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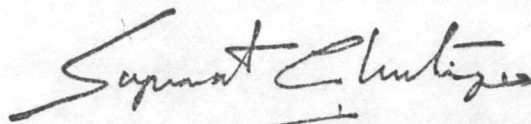
**PREDICTION OF NOISE EMISSION FROM POWER PLANT BY
A MATHEMATICAL MODEL**

MISS KRITTIKA LERTSAWAT

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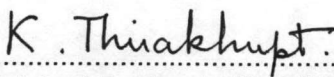
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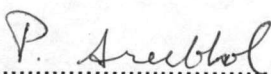


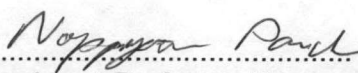
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หลักการแพร่กระจายของเสียงภายนอกอาคารถูกนำมาใช้พัฒนาแบบจำลองคณิตศาสตร์ในการทำนายค่าระดับเสียงจากโรงไฟฟ้ากังหันแก๊ส เพื่ออธิบายค่าความไม่แน่นอนของแบบจำลองคณิตศาสตร์ มีการตรวจวัดระดับความดันเสียง (Sound Pressure Level, SPL) ณ โรงไฟฟ้าระยอง ในช่วงฤดูแล้ง ตามมาตรฐาน ISO1996/1 และ Equals Angle Method คำนวณค่าระดับกำลังเสียง (Sound Power Level, PWL) ของแหล่งกำเนิดเสียงตามมาตรฐาน ISO 3476 การตรวจวัดและการคำนวณเพื่อพิจารณาเลือกแหล่งกำเนิดเสียงที่สำคัญในการใช้แบบจำลองคณิตศาสตร์ ใช้วิธีการหาค่า PWL ของแหล่งกำเนิดเสียงหลักจากการตรวจวัด SPL ภายนอกอาคาร แหล่งกำเนิดเสียงที่สำคัญที่ใช้คือ อาคารแหล่งกำเนิดเสียงหลัก (Main Building) และหอหล่อเย็น (Cooling Tower) คำนวณ PWL ของแหล่งกำเนิดเสียงทั้งสองโดยใช้วิธีการของ Colenbrander และวิธี Area Surface ตามลำดับ ค่า PWL ของอาคารแหล่งกำเนิดเสียงหลักส่วนซ้าย ขวา และ ตรงกลาง มีค่าเท่ากับ 114.7, 112.9, และ 118.2 เดซิเบล ตามลำดับ ค่า PWL ของอาคารหอหล่อเย็น มีค่าเท่ากับ 116.7 เดซิเบล ในขณะที่ทำการตรวจวัด SPL ณ จุดรับเสียงใด ๆ ภายนอกอาคาร ได้ทำการเก็บค่าข้อมูลของค่าแก้ไขระหว่างทางเดินเสียงในแต่ละเส้นทางเดินเสียงในสิ่งแวดล้อมไปด้วย

ผู้ทำการศึกษาได้พัฒนาโปรแกรมคอมพิวเตอร์ด้วยโปรแกรมภาษา Visual Basic เพื่อช่วยการคำนวณในแบบจำลองนี้ โปรแกรมสามารถนำค่า SPL จากการตรวจวัด เพื่อคำนวณ PWL จากแหล่งกำเนิดเสียงอุตสาหกรรม หรือค่า PWL จากข้อมูลพื้นฐานของเครื่องจักร และข้อมูลของค่าแก้ไขของเส้นทางเดินเสียงต่างๆ เพื่อใช้คำนวณค่าระดับเสียง ณ จุดใด ๆ ภายนอกอาคาร เมื่อนำค่า SPL ที่คำนวณได้เปรียบเทียบกับค่า SPL ที่ตรวจวัดได้จริง ผลการเปรียบเทียบจะนำไปใช้อธิบายระดับความถูกต้องของแบบจำลองคณิตศาสตร์นี้ จากกราฟการกระจายตัวของข้อมูลแสดงช่วงของค่าความถูกต้องของแบบจำลองคณิตศาสตร์ที่เบี่ยงเบนไปจากเส้นสมมูล เมื่อมีการพิจารณาสภาวะการณ์ที่เหมาะสมแล้ว มีค่าอยู่ในช่วง 10 เดซิเบล จากข้อมูลที่ตรวจวัดได้ นอกจากนี้ยังพบว่าที่จุดตรวจวัดระดับเสียงในเขตอิทธิพลของด้านเหนือลม ค่า SPL ที่จุดตรวจวัดมีค่าต่ำกว่าค่าที่ได้จากการคำนวณของแบบจำลองคณิตศาสตร์ และค่าแก้ไขทิศทางของแหล่งกำเนิดเสียง (Directivity) ซึ่งเกิดจากตำแหน่งที่ตั้งของแหล่งกำเนิดเสียงและสภาพแวดล้อมมีผลต่อผลการที่ทำนายได้จากแบบจำลองคณิตศาสตร์ด้วย

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The principles of outdoor sound propagation were used to develop a power plant noise prediction model in order to illustrate the accuracy level of the mathematical model. Sound Pressure Level (SPL) measurements were conducted during dry season at the Rayong Combined Cycle Power Plant (RPP) following the ISO 1996/1 and equal angle methods. Measurement and calculation methods for determining the significant sound source of the prediction model involved the determination of the Sound Power Level (PWL) using SPL measurement in outdoor environment according to ISO 3746. The representative noise sources were the main buildings and the cooling towers. The PWLs of both sound sources were calculated by Colenbrander's method and the area surface method. The PWLs of the left, right, and central parts of the main building were 114.7, 112.9, and 118.2 decibels, respectively. The PWL of the cooling tower was 116.7 decibels. During measurement at any point in the outdoor environment, the transfer function data of each transmission path were collected.

The author developed a computer program using the Visual Basic programming language in order to perform this model calculation. The program can use measured SPLs for calculating the PWL of an industrial sound source, or it can use the PWL from the machine's database and transfer function data to examine the SPL at any immission point in outdoor environment. Those predicted SPLs were compared with on-site measured SPLs. The comparison results were used to investigate the accuracy level of this model. Results showed that the accuracy level of the model is within 10 decibels from the measured data. It was also found that the measured SPL at immission positions under the influence of upwind conditions were lower than predicted levels and the directivity correction caused by source positions and the environment affects the predicted value.

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List of Symbols

Symbols	Units	Description	Location
p	Pascals	root-mean-square sound pressure	Eq.2.5
p_0	Pascals	reference root-mean-square sound pressure (2×10^{-5} Pa)	Eq.2.5
W	watts	sound power of a given source	Eq.2.6, 2.9, 2.10
W_0	watts	reference sound power (generally 10^{-12} W)	Eq.2.6
PWL, L_w	decibels	sound power level	Eq.2.6, 2.7, 2.8, 2.23, 2.31-2.37, 2.39-2.40, 2.42
SPL, L_p	decibels	sound pressure level	Eq.2.4, 2.5, 2.8, 2.15, 2.23, 2.24, 2.34-2.36, 2.40
SPL_{out}	decibels	sound pressure level outside enclosure wall	Eq.2.43, 2.44
SPL_{in}	decibels	sound pressure level inside enclosure wall	Eq.2.43, 2.44
SPL_i	decibels	Sound pressure level at an i^{th} immission point	Eq. 2.38
\overline{SPL}	decibels	Average sound pressure level at the measurement surface	Eq.2.37, 2.38
$L_p(r)$	decibels	sound pressure level at source-receiver distance	Eq.2.15
L_{pi}	decibels	sound pressure level in the measurement position no. i	Eq.2.23, 2.25
\overline{L}_p	decibels	The energy average of sound pressure level [re 20 μ Pa]	Eq.2.31-2.35
K	-	a function of the environment in which the sound source is located (to be zero in outdoor measurement)	Eq.2.7, 2.39
d	meters	distance between source and immission point	Eq.2.8, 2.15, 2.47, Table 2-18
I	W/m^2	sound intensity	Eq.2.9, 2.10
r	meters	distance far away from center of source	Eq.2.9, 2.16, 2.17, 2.40
A	-	total room absorption (sabines)	Eq.2.10
f_u	Hz	upper frequencies of octave band	Eq.2.11, 2.12, 2.13
f_l	Hz	lower frequencies of octave band	Eq.2.11, 2.12, 2.13, 2.14
f_c	Hz	central frequencies of octave band	Eq.2.12-2.14
DI_{revr}	decibels	source directivity index in the receiver direction	Eq.2.15
Ω	degree	solid angle at the source that is available for sound propagation	Eq.2.15
$A_{combined, re}$	decibels	combined attenuation from all significant propagation mechanisms between source and receiver	Eq.2.15
$L_{downwind}$	decibels	effective octave-band sound power level in the direction of propagation (re 1 picowatt)	Eq.2.16
L_{WD}	decibels	sound pressure level at an receiver shall be calculated for each point source and octave band with nominal midband frequencies from 63 Hz to 8 kHz	Eq.2.16, 2.18
A	decibels	octave-band attenuation during propagation from the point source to the receiver	Eq.2. 17
A_{div}	decibels	attenuation due to geometrical divergence	Eq.2.17
A_{atm}	decibels	attenuation due to air absorption	Eq.2.17
A_{ground}	decibels	attenuation due to the ground effect	Eq.2.17
A_{refl}	decibels	attenuation due to reflections by obstacles	Eq.2.17
A_{screen}	decibels	attenuation due to screening	Eq.2.17
A_{misc}	decibels	attenuation due to miscellaneous other effects	Eq.2.17
DC	decibels	directivity correction to the sound power level	Eq.2.19
DI	decibels	directivity index, indicated the sound pressure level of sound source in the direction of propagation under consideration exceeds that of a non-directional point source of the same power at the same distance	Eq.2.20, 2.19
K_0	-	correction index for emission into restricted solid angles or large source position correction	Eq.2.20, 2.21
L_s	decibels	Immission sound pressure level	Eq.2.23
D_s	decibels	Divergence attenuation correction	Eq.2.20
ΣD	decibels	summation of correction for noise propagation or transfer function or attenuation correction	Eq.2.22
D_{BM}	decibels	correction of meteorological effect (ground effects and air temperature)	Eq.2.25
Ω	radius	large source position angle correction (see Table 2-6)	Eq.2.21
D_L	decibels	correction of air absorption (temperature and relative humidity)	Eq.2.22
D_D	decibels	correction of reflecting obstacles	Eq.2.22
D_G	decibels	correction of residential obstacles	Eq.2.22
D_E	decibels	correction of sound screening	Eq.2.22
$L_{p(tij)}$	decibels	sound pressure level contributing via transmission path no. t from source no. j (dB re 20 μ Pa) in 1/1 octave band no. i at immission point	Eq.2.23

				(Cont.)
Symbols	Units	Description	Location	
$L_w(\Phi)_{ij}$	decibels	sound power level (dB re 1 pW) in direction Φ_i of transmission path no. t in 1/1 octave band no. 1 for source no. j	Eq.2.23	
ΔL_{tij}	decibels	transfer function value (dB) in 1/1 octave band no.i for transmission path no. t between source no. j and immission point	Eq.2.23	
$L_w(\Phi)$	decibels	horizontal directive or immission relevant sound power level in Φ direction [dB re 1pW]	Eq.2.23	
ΔL_Φ	decibels	correction for directional effects in a horizontal plane	Eq.2.24	
E		a near field correction term, always between 0 and 3 dB, dependent on the ratio between the surface areas of the reference box and the measurement box	Eq.2.24	
A	meter	Width of rectangular surface of solid surface method	Eq.2.40, 2.41	
B	meter	Length of rectangular surface of solid surface method	Eq.2.40, 2.41	
S	meters ²	measurement surface area	Eq.2.28, 2.37, 2.38, 2.39, 2.43	
S_0	meters ²	reference surface area	Eq.2.43	
K_i	decibels	environment correction in the same position	Eq.2.29	
N	-	number of measurement position	Eq.2.29	
ΔL_d	dB	correction taking into account the effect of divergence	Eq.2.25	
ΔL_a	dB	correction taking into account the effect of air absorption	Eq.2.25	
ΔL_r	dB	correction taking into account the effect of reflecting obstacles	Eq.2.25	
ΔL_s	dB	correction taking into account the effect of screening	Eq.2.25	
ΔL_v	dB	correction taking into account the effect of vegetation	Eq.2.25	
ΔL_i	dB	correction taking into account the effect of internal scattering	Eq.2.25, 2.33	
ΔL_g	dB	correction taking into account the effect of ground	Eq.2.25	
L_i	dB	sound pressure level at immission point	Eq.2.27, 2.26	
L_{pA}	dB	noise level at the reference point	Eq.2.26	
C_n	dB	adjustment for the number of measurements	Eq.2.26	
C_{ref}		adjustment for the distance different between the reference and the immission points	Eq.2.26	
ΔC_h		height correction term (Table 2.7)	Eq.2.26	
L_{WR}	dB	immission relevant sound power level of the source	Eq.2.28, 2.27, 2.29	
R_r	meters	distance between source and measuring point	Eq.2.28	
D_{bodem}	dB	Ground attenuation	Eq.2.28	
a_{lu}	dB/m	air absorption important with long distance and high frequencies	Eq.2.28	
D_{geo}	dB	attenuation in the noise level due to geometric propagation	Eq.2.30, 2.36	
D_{air}	dB	attenuation in the noise level due to absorption in the air	Eq.2.30, 2.36	
D_{refl}	dB	attenuation due to reflections against obstacles (this term is negative)	Eq.2.30, 2.36	
D_{screen}	dB	attenuation as a result of screening by acoustically well insulating obstacles	Eq.2.30, 2.36	
D_{veg}	dB	attenuation due to noise scattering and absorption by vegetation	Eq. 2.30	
D_{site}	dB	attenuation due to scattering and absorption by installations on the industrial site in so far as this is not included in the other terms (internal scattering)	Eq. 2.30	
D_{ground}	dB	attenuation as a result of reflections against, scattering by and absorption from the ground	Eq. 2.30	
$D_{building}$	dB	attenuation due to reflections against buildings in the vicinity of the receiver (Also the influence of noise propagation through built-up areas is included in this term)	Eq. 2.30	
E_2	dB	environmental correction factor is equal to $10 \log_{10} (1 + (4S/R))$	Eq.2.31, 2.32, 2.37	
E_{1Q}	dB	near -field correction (Table 2.10)	Eq.2.32	
E_{1R}	dB	The near-field correction (Table 2.11)	Eq.2.33	
a	meters	width of source surface	Table 2-12	
b	meters	length of source surface	Eq.2.39, Table 2-12	
ΔL	dB	attenuation correction factors of outdoor sound propagation	Eq.2.45	
n		over all numbers of the measurement points at the measurement surfaces	Eq.2.38	
S_c	m ²	area within the contour	Eq.2.45	
ΔL_{div}	dB	Divergence attenuation correction	Eq.2.45, 2.46, 2.47	
ΔL_{air}	dB	Air absorption by means of temperature and relative humidity attenuation correction	Eq.2.45, 2.48	
ΔL_{ref}	dB	Reflecting obstacles attenuation correction	Eq.2.45, 2.49	
ΔL_{scr}	dB	Screening obstacles attenuation correction	Eq.2.45	
ΔL_{grd}	dB	Ground effects correction	Eq.2.45, 2.50	
R_d	m ²	Displacement between source and immission point, meters ($R_d = d^2 + (H_s - H_i)^2$)	Eq.2.45, 2.47, 2.50	

			(Cont.)
Symbols	Units	Description	Location
H_s	meters	Height of source	Eq.2.46, 2.47
H_i	meters	Height of immission	Eq.2.46, 2.47
α_a	dB/m	air absorption coefficient	Eq.2.48
ρ	-	reflection coefficient of the surface of the reflecting obstacle (Table 2.15)	Eq.2.49, 2.50
K_p		intersection between the line SI from the source S to the immission point I and the screen representation	Table 2-18
T_p		intersection between the screen top edge and the vertical plane V	Table 2-18
Q_p		intersection between the screen plane and the curved transmission path from S to I as it would have been in the absence of the screen	Table 2-18
d_1	meters	Horizontal distance from the source to the screen	Table 2-18
d_2	meters	Horizontal distance from the immission point to the screen	Table 2-18
δ_v	meters	vertical transmission path difference	Table 2-18
δ_r	meters	horizontal transmission path difference on the right vertical edge	Table 2-18
δ_l	meters	vertical transmission path difference on the left vertical edge	Table 2-18
N_v	-	Fresnel number of the vertical transmission path difference	Table 2-18
N_r	-	Fresnel number of the right horizontal transmission path difference	Table 2-18
N_l	-	Fresnel number of the left horizontal transmission path difference	Table 2-18
f_c	Hz	Octave band center frequency	Table 2-18
H_t	meters	Height of screen top	Table 2-18
H_g	meters	Height of lowest ground surface	Table 2-18
$\Delta L_{g,s}$	dB	Ground effects correction of source part	Eq.2.50
$\Delta L_{g,i}$	dB	Ground effects correction immission part	Eq.2.50
$\Delta L_{g,c}$	dB	Ground effects correction center part between source and immission	Eq.2.50
H_{e1}		Effective height of screen no. 1	Table 2-16
H_{e2}		Effective height of screen no. 2	Table 2-16
d_{s1}	meters	Distance from source to the nearest screen included in the calculation of δ_v	Table 2-16
d_{i2}	meters	Distance from immission point to the nearest screen included in the calculation of δ_v	Table 2-16
RPP	-	Rayong Power Plant	-
GT	-	Gas Turbine	-
ST	-	Steam Turbine	-
S	-	South direction	table 4-1
SE	-	Southeast direction	table 4-1
SW	-	Southwest direction	table 4-1
W	-	West direction	table 4-1
C	-	Calm	table 4-1
K	-	Environmental Factor	eq.2.37