Int. J. Chem. Sci.: 14(3), 2016, 1225-1235
ISSN 0972-768X
www.sadgurupublications.com

INVESTIGATION OF THE TOTAL ABSORPTION ACOUSTIC COEFFICIENTS IN ZOBEAR CITY

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ABSTRACT

The aim of this paper to present a mathematical model to study the metrological parameters effects on the total absorption coefficients A_{α}, which calculated for different acoustic sources for one day in Zobear city, based on several empirical equations. The results shows the atmospheric absorption is sensitive to the composition of air, particularly to the wide varying concentration of water vapor and temperature variance where the air temperature plays and frequency variation are dominate that controlling the values of A_{α}.

Key words: Total acoustic absorption coefficients, Atmospheric absorption, Relative humidity, Temperature, Pressure.

INTRODUCTION

As an acoustic wave propagates, all it is energy is converted into random thermal energy. The sources of this dissipation may divide into two general categories.

Those intrinsic to the medium and 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]:

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

(ii) 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). Bohn[7] studied analytically the environmental effects like temperature and humidity on the acoustic absorption. Gavin[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. Penton et al.[9] illustrate 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). Bohn[10] expanded, and clarified 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 50 Hz to 8000 Hz in a summer day in Tikrit city by depending on a global empirical method given by[11], which take account the meteorological parameters (pressure-temperature-relative humidity) that influence A_α values.

EXPERIMENTAL

The meteorological elements affecting the outdoor sound propagation

Sound wave propagation is determined by the inertial, restoring and loss parameters of the medium. Density and compressibility determine sound speed, variations of which result in refraction. Spatial fluctuations in either density or compressibility (which together determine characteristic acoustic impedance), or sound absorption, may give rise to scattering or reflection[13]. Meteorological conditions can have important effects on sound propagation in air as a wave in an elastic medium. Since air is not a perfectly elastic medium, this pulsating action causes several complex irreversible process occurs[7]. For relatively short source-receiver distances, these effects are small and generally ignored, as a conservative assumption. However, when considering sound (noise) impacts from large industrial complexes, such as petrochemical facilities and electrical power plants, the potential impact zone and corresponding source-receiver distances can be quite large (> 2 Km). No including meteorological and terrain effects can result in severe over- or underestimations of off-site sound levels, affecting mitigation requirements and project costs[9]. 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[13]

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_2O)	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[14].

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[15]:

$$H = \left(\frac{\text{Density of water vapour present in air}}{\text{Density of the saturated air at the same temperature}} \right) 100\% \qquad \ldots(1)$$

Since both volumes are equal, the above equation can be reduced to the form –

$$H = \left(\frac{m}{M} \right) 100\% \qquad \ldots(2)$$

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 (20 Hz-20 KHz) combined together[16].

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[16]. As a pure tone sound propagate through atmosphere over a distance r, the sound pressure amplitude p_T decreases exponentially[11].

$$p_T = p_i \exp(-0.1151\, \alpha r) \qquad \ldots(3)$$

Where p_i is the initial value of the pressure and α is the attenuation coefficient of sound for frequency and meteorological state.

Temperature dependence

As a fluid (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[17]:

$$V_T = 331.3 \text{ m/sec } \sqrt{1 + \frac{T}{273.15^{\circ}\text{C}}} \quad \ldots(4)$$

Where 331.3 m/sec is the speed of sound in air at 0^{o}C and T is the temperature of air in degree Celsius. Hence the increase in velocity for an increment of 1^{o}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].

Methodology

It is known that 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 (O_2 20.96% and N_2 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[18]. On the other hand, if the acoustic period is much shorter than the before condition ($\omega\tau >> 1$), 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]:

$$\alpha = 8.69 \times f^2 [1.84 \times 10^{-11} \left(\frac{pa}{pr}\right)^{-1} \left(\frac{T}{To}\right)^{\frac{1}{2}} + \left(\frac{T}{To}\right)^{-\frac{5}{2}} \left[0.01275 \frac{e^{\frac{22392}{T}}}{f_{r,O} + f^2/f_{r,O}} + 0.1068 \frac{e^{\frac{3352}{T}}}{f_{r,N} + f^2/f_{r,N}}\right] \quad \ldots(5)$$

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

$$f_{r,O} = \left(\frac{p_a}{p_r}\right)\left[24 + 4.04 \times 10^4 H \frac{0.02 + H}{0.391 + H}\right] Hz \quad \ldots(6)$$

And the Nitrogen relaxation frequency is given by

$$f_{r,N} = \left(\frac{1}{p_r}\right)\left(\frac{T}{T_\circ}\right)^{-1/2}\left(9 + 280\, H \exp(-4.17\{(\frac{T}{T_0})^{-\frac{1}{3}} - 1)\}\right) Hz \quad \ldots(7)$$

Where α is the distance-independent absorption coefficient and 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:

$$H = p_r \left(\frac{H_r}{p_a}\right)\left(\frac{p_{sat}}{p_r}\right) \% \quad \ldots(8)$$

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

$$p_{sat} = p_r \times 10^{\left[-6.8346\left(\frac{T_{01}}{T}\right)^{1.261} + 4.6151\right]} \quad \ldots(9)$$

The symbols are defined as –

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

T = Ambient atmosphere temperature in Kelvin scale.

T_{01} = 273.16 K

p_r = Reference ambient atmosphere pressure = 101.325 kPa.

p_a = Ambient atmosphere pressure in pas.

H = Relative humidity.

f = Frequency source.

The total absorption A_α measured in decibels due to atmosphere absorption 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]:

$$A_\alpha = \alpha\, r/1000 \text{ dB/km} \quad \ldots(10)$$

Where in this calculations, we presumed the attenuation distance equals to r = 1000 m.

RESULTS AND DISCUSSION

All the meteorological data employed throughout this work has been taken from[19] for one day 27/7/2013 in Zobear city. And the frequencies ranges are used here taken from[17] with a some approximations as given in Fig. 1.

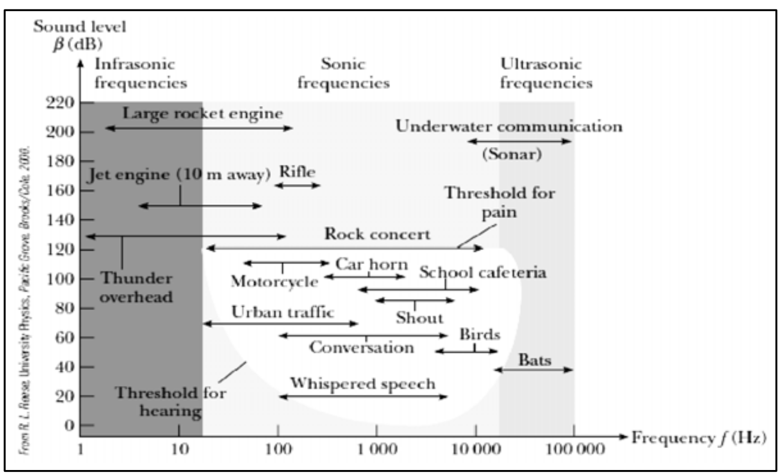

Fig. 1: Approximate frequency and sound level ranges of various sources and that of normal human hearing, shown by the white area[17]

As known the atmospheric absorption is sensitive to the composition of air, particularly to the wide varying concentration of water vapor. By checking the results given in the Table 2.

Table 2: The meteorological data and acoustic absorption coefficients

Sound source	Climate conditions (pressure p in Pas, Air temperature T in centigrade, relative humidity H percent)	Absorption coefficients ranges A_α (dB/km)
Motor cycle	p = 100338.1372 pas T= 26^{o}C, H = 47%	0.07 ↔ 0.57555
Rifle		0.175 ↔ 0.5077
Urban traffic		0.07 ↔ 4.9367
Car horn		0.57555 ↔ 7.04974
Conversion		0.2704 ↔ 79.6227
Shouting		5.7995 ↔ 89.6384
Motor cycle	p = 100244.18 pas T = 29^{o}C, H = 27%	0.10844 ↔ 0.81877
Rifle		0.26751 ↔ 0.730149
Urban traffic		0.10844 ↔ 4.8877
Car horn		0.81877 ↔ 7.44103
Conversion		0.40446 ↔ 118.529
Shouting		5.830 ↔ 133.420
Motor cycle	p = 100338.137 pas T = 39^{o}C, H = 9%, h =	0.22492 ↔ 1.3654
Rifle		0.52527 ↔ 1.24693
Urban traffic		0.22492 ↔ 6.16186
Car horn		1.3654 ↔ 11.2944
Conversion		0.75982 ↔ 225.607
Shouting		7.950136 ↔ 250.1053
Motor cycle	p = 100045.105 pas T = 43^{o}C, H = 8%	0.21839 ↔ 1.4699
Rifle		0.5241 ↔ 1.32832
Urban traffic		0.21839 ↔ 6.87981
Car horn		1.4699 ↔ 11.40
Conversion		0.7746 ↔ 208.645
Shouting		8.492 ↔ 233.095

We note that as sound source frequencies are increased the acoustic absorption coefficient according to the equations (5) and (10). By comparison the obtained results of absorption coefficients, in the first two column, we found that these coefficients decreased with increasing the relative humidity and this behavior satisfying the equations (6) and (7), which are influence directly on the relaxation frequencies of both nitrogen and oxygen (increasing the relaxation frequencies) and in turn the attenuation coefficient will increases and this behavior applied for all data 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 2, 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 100 Hz to 1 KHz. 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 absorption coefficient increases while the relation is inversely with temperature, humidity and pressure respectively. Finally All the model equations employed here[11,20-22] 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.

CONCLUSION

(i) Absorption works with divergence. Divergence of sound causes a reduction in the sound intensity due to spreading of the acoustic wave throughout the medium.

(ii) Absorption describes the energy-exchanging mechanism occurring during the sound divergence, so not only the wave spreading, it is also dying.

(iii) Atmospheric absorption 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.

(iv) The most accurate information about atmospheric absorption climate is achieved if the study continuous for long time to include all.

(v) The most powerful parameters that influences the fluctuations of A_α is that the air temperature with frequency-dependent to all sources.

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Revised : 17.03.2016 *Accepted : 20.03.2016*