

Computation of the Total Acoustic Atmospheric Attenuation Coefficient A_a for Several Acoustic Sources in Tikrit City



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Abstract:

In this work, the attenuation coefficients A_a had determined for different acoustic source by the air atmosphere for one day in Tikrit city, based on an analytical method which employed on several empirical equations that taking in consideration the various meteorological conditions in which the climate elements changed in additional to frequencies sources. The results shows the atmospheric attenuation is sensitive to the composition of air, particularly to the wide varying concentration of water vapor and temperature where the air temperature play and frequency variation are dominate that controlling the values of A_a .

Keywords: *acoustic attenuation coefficients, Atmospheric absorption, relative humidity, temperature, pressure, Oxygen and Nitrogen relaxation frequencies*

Introduction:

When the acoustic wave propagates, all its energy is converted into random thermal energy. The sources of this dissipation may be divided into two general categories:

(1) those intrinsic to the medium and (2) those associated with boundaries of the medium. Losses in the medium may be further subdivided into the basic types: viscous losses, heat conduction losses, and losses associated with internal molecular processes. Viscous losses occurs whenever there is relative motion between adjacent portions of the medium, such as during compressions and expansions that accompany the transmission of a sound wave. Heat conduction losses results from conduction of thermal energy from higher temperature condensations to lower temperature rarefactions. The molecular processes leading to absorption include the conversion of kinetic energy of molecules into [1]:

(1) Stored potential energy (as the structural rearrangement of adjacent molecules in some cluster).

(2) Rotational and vibrational energies (for polyatomic molecules).

In a real atmosphere, the sound propagation deviates from spherical wave

diffusion due to a number of factors, including absorption of sound in air, non-uniformity of the propagation medium due to meteorological conditions (refraction and turbulence), and interaction with an absorbing ground and solid obstacles such as barriers [2].

Stokes [3] developed the first successful theory of sound absorption due to effect of molecular viscosity of a fluid. Tyndall [4] experimentally investigated sound propagation in aerosols like fog. Rayleigh [5] estimated the scattering effect of small spherical obstacles in a non-viscous atmosphere and showed that the effect depends on the number of scattering particles and the ratio of their diameter to the wavelength of the sound. Sewell [6] studied theoretically the attenuation of sound in a viscous medium containing suspended cylindrical and spherical particles (obstacles). Dennis A. Bohn [7] studied analytically the environmental effects like temperature and humidity on the acoustic absorption. Gavin R. [8] used a simple algebraic formulas for calculating the linear acoustical properties of air, except the absorption coefficient, in terms of ambient temperature and pressure. Scott Penton et al [9] illustrates the meteorological effects on predicted noise

levels reduction, by comparing modeling results from five calculation algorithms, including basic modeling (considering distance attenuation and barrier effects only). Dennis A. Bohn[10] expands, and clarifies the environmental effects of temperature and humidity on the speed of sound. These effects increase the speed of sound and complicate the task of room equalization immensely. The aim of this study is to determine the acoustic attenuation coefficient by atmosphere components for frequency range 50Hz to 8000Hz in a summer day in Tikrit city by depending on a global empirical method given by [11].

The Meteorological elements affecting the outdoor sound propagation:

The atmosphere basically consists of has two-component system, one component is dry air and the other is water existing in vapor phase may one of the condensed phases (liquid water or ice). Table (1) shows the stable and unstable gaseous components of the atmosphere.

Table 1: Composition of atmospheric gases [12].

Constant configuration (Values stable over time and place)	
Nitrogen (N ₂)	78.08 %
Oxygen (O ₂)	20.95 %
Argon (Ar)	0.93 %
Neon, helium, krypton	0.0001 %
Variable configuration (Values unstable over time and place)	
Carbon dioxide (CO ₂)	0.039 %
Water vapor (H ₂ O)	0 to 4 %
Methane (CH ₄)	traces
Sulfur dioxide (SO ₂)	traces
Ozone (O ₃)	traces
Nitrogen oxides (NO, NO ₂)	traces

In the next section, we review all the atmospheric parameters that affect sound propagation as follow.

Turbulence:

Turbulence causes scattering of sound and results in short-term temporal variations in sound levels. This means that when sound propagates through turbulent air, the sound levels will fluctuate by several decibels even when there is no change in the acoustic source frequency and other meteorological conditions are stable. Since atmospheric conditions are never completely stable, the combination of turbulence and wind fluctuations causes the sound levels at distances of 400 m or greater from a sound source to constantly varying, in other word, the distance proportional to the fluctuations where the maximum fluctuation is about ± 6 dB[13].

Humidity (H)dependence:

It is important to know the saturation condition of air i.e. how far its removed from its saturation limit. In other words, the important factor is not the actual amount of water vapor present in air but its closeness to the saturation value. The degree of saturation of the air determines its Relative Humidity H and defined by [14]:

$$H = \left(\frac{\text{density of water vapour present in air}}{\text{density of the saturated air at the same temperature}} \right) 100\%$$

Since both volumes are equal, the above equation can reduce to in the form

$$H = \left(\frac{m}{M} \right) 100\%$$

Where m is the mass of water vapor present in the air and M is the mass of saturated atmospheric air and here H is a dimensionless quantity.

Frequency dependence:

The frequency (f), which is the number of pressure variation cycles in the medium per unit time, or simply, the number of cycles per second, and is expressed in Hertz (Hz). Audible range is usually composed of many frequencies(20Hz-20KHz) combined together[15].

Pressure Dependence:

Atmospheric pressure, also called barometric pressure, force per unit area exerted by an atmospheric column (that is, the source of air above the specified area). Atmospheric pressure can be measured with a mercury barometer (hence the commonly used synonym *barometric pressure*), which indicates the height of a column of mercury that exactly balances the weight of the column of atmosphere over the barometer[15]. As a pure tone sound propagate through atmosphere over a distance r , the sound pressure amplitude p_T decreases exponentially [11].

$$p_T = p_i \exp(-0.1151\alpha r)$$

Where p_i is the initial value of the pressure and α is the attenuation coefficient of sound.

Temperature dependence:

When a gas (here air) is heated at constant pressure, its volume increases and its density is decreased, because of this decrease in density, velocity increased with the rise in air temperature [16]:

$$v_T = 331.3 \text{ m/sec} \sqrt{1 + \frac{T}{273.15^\circ \text{C}}}$$

Where 331 m/sec is the speed of sound in air at 0 °C and T is the temperature of air in degree Celsius. Hence the increase in velocity for an increment of 1 °C is 0.61 m/sec. We note the percentages of gases from table 1 that diatomic molecules and carbon dioxide each have two degree of rotational freedom, fully excited at room temperature. Water vapor has three rotational degrees, but due to its low concentration (even at high relative humidity) contributes only slightly to the rotational component of specific volume heat capacity of air [1].

Theoretical aspects:

To certain degree, everything absorbs sound, especially air, wet air absorbs sound better than dry air. The predominant mechanism of absorption (the classical and rotational relaxation) proportional to the square of frequency. The vibration relaxation effect depends on the relaxation frequencies of the gas constituents (O₂ 20.96% and N₂

78.03%) and is highly dependent on the relative humidity[2]. The mechanism for acoustic attenuation can be predicted by account the internal structure of the air molecules and interactions between them that lead to internal vibrations, rotations and short-range ordering. The oldest and most successful of many approaches to this problem is that treating molecular thermal relaxation in gases composed of polyatomic molecules. In the thermal relaxation theory it is acknowledged that in addition to the three degrees of translational freedom each molecule possess, there are also internal degrees of freedom associated with rotation and vibration. The time necessary for energy to be transferred from translational motion of the molecule into internal states compared to the period of the acoustic process determines how much acoustic energy will converted to thermal energy during the transitions. If the period of the acoustic excitation is long compared to the relaxation time τ of the internal energy state ($\omega\tau \ll 1$), then the state can be fully populated ; the phase lag is finite but small, so the fraction of energy lost is very small, so the fraction of energy lost is very small over each period of the motion [17]. On the other hand, if the acoustic period is much shorter than the before condition ($\omega\tau \gg 1$), the internal energy state cannot be heavily populated before conditions are reversed, and the energy loss over each period will also be small [1]. The related equation for computing A_α is given by [11]:

$$\alpha = 8.69 \times f^2 [1.84 \times 10^{-11} \left(\frac{p_a}{p_r}\right)^{-1} \left(\frac{T}{T_0}\right)^{\frac{1}{2}} + \left(\frac{T}{T_0}\right)^{\frac{5}{2}} \left[0.01275 \frac{e^{\frac{22391}{T}}}{f_{r,O} + f^2/f_{r,O}} + 0.1068 \frac{e^{\frac{3352}{T}}}{f_{r,N} + f^2/f_{r,N}} \right] \text{ Hz}$$

Where $f_{r,O}$ and $f_{r,N}$ are the oxygen and Nitrogen relaxation frequencies respectively which are defined as below:

$$f_{r,O} = \left(\frac{p_a}{p_r}\right) [24 + 4.04 \times 10^4 H \frac{0.02 + H}{0.391 + H}] \text{ Hz}$$

And the Nitrogen relaxation frequency is given by

$$f_{r,N} = \left(\frac{1}{p_r}\right) \left(\frac{T}{T_0}\right)^{-1/2} \left(9 + 280H \exp(-4.17\{(\frac{T}{T_0})^{-1/3} - 1\})\right)$$

In equations 6 and 7 the symbol H is the molar concentration of water vapor (absolute humidity) in percent is calculated from the relative humidity H_r as follows:

$$H = p_r \left(\frac{H_r}{p_a}\right) \left(\frac{p_{sat}}{p_r}\right) \%$$

Where the saturated vapor pressure p_{sat} is given by:

$$p_{sat} = p_r \times 10^{\left[-6.8346\left(\frac{T_{01}}{T}\right)^{1.261} + 4.6151\right]}$$

The symbols are defined as:

T_0 = reference temperature 293.15 K (20°C).

T = ambient atmosphere temperature in Kelvin scale.

$T_{01} = 273.16K$

p_r = reference ambient atmosphere pressure = 101.325kPa.

p_a = ambient atmosphere pressure in pas.

H = Relative Humidity.

f = frequency source.

$f_{r,O}$ and $f_{r,N}$ are the oxygen and Nitrogen relaxation frequencies.

The total attenuation A_α measured in decibels due to atmosphere attenuation at a distance r in the level of a pure tone with frequency f at the initial level at $r=0$ to level at range of r , is given by [11]:

$$A_\alpha = \alpha r / 1000 \text{ dB/Km}$$

Here in the calculations, we presumed the attenuation distance equals to $r=1000m$.

Results and Discussion:

All the meteorological data employed throughout this work has been taken from [18] for one day 27/7/2013 in Tikrit city. And the frequencies ranges are used here taken from [14] with a some approximations as given in Table (2).

Table2: The Sources types and frequencies ranges with some approximations [16].

Sound Source	Frequency Ranges (Hz)
Motor cycle	50→150
Rifle	80→140
Urban Traffic	50→800
Car horn	150→1300
Conversion	100→7500
Shouting	1000(7)→8000

As known the atmospheric attenuation is sensitive to the composition of air, particularly to the wide varying concentration of water vapor. By checking the results given in the table 3, we note that as sound source frequencies are increased (8) the acoustic attenuation coefficient According to the equations (5) and (10). By comparison the obtained results of attenuation coefficients, in the first two column, we found that these coefficients decreased with increasing the relative humidity and this behavior (9) or satisfying the equations(6) and (7) which are influence directly on the relaxation frequencies of both nitrogen and oxygen (increasing the relaxation frequencies) and this behavior applied for all columns in the same table.

It is interesting to note that the absorption increases rapidly with temperature, water vapor appears to act as a catalyst, increasing the relaxation frequencies associated with vibrational states of N_2 and O_2 , in other words, from the table 3, we note that the A_α increases with increasing temperature in all the meteorological conditions which, reflects the fact that the temperature play an important role in variation of A_α . Oxygen and water vapor collisions exciting the O_2 vibrational states and assume greatest importance for absorption at frequencies between about 100Hz to 1KHz. (10) In a very dry air the collisions with water vapor become unimportant, and collisions of N_2 with CO_2 become important and since the moist air is lighter than dry air, the velocity of sound is greater in moist air than in dry air. Moisture also causes the specific-heat ratio to decrease, which would cause the speed of sound to decrease. However, the decrease in density dominates, so the speed of sound increases with increasing moisture. We note as frequency increases the attenuation coefficient increases while the relation is

inversely with temperature, humidity and pressure respectively. Finally All the model equations employed here [11] are applicable only for steady meteorological conditions, in other words this formulas are applicable only

in clear day, when there are no fog, storms, hurricanes and rain because the model equations are not included specific parameter related to metrological factors mentioned above

Table 3: The Meteorological data and acoustic attenuation coefficients.

Sound Source	Climate conditions (pressure p in Pas, Air temperature T in centigrade, relative humidity H percent)	Attenuation coefficients ranges A_{α} (dB/Km)
Motor cycle	p =100245.105pas T=33 °C, H= 9 %	0.2543↔1.24729
Rifle		0.5558↔1.15899
Urban Traffic		0.2543↔6.324531
Car horn		1.24729↔13.4434
Conversion		0.76743↔250.87
Shouting		8.79↔271.91266
Motor cycle	p =99845.137pas T=33 °C, H= 17 %	0.14982↔1.04186
Rifle		0.36248↔1.145765
Urban Traffic		0.14982↔5.239158
Car horn		1.041866↔8.600
Conversion		0.53921↔158.888
Shouting		6.43514↔178.1262
Motor cycle	p =99845.137pas T=41 °C, H= 7 %,	0.268335↔1.49146
Rifle		0.61089↔1.327927
Urban Traffic		0.268315↔6.73723
Car horn		1.491465↔13.12319
Conversion		0.86717↔258.82122
Shouting		8.952↔284.32924
Motor cycle	p =99205.167pas T=43 °C, H= 6 %,	0.2955781↔1.58388
Rifle		0.6654↔1.462423
Urban Traffic		0.295578↔7.19169
Car horn		1.58388↔14.28653
Conversion		0.93714↔275.807
Shouting		9.65137↔301.704

Conclusions:

- Atmospheric attenuation of sound is important for outdoor sound propagation. Weather changes over the day and the year, and this alters the atmospheric attenuation. The size of the daily variances was frequency-dependent.
- The most accurate information about atmospheric absorption climate is achieved if the study continuous for long time to include all.

- The most powerful parameters that influences the fluctuations of A_{α} is that the air temperature with frequency-dependent to all sources.
- The formulas presented may be regarded as adequate for the modeling of small acoustic sources in which atmospheric attenuation of sound waves is not significant.

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