USP Assignment 02

Calculation of sound attenuation in seawater using Thorp formula, Schulkin & Marsh formula and Francois& Garrison formula, 07-05-2024

Naga Sai Vamsi Uppuluri
5305739
City University of Applied Sciences
Bremen, Germany
nuppuluri@stud.hs-bremen.de

Vandana Chegondi
5305726
City University of Applied Sciences
Bremen, Germany
vchegondi@stud.hs-bremen.de

***Abstract*—This report presents an analysis of sound attenuation in seawater utilizing three distinct formulas: the Thorp formula, the Schulkin & Marsh formula, as well as the Francois & Garrison formula. The investigation is based on comparative studies of these formulas to identify how they affect sound propagation in seawater. Additionally, the Francois& Garrison formula's dependence on frequency, salinity, and temperature is scrutinized at a fixed depth. The report employs MATLAB to run computations and visualize data so that we can understand and compare comprehensively. Thus, the study provides an understanding of the most significant factors that lead to the attenuation of sound in seawater.**

***Index Terms*—Thorp Formula, Schulkin and Marsh Formula, Francois and Garrison Formula,Attenuation, Attenuation Modeling.**

I. Introduction

Underwater acoustics encompasses the science of sound wave propagation and its applications are vast, found in studies of communication, navigation, and marine life. The propagation of sound in seawater is a complex phenomenon that may be affected by factors including temperature, salinity, depth, and frequency. Furthermore, an abundance of empirical equations were calculated to predict sound attenuation in seawater.

L. A. Thorp suggested the Thorp formula in 1968 to describe the connection between sound attenuation and frequency, considering that most effects are caused by temperature and depth. With the formulation of another widely used formula, which is by Schulkin & Marsh, which has increased wave absorption and is attributed to regularity, the accuracy has been seen to improve especially at high frequencies. Furthermore, the Francois and Garrison equation, which includes temperature, salinity, and frequency components as factors, proposes a more comprehensive model of sound attenuation in seawater.

This paper aims to analyze and compare these three formulas for sound attenuation in seawater. Additionally, we investigate the specific influences of frequency, salinity, and temperature on sound attenuation using the Francois & Garrison formula, providing insights into the dominant mechanisms governing underwater sound propagation. Through this analysis, we seek to enhance our understanding of underwater acoustics.

II. Methodology

The methodology in this study is made up of both theoretical formulations and computational techniques utilized for the analysis of sound attenuation in seawater. Initially, we derived expressions for sound attenuation using three established formulas: the Thorp formula, the Schulkin & Marsh formula, and the Francois & Garrison formula. The formulas were chosen because of their widespread utilization and they can capture various mechanisms that influence attenuation, e.g., temperature, salinity, depth, and frequency. Through the utilization of these formulas, our goal was to conduct a comprehensive study of the factors that influence sound transmission in the underwater environment.

After the theoretical derivation, we performed our numerical computations using MATLAB for calculations in a wide range of frequencies. This was achieved by assigning the frequency range of interest and then, one after another, determining attenuation values for each formula. Furthermore, we used the MATLAB plot function to plot and compare the results of the different formulas. This enabled us to gain insights into the relative strengths and limitations of each approach and identify potential areas for further investigation.

To further investigate how frequency, salinity, and temperature statistically effect sound attenuation, we performed detailed examinations using the Francois & Garrison formula. To be specific, we investigated the factors such as decreasing depth, frequency, and angle that were responsible for the attenuation at a fixed depth of 50 meters. By changing the frequency, salinity, and temperature systematically within the relevant ranges we aimed to quantify their individual effects on sound attenuation and find some patterns or trends that are prominent among all of them. The systematic approach enabled us to determine the main influencing factors of diminution in seawater and provided precious suggestions into the core physics of underwater acoustics.

III. Implementation

The implementation of our methodology required the development of MATLAB codes for the construction of theoretical models and computational algorithms so that the attenuation of the sound could be calculated and illustrated. We established the necessary constants like depth (z), salinity (S), and temperature (T) and additionally inserted the specific frequency range components. Subsequently, we utilized MATLAB's built-in functions to compute attenuation values for each formula across the frequency range.

After the computations, we used MATLAB's plotting functions to generate visualizations of how the attenuation from Thorp formula, Schulkin & Marsh formula, and Francois & Garrison formula compared to each other. This facilitated a comprehensive comparison of the different approaches and provided insight into their relative accuracy and applicability under various conditions. The thorp formula to calculate the attenuation co-efficient is valid on frequencies between 100Hz and 3KHz. Frequency higher than 3KHz is observed to have a constant sound attenuation. The formula is given as.
Thorp's formula:

$$\alpha_w = \frac{0.11 f^2}{1+f^2} + \frac{44 f^2}{4100+f^2}\ [dB/km]\ with\ f\ in\ [kHz]$$

The Schulkin and Marsh formula applies for the frequency range of 3 kHz to 0.5 MHz. The formula is given as.
Schulkin and Marsh formula:

$$\alpha_w = 8.686.10^3 (\frac{SAf_T f^2}{f_T^2+f^2} + \frac{Bf^2}{f_T})(1-6.54.10^{-4}P)[dB/km]$$

where
$A = 2.34.10^{-6}, B = 3.38.10^{-6}, S\ in\ [ppt], fin[kHz]$

The relaxation frequency.
$f_T = 21.9.10^{6-1520/(T+273)}$ with T in[C]

and the hydrostatic pressure is determined by
$P = 1.01(1+z.0.1)\ in\ [kg/cm^2 = at]$

The Francois and Garrison formula consist of the contribution of boric acid, magnesium sulphate, and pure water viscosity. The formula is valid from 100 Hz to 1 MHz frequency range and the formula is given as.
Francois and Garrison formula :

$$\alpha_w = \frac{A_1 P_1 f_1 f^2}{f_1^2+f^2} + \frac{A_2 P_2 f_2 f^2}{f_2^2+f^2} + A_3 P_3 f^2\ [dB/km]$$

The coefficients for the contribution of

$Boricacid,\ B(OH)_3$
$A_1 = \frac{8.686}{c} 10^{0.78ph-5}, f_1 = 2.8\sqrt{\frac{S}{35}}.10^{4-\frac{1245}{T+273}}$

$P_1 = 1, c = 1412 + 3.21T + 1.19S + 0.0167z_{max}$

$Magnesiumsulphate, MgSO_4$
$A_2 = 21.44\frac{S}{c}(1+0.025T), f_2 = \frac{8.17.10^{8-1990/(T+273)}}{1+0.0018(S-35)}$

$p_2 = 1 - 1.37.10^{-4} Z_{max} + 6.2.10^{-}9.Z_{max}^2$

Pure water viscosity

$$A_3 = 4.937.10^{-4} - 2.59.10^{-5}T + 9.11.10^{-7}T^2 - 1.5.10^{-8}T^3 forT \leq 20C$$

$$A_3 = 3.964.10^{-4} - 1.146.10^{-5}T + 1.45.10^{-7}T^2 - 6.5.10^{-10}T^3 forT \geq 20C$$

$$P_3 = 1 - 3.83.10^{-5} Z_{max} + 4.9.10^{-10} Z_{max}^2$$

We also performed a detailed analysis of the frequency, salinity, and temperature dependencies of sound attenuation based on the Francois & Garrison formula. This task involved a systematic variation of these parameters within the relevant ranges, and the next step was to plot the corresponding attenuation values to examine the effect of each of these parameters. The careful implementation of the experiment and data analysis led us to reveal the intricate relationship between these factors and their effect on sound transmission in seawater.

IV. Results and Discussions

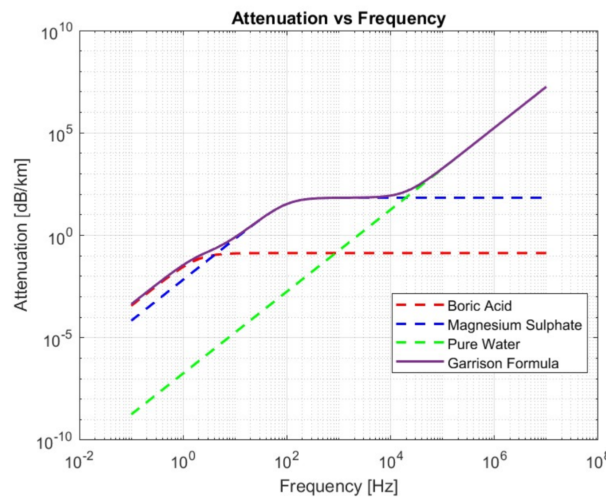

Fig. 1. Frequency dependence of the different attenuation processes employed in the Francois-Garrison model

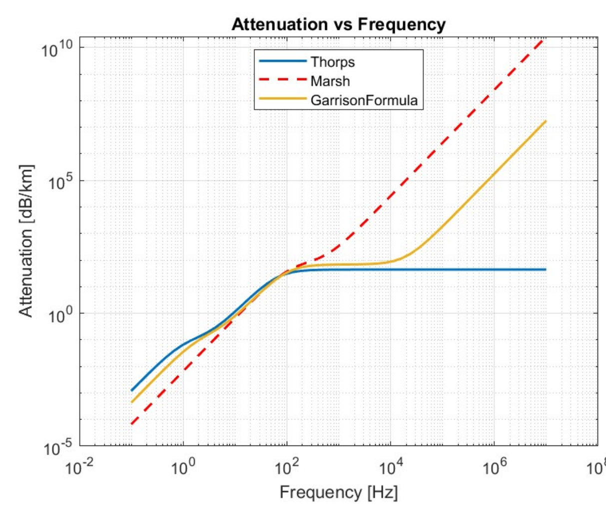

Fig. 2. Comparison of the Thorp, Schulkin-Marsh and Francois-Garrison Attenuation Formulae

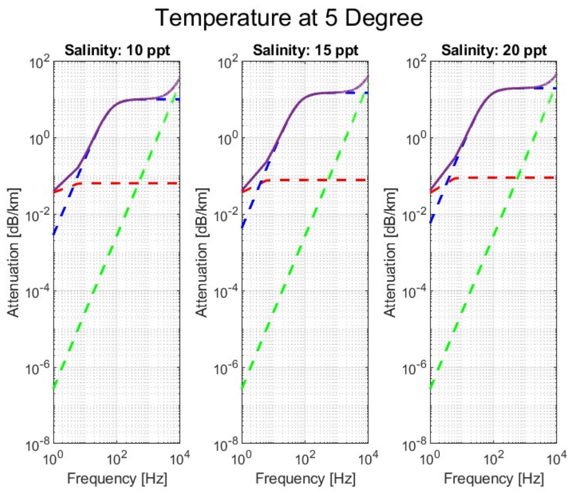

Fig. 3. Sound attenuation over varying salinity and fixed temperature using Francois and Garrison formula

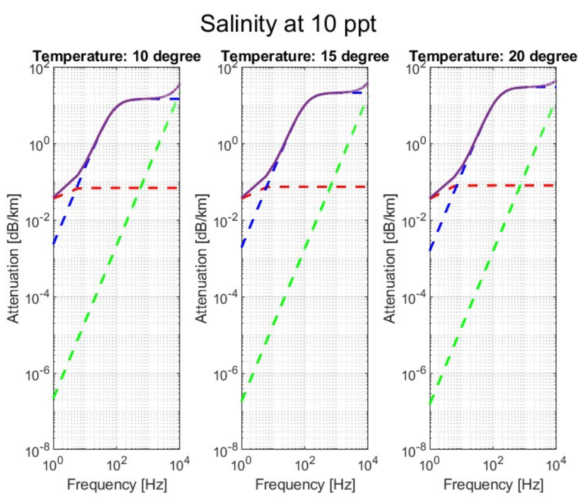

Fig. 4. Sound attenuation over varying temperature and fixed salinity using Francois and Garrison formula

The attenuation of sound applies to phenomena that occur in a seawater medium and are related to a reduction in the sound intensity as the sound propagates through the water. This is observed as a result of different physical mechanisms that lose, scatter, or change sound energy into other forms of energy such as heat energy. Absorption: The sound waves are transferred to the nearest water molecules and then the vibration generates heat as this last reaction goes on. The absorption coefficient may vary with such as frequency, temperature, salinity, and pressure. Scattering: The interference between the sound waves requires minute particles, bubbles, or a density variation, which causes them to change direction and expend some energy. Scattering allows for a rain of different directions; it becomes impossible to follow the path of coherent energy propagation. Attenuation due to Chemicals: Substances such as gas, salt, and other substances that exist in the sea solution can be the main factor that affects the sound propagation because these compounds reduce the physical in the water column. For example, the acoustic properties of these gases could strongly suppress sound propagation in specific frequency ranges.

Sound Attenuation can be determined by using below three formulas based on different parameters.

The calculation of the attenuation coefficient of seawater can be made by Thorp's equation that involves absorption of dissolved substances. It is ensured by but not limited to temperature, salinity and accordingly, depth and can be simply demonstrated as the function of frequency.

Thorps, Marsh, and Garrison Sound attenuation in seawater at some conditions such as temperature 15 ° C and salinity 35 parts per thousand (ppt) includes intricate relationships of physical and chemical aspects. The noise reduction underwater is affected by factors including temperature, salinity, pressure, and frequency. At 15 ° C temperature and 35 ppt salinity, the seawater becomes acoustically unique, which then influences the sound propagation. Thorps, Marsh, and Garrison Sound Attenuation models embody the three factors in detail to show how sound energy decays with the increase in distance of a sound wave through seawater. Temperature is a parameter that has a great impact on sound reduction in seawater. While the temperature increase, the speed of sound in water vary as well which affects the sound absorption in water. Nevertheless, regarding the 15°C temperature, the effects of the sound attenuation are moderately affected by the temperature, compared to the extreme temperatures of higher or lower than 15 ° C. Similarly, although even minor changes in the temperature of the water could make it denser and more viscous, they can still affect the propagation of sound.

The other factor, salinity, that is, the concentration of dissolved salts in seawater, is also very important. The seawater density of 35 ppt with higher sound speed and speed of sound makes it distinctive from fresh waters.

The Thorps, Marsh, and Garrison Sound Attenuation models, which take into account the frequency dependent properties, are used to precisely predict sound propagation in underwater environments.

The sound damping due to the variations in temperature and salinity was determined with the help of the garrison formula. The formula by Garrison allows for the inclusion of the specific parameters that are necessary for the calculation of the attenuation coefficient, which is a measure of the rate at which sound energy decreases as it passes through seawater.

By varying temperature and salinity, the sound attenuation was determined using the garrison formula. The Garrison formula incorporates these parameters to calculate the attenuation coefficient, representing the rate at which sound energy dissipates as it travels through seawater. At a temperature of 10 ° and a salinity level of 10 ppt, the sound attenuation was observed. The lower temperature and salinity levels indicated the higher attenuation of sound due to the increased viscosity and density of the water. Due to this, energy is absorbed and scattered more which causes a decrease in the speed of sound over a distance.

At 15 ° C temperature and 10 ppt salinity, the Garrison formula predicted a slightly different attenuation coefficient compared to the 10°C scenario. With a moderate increase in temperature, the speed of sound in seawater rises, influencing attenuation behavior. Additionally, the salinity level of 10 ppt maintains a similar density profile, affecting sound propagation similarly to the previous case but with minor variations due to the temperature change. Similarly, at 20 ° C temperature and 10 ppt salinity, the Garrison formula anticipates further adjustments in the properties of sound attenuation. The higher temperature accelerates the speed of sound in the water, potentially reducing the attenuation coefficients compared to lower-temperature scenarios. sound attenuation at 5°C temperature and varying salinities (10 ppt, 15 ppt, 20 ppt), the Garrison formula adapts to colder water conditions. Lower temperatures typically increase the density and viscosity of seawater, enhancing attenuation effects. Meanwhile, changes in salinity introduce additional complexities, altering the acoustic impedance of the medium and further influencing the sound propagation characteristics.

At salinity level 10ppt and different temperatures(10,15,20) degrees. From the plot, we can observe that at a temperature of 10 degrees, the sound attenuation is constant at around 100 Hz. However, if the temperature increases, the sound attenuation also increases which means the temperature and frequency behave like directly proportional to each other.

In summary, determining sound attenuation using the Garrison formula across different temperature and salinity combinations provides insights into how environmental factors affect underwater sound propagation. By accounting for variations in temperature and salinity, researchers can better understand and predict acoustic behaviors in diverse marine environments, contributing to various applications such as underwater communication, navigation, and marine biology studies.

REFERENCES

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APPENDIX A
MATLAB CODE1

```
f = logspace(-1,7);
depth = 50;
temp = 15; % Assuming temperature in C
salinity = 35; % Assuming salinity in ppt
aw = (((0.11 .* f.^2)./(1 + f.^2)) + ((44
     .* f.^2)./(4100 + f.^2)));

% No need for disp() here
% disp(aw)

%Marsh Formula
freq = logspace(-1,7);

A = 2.34 .* 10.^-6;
B = 3.38 .* 10.^-6;
Z = (6-(1520./(temp+273)));
Ft = 21.19 .* (10^Z);
P = 1.01 .* (1 + 0.1 .* depth);
aw_Marsh = (8.686 .* 10.^3) * ((((
    salinity .* A .* Ft .* freq.^2)./(Ft
    .^2 + freq.^2)) + ((B .* freq.^2)./Ft)
    )) .* (1 - P .* (6.54 .* (10.^-4 )));

% No need for disp() here
% disp(aw_Marsh);


%% Boric ACID
% Given data
ph = 7.8;
depth = 50; % Depth in meters

% Calculating C
C = 1412 + (3.21 .* temp) + (1.19 .*
    salinity) + (0.0167 .* depth);
x2 = (0.78 .* ph) - 5;

% Calculating A1
A1 = (8.686./C) .* (10.^x2);

% Calculating f1
f1 = 2.8 .* sqrt((salinity./35) .*
    (10.^(4 - (1245./(temp+273)))));

% Frequency array
frequency = logspace(-1,7); % Assuming a
    frequency range
aw_boric_acid = zeros(size(frequency));

% Calculating attenuation for Boric Acid
aw_boric_acid = ((A1 .* f1 .* frequency
    .^2)./ (f1.^2 + frequency.^2));
```

```
aw_pure_water = zeros(size(frequency));



% Magnesium Acid
A2 = 21.44 .* ((salinity./C).*(1+0.025 .*
     temp));
f2 = (8.17 .* (10.^(8 - (1990./(temp +
    273)))) / (1 + 0.0018 * (salinity -
    35)));
p2 = 1 - (1.37 .* 10.^-4 .* depth) + (6.2
     .* 10.^-9 .* depth^2);

aw_Magnesium = zeros(size(frequency));
aw_Magnesium = ((A2 .* p2 .* f2 .*
    frequency.^2)./ (f2.^2 + frequency.^2)
    );

% Pure Water Viscosity
A3 = (4.937 .* 10.^-4) - (2.59 .* 10^-5
    .* temp) + (9.11 .* 10^-7 .* temp^2) -
     (1.5 .* 10^-8 .* temp^3);
p3 = 1.383 .* 10.^(-5) .* depth + 4.9 .*
    10.^(-10) .* depth.^2;

% Calculating attenuation for Pure Water
aw_pure_water = A3 .* p3 .* frequency.^2;

% Garrison Formula
Garrison_Formula = aw_boric_acid +
    aw_Magnesium + aw_pure_water;
figure;
loglog(f,aw,'LineWidth',1.5);
hold on;
loglog(freq,aw_Marsh,'--r','LineWidth'
    ,1.5);
hold on;
loglog(frequency,Garrison_Formula,'
    linewidth',1.5);
hold off;
xlabel("Frequency [Hz]");
ylabel("Attenuation [dB/km]");
title("Attenuation vs Frequency");
grid on;
legend('Throps','Marsh','GarrisonFormula'
    ,'Location','north');

% Plotting
figure;
loglog(frequency, aw_boric_acid,'--r','
    LineWidth',1.5);
hold on;
loglog(frequency, aw_Magnesium,'--b','
    LineWidth',1.5);
hold on;
loglog(frequency, aw_pure_water,'--g','
    LineWidth',1.5);
hold on;
loglog(frequency, Garrison_Formula, '
    linewidth', 1.5);
hold off;
xlabel("Frequency [Hz]");
ylabel("Attenuation [dB/km]");
title("Attenuation vs Frequency");
legend('Boric Acid', 'Magnesium Sulphate'
    , 'Pure Water', 'Garrison Formula', '
    Location', 'northeast');
grid on;
```

APPENDIX B
MATLAB CODE2

```
frequency = linspace(1,10000,2000);
% Assuming temperature in  C
salinity = 10;
% Assuming depth in meters
depth = 50;
% Create a figure outside the loop
figure;
for t = 10:5:35 % Assuming salinity in
    ppt
    ph = 7.8;
    % Calculating C
    C = 1412 + (3.21 .* t) + (1.19 .*
        salinity) + (0.0167 .* depth);
    x2 = (0.78 .* ph) - 5;
    % Calculating A1
    A1 = (8.686./C) .* (10.^x2);
    % Calculating f1
    f1 = 2.8 .* sqrt((salinity./35) .*
        (10.^(4 - (1245./(t+273)))));
    % Frequency array
    % Assuming a frequency range
    aw_boric_acid = zeros(size(frequency)
        );
    % Calculating attenuation for Boric
        Acid
    aw_boric_acid = ((A1 .* f1 .*
        frequency.^2)./ (f1.^2 + frequency
        .^2));
    aw_pure_water = zeros(size(frequency)
        );
    % Magnesium Acid
    A2 = 21.44 .* ((salinity./C)
        .*(1+0.025 .* t));
    f2 = (8.17 .* (10.^(8 - (1990./(t +
        273)))) / (1 + 0.0018 * (salinity
        - 35)));
    p2 = 1 - (1.37 .* 10.^-4 .* depth) +
        (6.2 .* 10.^-9 .* depth^2);
```

```
    aw_Magnesium = zeros(size(frequency));
    aw_Magnesium = ((A2 .* p2 .* f2 .* frequency.^2)./ (f2.^2 + frequency.^2));
    % Pure Water Viscosity
    A3 = (4.937 .* 10.^-4) - (2.59 .* 10^-5 .* t) + (9.11 .* 10^-7 .* t^2) - (1.5 .* 10^-8 .* t^3);
    p3 = 1.383 .* 10.^(-5) .* depth + 4.9 .* 10.^(-10) .* depth.^2;
    % Calculating attenuation for Pure Water
    aw_pure_water = A3 .* p3 .* frequency.^2;
    Garrison_Formula = aw_boric_acid + aw_Magnesium + aw_pure_water;
    % Plotting in subplots
    subplot(1,3,t/5-1); % Adjust subplot index according to the salinity range
    loglog(frequency, aw_boric_acid,'--r','LineWidth',1.5);
    hold on;
    loglog(frequency, aw_Magnesium,'--b','LineWidth',1.5);
    hold on;
    loglog(frequency, aw_pure_water,'--g','LineWidth',1.5);
    hold on;
    loglog(frequency,Garrison_Formula,'linewidth',1.5);
    xlabel("Frequency [Hz]");
    ylabel("Attenuation [dB/km]");
    title(sprintf("Temperature: %d degree", t));
    sgtitle(sprintf("Salinity at %d ppt", salinity));
    grid on;
    hold off;
end
 legend('Boric Acid', 'Magnesium Sulphate', 'Pure Water', 'Location', 'northeast');
```