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Simulation Model for Comparative Study of Acoustic Wave Absorption

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Abstract: This paper reports the comparative study of acoustic wave absorption carried out by means of modeling in MATLAB. The results of simulation have been compared with the practically measured values in the Arabian Sea near Goa and Atlantic Ocean. The model has been used to determine sound absorption for given values of depth (D), salinity (S), temperature (T), pH, and acoustic wave transmitter frequency (f). The sim model of sound absorption can predict the coefficient of absorption at any place on the earth.

Keywords- Sim model, depth, salinity, temperature, pressure, coefficient of absorption

1. INTRODUCTION

The absorption of sound waves in sea water has been studied by many investigators [1 - 4]. Some researchers have carried out these studies using the measurements made by mixing the various ingredients present in sea water while others have used the measurements actually taken in the sea water. The results so far reported through former studies suffer from errors. This may be because the mixing of different ingredients is not taking place in the required proportions. Empirical formulae have been developed by the investigators however. Because the electro-magnetic wave is highly attenuated by seawater, research on underwater communication is done using acoustic wave [2].In recent years, the need for high-speed underwater acoustic communication to construct sensor networks on the sea floor or to communicate with underwater vehicles has become prominent. In this paper we report the SIM[1] model developed to calculate and represent graphically the absorption coefficient of sea water by using formulations of four different workers namely a) Francois[3,4] b) Fisher[5] c) Schulkin[6] and d) Thorp [7,8].The results have been presented in this communication.

1.1 DATABASE

The main database necessary for acoustic propagation prediction is sound absorption coefficient.

Sound absorption coefficient.

We have used the database of different oceans to calculate the coefficient of sound absorption .The practical values of depth, salinity, temperature, pH, pressure and frequency of sound wave propagation have been used to calculate the coefficient of absorption (alpha) by the empirical formulae derived by a) Francois b) Fisher c) Schulkin and d) Thorp.

2. SOUND ABSORPTION SIM MODEL

The fig. 1 shows the sim model of sound absorption in sea water. The model consists of eleven edit boxes named as Depth, Temp, Pressure, Salinity and Sound speed. The data is read in this sim model. These buttons invoke the programs which calculate the sound absorption coefficient (alpha).When the acoustic wave propagates in sea water, absorption loss occurs, which is caused by a part of the energy changing into the heat owing to the viscous friction of the water molecule, aside from the spreading loss. The absorption loss is represented as αr, where α is the coefficient in dB/Km and r is the transmission distance.

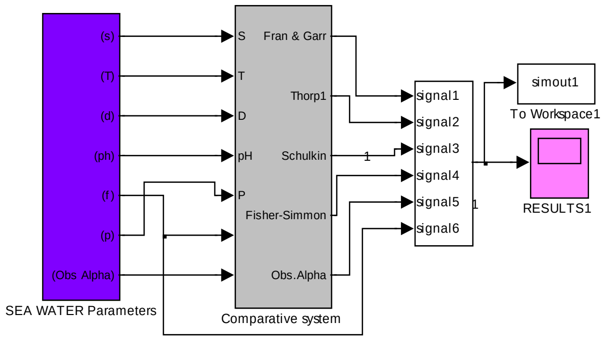

Fig.1 Main sim model of Coefficient of Absorption

The main simulation model in fig 1 has been designed using simulink toolbox of MATLAB [1] to determine the coefficient of absorption in the sea water .The input data like depth, salinity, temperature, frequency, pressure and observed coefficient of absorption have been read from workspace through the simin block in the simulink library. The empirical formulae proposed by different investigators have been used to calculate the coefficient of absorption. Each subsystem has been designated by the name of the investigator e.g. Francois b) Fisher c) Schulkin and d) Thorp. The exhaustive model showing the different methods used is shown in fig.2.

Expressions of absorption coefficient α have been proposed by various researchers on the basis of the laboratory and sea –based experiments. Some of these expressions have been given below.

The empirical expression of Francois-Garrison as a function of salinity, frequency, depth, pH and temperature is expressed as follows.

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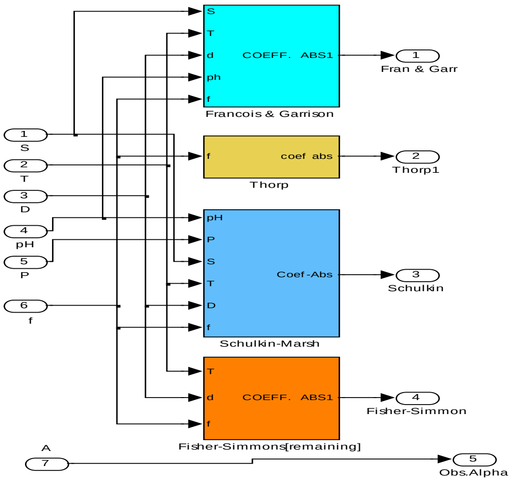

Fig.2 Detail Sim model of Coefficient of Absorption

$$\alpha = \frac{A_1 P_1 f_1 f^2}{f_1^2 + f^2} + \frac{A_2 P_2 f_2 f^2}{f_2^2 + f^2} + A_3 P_3 f^2$$

The first term gives the sound absorption due to the Boric Acid and second term gives the sound absorption due to the magnesium sulfate. The contribution of sound absorption due to these chemical ingredients has been found to be small. The third term represents the sound absorption due to pure water. The pressure dependency of above equation is shown by P_1 ,P_2 and P_3 constants .Frequency dependency is given by f_1,and f_2 which are the relaxation frequencies of Boric Acid and Magnesium sulfate. f is the frequency of sound. The constants A_1, A_2 and A_3 shown are not purely constants but it has been experimentally proved that their values vary with the water properties, like temperature, salinity and pH of water.

The total coefficient of absorption of sea water is calculated by considering separately the absorption due to boric acid, magnesium sulphate and pure water. Separate contribution by the ingredients has been given below.

On entering the depth (d), temperature (t), pressure(p),salinity(s),pH and frequency in edit boxes and pressing the push button 'plot(Alpha v/s d)' displays the graph of coefficient of absorption v/s depth and pressing the push button 'plot(Alpha v/s f)' displays the graph of coefficient of absorption v/s frequency . The coverage of parameters in each method is given in table 1.

Table1. Coverage of parameters in each equation.

	T (0C)	S (ppt)	D (Km)	pH	Frequency (KHz)
Thorp	4	35	1	8	
Francois Garrison	-2 to 22	30-35	0-3.5	8	10-500
Schulkin-Marsh	-	35	-	8	-
Fisher-Simmons	-	35	-	8	-

Absorption coefficient due to Boric Acid

$$attn_1 = \frac{A_1 P_1 f_1 f^2}{f_1^2 + f^2}$$

$$A_1 = \frac{8.86}{c} \times 10^{(0.78\,pH - 5)}, \qquad dB\ Km^{-1} KHz^{-1}$$

$$P_1 = 1,$$

$$f_1 = 2.8\left(\frac{S}{35}\right)^{0.5} \times 10^{\left(4 - \frac{1245}{\theta}\right)}, \qquad KHz$$

Where c is the sound speed (m/s), given by

$c = 1412 + 3.21T + 1.19\,S + 0.0167\,D$,

T is the temperature(^{0}C),

$\theta = 273 + T$,

S is the salinity(‰), and D is the depth (m).

Absorption coefficient due to $MgSO_4$

$$attn_2 = \frac{A_2 P_2 f_2 f^2}{f_2^2 + f^2}$$

$$A_2 = 21.44\,\frac{S}{c}\,(1 + 0.025T) \qquad dB\ Km^{-1}\ KHz^{-1}$$

$$P_2 = 1 - 1.37 \times 10^{-4}\ D + 6.2 \times 10^{-9}\ D^2$$

$$f_2 = \frac{8.17 \times 10^{\left(8 - \frac{1990}{\theta}\right)}}{1 + 0.0018(S - 35)} \qquad KHz$$

Absorption coefficient due to Pure Water

$$attn3 = A_3 P_3 f^2$$

For $T \le 20^0C$,

$$A_3 = 4.937 \times 10^{-4} - 2.59 \times 10^{-5}\ T + 9.11 \times 10^{-7}\ T^2 - 1.50 \times 10^{-8}\ T^3 \qquad dB\ Km^{-1}\ KHz^{-2}$$

For $T \succ 20^0C$,

$$A_3 = 3.964 \times 10^{-4} - 1.146 \times 10^{-5} T + 1.45 \times 10^{-7}\ T^2 - 6.5 \times 10^{-10}\ T^3 \qquad dB\ Km^{-1} KHz^{-2}$$

$$P_3 = 1 - 3.83 \times 10^{-5}\ D + 4.9 \times 10^{-10}\ D^2$$

The empirical expression of Thorp is shown as a function of the frequency by

$$\alpha = f^2\left(3.01 \times 10^{-4} + \frac{43.7}{4100 + f^2} + \frac{0.109}{1 + f^2}\right) \qquad (dB/Km)$$

Where f is the frequency in KHz

The expression of Schulkin Marsh is shown as function of the frequency, salinity,temperature,pressure,pH, and speed of sound as

$$\alpha = \left\{\left[\frac{2(\alpha\lambda)_r}{c}\right]\frac{f_r f^2}{f_r^2 + f^2} x10^3 + \left(\frac{SAf_T f^2}{f_T^2 + f^2} + \frac{Bf^2}{f_T}\right)\left(1 - 6.54x10^{-4} p\right)\right\} \times 8686 \qquad (dB/Km)$$

Where

$$(\alpha\lambda)_r = 3.1 \times 10^{(0.69\,pH - 6)} \times 10^{-5} \qquad (Np/wavelength),$$

$$f_r = 6.1 \times \left(\frac{S}{35}\right)^{0.5} \times 10^{[3 - (1051/\theta)]} \qquad (KHz)$$

$$\theta = 273 + {}^0C$$

$$f_T = 21.9 \times 10^{[6 - (1520/\theta)]} \qquad (KHz)$$

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The expression of Fisher-Simmons is shown as function of the frequency, temperature, and pressure as

$$\alpha = \left(\frac{A_1 P_1 f_1 f^2}{f_1^2+f^2} + \frac{A_2 P_2 f_2 f^2}{f_2^2+f^2} + A_3 P_3 f^2\right)\times 8686 \text{ (dB/Km)},$$

Where

$$A_1 = 1.03\times10^{-8} + 2.36\times10^{-10}T - 5.22\times10^{-12}T^2 \text{ (s/m)}$$

$$f_1 = 1.32\times10^{3}\left(T+273.1\right)\times \exp^{\left[-1700/(T+273.1)\right]} \text{ (Hz)}$$

$$A_2 = 5.62\times10^{-8} + 7.52\times10^{-10}\times T \quad \text{(s/m)}$$

$$f_2 = 1.55\times10^{7}\left(T+273.1\right)\times \exp^{\left[-3052/(T+273.1)\right]} \text{ (Hz)}$$

$$p_2 = 1 - 10.3\times10^{-4}p + 3.7\times10^{-7}p^2,$$

$$A_3 = (55.9 - 2.37T + 4.77\times10^{-2}T^2 - 3.48\times10^{-4}T^3)\times10^{-15} \quad (s^2/m)$$

$$p_3 = 1 - 3.84\times10^{-4}p + 7.57\times10^{-8}p^2$$

Where f is frequency in Hz, T is temperature in ^{0}C, and p is the pressure in atm

3. RESULTS

Comparative graphs given in fig 3 to fig 7 clearly indicate the validation of sim model.

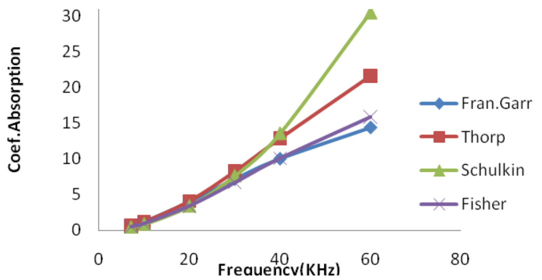

Fig.3 Comparison of sim model results at Chukshi Sea

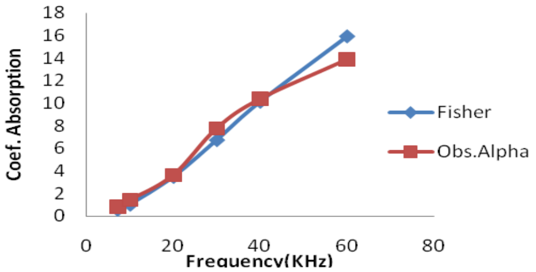

Fig.4 Comparison of Fisher sim model result with observed values of sound absorption (alpha) at Chukshi Sea

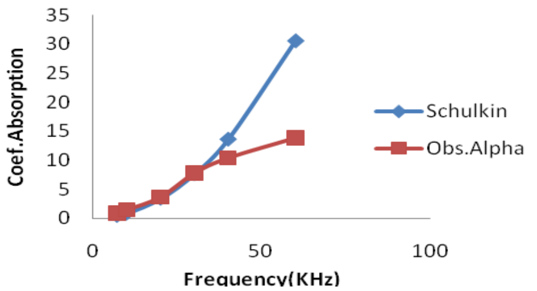

Fig.5 Comparison of Schulkin sim model result with observed values of sound absorption (alpha) at Chukshi Sea

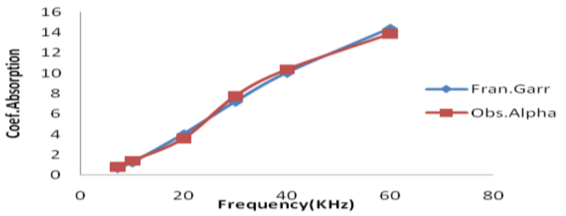

Fig.6 Comparison of Francois Garrison sim model result with observed values of sound absorption (alpha) at Chukshi Sea

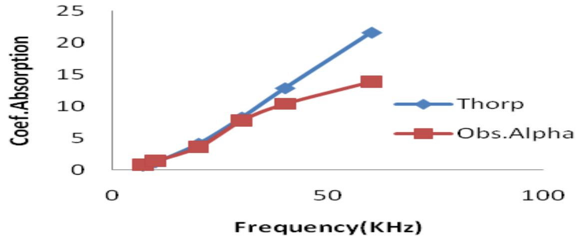

Fig.7 Comparison of Thorp sim model result with observed values of sound absorption (alpha) at Chukshi Sea

4. CONCLUSION

The results obtained from SIM model for different methods on comparison with the observed values of coefficient of absorption clearly show that the results by Francois and Garrison method are closely matching with the observed values. Thus the sim model of sound absorption can predict the coefficient of absorption at any place on the earth.

5. ACKNOWLEDGMENT

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