turbid seawater, $T_0$ is the reverberation time of pure water, $T$ is the reverberation time of turbid water, $c_0$ and $c$ are the sound speed of pure water and turbid seawater respectively. $\beta_0'$ and $c_0$ can be looked up in the handbook[7]. The paper[6] demonstrates that the speed discrepancy between turbid seawater and clear seawater is very small. The sound speed of turbid seawater can be considered to be that of clear seawater.

# 4       The design of experiment

In the low frequency range, the coefficient of sound absorption is a much smaller quantum. The coefficient of sound absorption in clear seawater is at $10^{-3}$ level when the frequency is from 10 kHz to 40 kHz. When the experimental system is designed, the coefficient of sound absorption caused by reverberation barrel must be small. The experimental system needs to be dealt with by vibration isolation, so as to reduce the energy loss through sound radiation. The system also needs to be degassed, because the air bubble brought by the wind exists usually in the surface layer of seawater, of which the thickness is several meters approximately. In order to make the measurement results stable and practical, the turbid seawater to be measured needs to be degassed.

The reverberation barrel is a cylindrical barrel in the experiment, which is formerly a forged aluminum ingot, and then the forged aluminum ingot is dealt with by turning. The barrel has no welding seam. Its inner diameter, height and wall thickness is 100, 54 and 0.45 cm respectively. The cubage of the barrel is 430 L. The minimum measured frequency is about 3 kHz. The aluminum barrel's inner surface has been covered by lacquer in order to prevent the barrel surface from corrosion. The aluminium barrel is placed in a coaxial cylindrical steel barrel. The aluminum barrel is supported at four points of its lower rim by means of hard-wood chocks in order to reduce sound radiation. There are air-extracted holes, air-bleed holes, inspection windows and wire connection holes in the steel barrel. The sound absorption experiment can be carried out in the vacuum. In order to maintain the temperature stable, the two layer plastic foam, of which the thickness is 0.03 meters, is enwrapped on the outer surface of steel barrel. The diagrams of the experimental system connection and practical experimental apparatus are shown in figure 1, figure 2 and figure 3.
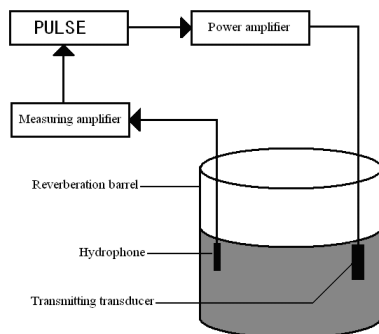


Fig. 1 The scheme of experimental apparatus' connection



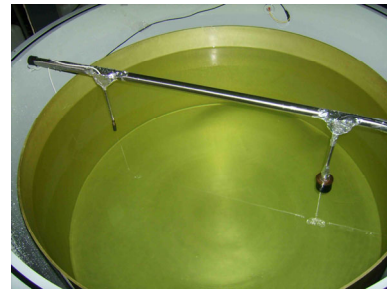Fig. 2 The design of vibration isolation and degassing



Fig. 3 The practical scheme of experimental system

In the calculation formula of sound absorption, only the reverberation time needs to be measured. The other quanta can be looked up in the handbook. There are several methods for measuring the reverberation time, such as steady random noise cut-off method, impulse backward integration method, etc. The first method is adopted to measure the reverberation time in the experiment. Firstly, the signal source in the PULSE (type B&K 3560E) transmits the random noise. Then, the signal is magnified by the power amplifier (type B&K 2713), and then the magnified signal is loaded to the transducer. A steady sound field will be built up in the reverberation barrel. After the signal source is cut off, the hydrophone (type B&K8103) watches the decay of sound pressure level. The signal received by the hydrophone is magnified by the measuring amplifier (type B&K 2692), and then the signal is collected by PULSE. The decay of sound pressure level is recorded by PULSE. The reverberation time is calculated by the decay of sound pressure level to fall by 60 dB, which had been carried out by the reverberation time template in PULSE.
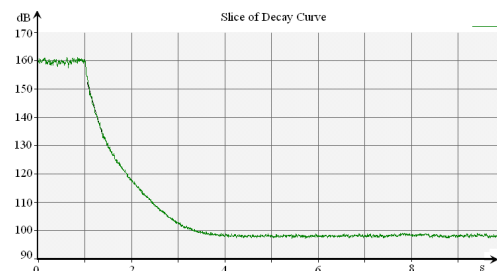


Fig. 4 The decay curve in the experiment

# 5       Experimental results

Ideally, the reverberation time is determined from the decay of a diffuse sound field. A diffuse sound field is one where the average energy density is the same throughout the volume considered and all directions of propagation are equally probable. The onset of a diffuse sound field in an enclosure can be described by the Schroeder cutoff frequency. This gives an indication of the lowest frequency at which the modal density is sufficient to constitute a diffuse field. The Schroeder cutoff frequency, $f_{sch}$, can be expressed as

$$f_{sch} = \left( \frac{c^3}{4\ln 10} \right)^{1/2} \left( \frac{T}{V} \right)^{1/2} \qquad (6)$$

where $T$ is the reverberation time, $c$ is the sound speed of the water., and $V$ is the volume of the enclosure. Values of $f_{sch}$ for the designed system are between 20 and 25 kHz.

This is near the lower limit of the frequency range under consideration in this project. The recorded frequencies are 20, 25, 31.5, 40, 50, 63 kHz in the experiment. In order to validate the accuracy and reliability of the results in the measuring system, the coefficient of sound absorption in magnesium sulfate solutions of the known concentration has been measured in the reverberation barrel. The error of the measuring system can be gotten by the comparison between the measured sound absorption coefficient in the experiment and the calculated sound absorption coefficient of the same concentrations through the specified expressions in reference books.
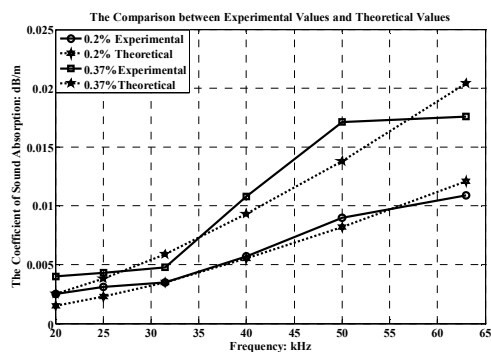


Fig. 5 The comparison between the measured values and theoretical values

In figure 5, the mass concentration of magnesium sulfate solution is 0.2%, 0.37% respectively, while the temperature is $20^0 C$. From the experimental results, the difference exists between the theoretical calculation values and the experimental measured values. The measuring error of the designed system is 15 %, the measuring error caused by the location difference of the transducer and hydrophone is 4 %[6]. However, the deviation between the measured values and the theoretical calculation values is mostly at the range of ±19 %.

In the studied frequency, the sound absorption caused by the electrolyte in turbid seawater is mainly magnesium sulfate. The solute in turbid seawater is magnesium sulfate and fine clay particles. The mass percentage of magnesium sulfate is 0.34% and equal to 0.014 mol/L. The coefficient of sound absorption in the magnesium sulfate solution, of which the concentration is 0.014 mol/L, is equal to the coefficient of sound absorption in seawater, when the temperature is $20^0 C$.
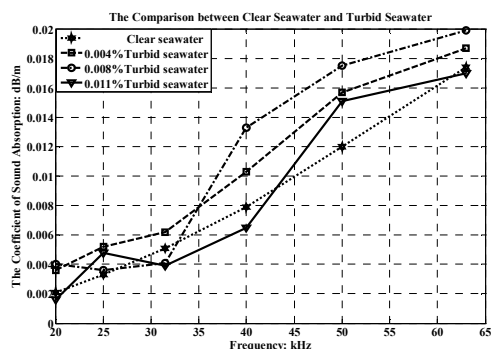


Fig. 6 the coefficient of sound absorption in turbid seawater of small concentration
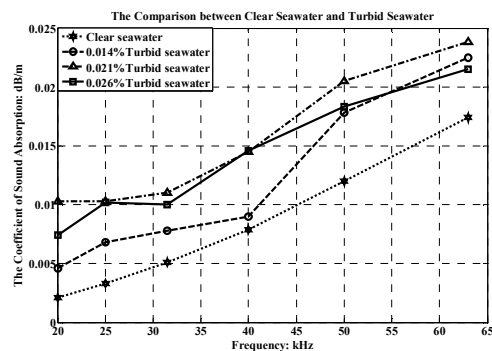


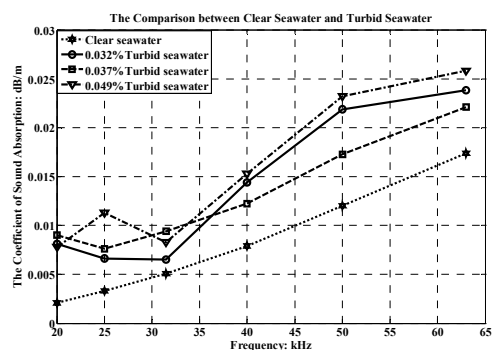Figure 7 the coefficient of sound absorption in turbid seawater of middle concentration



Figure 8 the coefficient of sound absorption in turbid seawater of big concentration

# 6    Conclusions

From figure 6, 7, 8, some conclusions can be gotten.

First, at a fixed concentration, the coefficient of sound absorption in turbid seawater is augmenting with the frequency increasing.

Second, at a fixed frequency, the coefficient of sound absorption in turbid seawater is approximately augmenting with concentrations increasing.

Third, when the mass concentration of fine clay particles is below 0.011%, the main cause of sound absorption in turbid seawater is electrolyte. However, the magnesium sulfate is the main cause of the sound absorption in the paper.

Fourth, when the concentration of the mud is beyond 0.014%, the effect of sound absorption caused by suspended particles is remarkable. The coefficient of sound absorption in turbid seawater is as twice as that of the clear seawater.

## Acknowledgments

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