APPENDIX 3A

Details of Hydrogen Sulphide Emission Calculation

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1. Sulphide Build-up Calculation for Ngong Ping Sewerage System (Prior to Ngong Ping STW)

Gravity Sewer Flow Conditions

ADWF (L/s)	17.64	
Average flow velocity (m/s)	1.2	
Pipe Length (m)	400	
Pipe Diameter (mm)	400	
Sewer Gradient (m/m)	0.005	(equivalent to 1:200)

Quality of Raw Sewage

pH	7.00	
BOD_5	522	mg/L (from Final Adoptive Review Report)
Temperature	30	°C

Equations for Gravity Sewers

Calculations for P, r and w

[USEPA (1985), *Design Manual - Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants*, Cincinnati. pp.23-24]

d = depth of flow (m)	0.070	m
D = pipe diameter (m)	0.394	m
w = surface width of flow (m)	0.302	m
P = wetted perimeter (m)	0.343	m
A = cross-sectional area of flow (m^2)	0.015	m^2
r = Hydraulic radius = A/P (m)	0.043	m
Average flow (m^3/s)	0.018	m^3/s
Calculated velocity (m/s)	1.20	m/s

Pomeroy and Parkurst equation

[Technological Standing Committee on Hydrogen Sulphide Corrosion in Sewerage Works (1989), *Hydrogen Sulphide Control Manual*, vol.1, pp. 29-30]

$S_2 = [(aS_1-b)e^{-at}+b)]/a$ (for gravity sewer with known retention time)

where

T = temp in °C	30	°C
$[BOD_5]$ = 5-day biochemical oxygen demand (mg/L)	522	mg/L
M' = specific sulphide flux (m/h)	0.00032	(*ibid*, p. 29)
N = constant used in H_2S build-up equation	0.96	(*ibid*, p. 29)
S = total energy head gradient	0.005	
w = surface width of gravity sewer (m)	0.302	m
dm = mean hydraulic depth (m) = A/w	0.0487	m
V = sewage velocity (m/s)	1.20	m/s
$a = [N(SV)^{3/8}]/dm$	2.52	
$b = (M'[BOD_5]1.07^{T-20})/r$	7.68	
t = retention time (h)	0.0926	h (Calculated from pipe length and flow velocity)
$S_1 = [H_2S]$ at the start of section (mg/L)	0	mg/L (negligible for fresh sewage)
$S_2 = [H_2S]$ at the end of section (mg/L)	**0.634**	**mg/L**

2. Hydrogen Sulphide Emission from Ngong Ping STW

2a. Inlet work

Odour sources including coarse/fine screen and grit removal simulated by an open channel flow

Dimensions of the Unit

Number of unit(s)	1	
Length of Unit (m)	11.2	m
Width of Unit (m)	16	m
Depth of Unit (m)	2	m
Surface area (m^2)	179.2	m^2
Cross-sectional area (m^2)	32	m^2

Manning's equation (to estimate S based on R, V and n)

[USEPA (1985), *Design Manual - Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants*, Cincinnati. p.24]

$V = R^{2/3}S^{1/2}/n$

where

Velocity (m/s)	2.0	m/s
R = hydraulic mean radius (m)	1.60	
n = Manning's equation	0.013	(Typical value for sewer)
S (from Manning's equation)	0.000361	

Open channel sulphide release equation

[USEPA (1985), *Design Manual - Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants*, Cincinnati. p.15]

$phi = 0.69(SV)^{3/8}[H_2S]$

where

S = total energy head gradient	0.000361	
V = sewage velocity (m/s)	2.00	m/s
$[H_2S]$ = soluble sulphide concentration (mg/L)	0.311	mg/L or g/m^3

where

Fraction of sulphide in molecular form =	0.49	(@ 30°C and pH = 7.00)
phi = sulphide flux (g/m^2-h)	0.01423	g/m^2-h
Emission rate in unit area (ug/m^2-s)	3.95	ug/m^2-s
Emission rate (ug/s)	708.14	ug/s

2b. Aerobic digester facility building

Assume odour sources with same sulphide emission flux as inlet works

Dimensions of the Unit

Number of unit(s)	1	
Length of Unit (m)	28.8	m
Width of Unit (m)	11.2	m
Height of Unit (m)	8	m
Surface area (m^2)	322.56	m^2

Emission of sulphide from the building

Emission rate in unit area (ug/m^2-s)	3.95	ug/m^2-s
Emission rate (ug/s)	1274.65	ug/s

2c. Sludge dewatering and storage facility building

Assume odour sources with same sulphide emission flux as inlet works

Dimensions of the Units

Number of unit(s)	1	
Length of Unit (m)	29.6	m
Width of Unit (m)	11.2	m
Depth of Unit (m)	8	m
Surface area (m^2)	331.52	m^2

Emission of sulphide from the building

Emission rate in unit area (ug/m^2-s)	3.95 ug/m^2-s
Emission rate (ug/s)	1310.06 ug/s

2d. Sludge thickener

Assume odour sources with same sulphide emission flux as inlet works

Dimensions of the Units

Number of unit(s)	1 (1 operation + 1 standby)
Diameter of Unit (m)	1 m
Surface area (m^2)	0.8 m^2
Total surface area (m^2)	0.8 m^2
Emission of sulphide from the building	
Emission rate in unit area (ug/m^2-s)	3.95 ug/m^2-s
Emission rate (ug/s)	3.10 ug/s

2e. SBR tanks

Assume odour sources with same sulphide emission flux as inlet works

Dimensions of the Units

Number of unit(s)	4
Length of Unit (m)	14 m
Width of Unit (m)	14 m
Depth of Unit (m)	6 m
Surface area (m^2)	196 m^2
Total surface area (m^2)	784 m^2
Emission of sulphide from the building	
Emission rate in unit area (ug/m^2-s)	3.95 ug/m^2-s
Emission rate (ug/s)	3098.11 ug/s

2f. Emergency storage tank (with raw sewage)

Odour source simulated as a sump tank

[USEPA (1995), *Compilation of Air Pollutant Emission Factors AP-42*, fifth edition, Chapter 4.3, pp.4.3-9 to 4.3-16]

Dimensions of the Unit

Number of unit(s)	1
Length of Unit (m)	50 m
Width of Unit (m)	40 m
A = Surface area (m^2)	2000 m^2
D = Depth of sewage (m)	10 m
Parameters	
rho_A = Air density (g/cm^3)	1.18E-03 g/cm^3
rho_W = Water density (g/cm^3)	0.996 g/cm^3
R = Universal gas constant (atm-m^3/gmol-K)	8.21E-05 atm-m^3/gmol-K
T = Temperature of water (K)	303 K
U_{10} = Wind speed at 10 m above the liquid surface (m/s)	2 m/s
mu_A = Air viscosity (g/cm-s)	1.86E-04 g/cm-s
mu_W = Water viscosity (g/cm-s)	7.98E-03 g/cm-s
D_A = Diffusivity of sulphide in air (m/s)	0.181 m/s
D_{ether} = Diffusivity of ether in water (cm^2/s)	9.68E-06 cm^2/s
D_W = Diffusivity of sulphide in water (cm^2/s)	1.83E-05 cm^2/s
H = Henry's law coefficient of constituent (atm-m^3/gmol)	0.0206 atm-m^3/gmol
Q = Sewage flowrate (m^3/s)	0.018 m^3/s
C_O = Initial sulphide concentration (mg/L)	0.634 mg/L

Calculations leading to emission rate

$U^* = (0.01)(U_{10})(6.1+0.63(U_{10})^{0.5}$	(*Ibid*, p.4.3-9)	where	U^* = Friction velocity (m/s) 0.0543 m/s
$Sc_L = mu_W/(rho_W x D_W)$	(*Ibid*, p.4.3-9)	where	Sc_L = Liquid side Schmidt number 436.82 (dimensionless)
$F/D = 2(A/pi)^{0.5}/D$	(*Ibid*, p.4.3-9)	where	F/D = Fetch to depth ratio

			5.05 (dimensionless)
$k_l = (2.78x10^{-6})(D_W/D_{ether})^{2/3}$	(*Ibid*, p.4.3-9)	where	k_l = Liquid phase mass transfer coefficient (m/s)
			4.26E-06 m/s
$Sc_G = mu_A/(rho_A x D_A)$	(*Ibid*, p.4.3-9)	where	Sc_G = Gas side Schmidt number
			0.871 (dimensionless)
$d_e = 2(A/pi)^{0.5}$	(*Ibid*, p.4.3-9)	where	d_e = Effective diameter (m)
			50.46 m
$k_g = (4.82x10^{-3})(U_{10})^{0.78}(Sc_G)^{-0.67}(d_e)^{-0.11}$	(*Ibid*, p.4.3-9)	where	k_g = Gas phase mass transfer coefficient (m/s)
			5.90E-03 m/s
$K_{eq} = H/(RT)$	(*Ibid*, p.4.3-10)	where	K_{eq} = Partition coefficient
			0.827 (dimensionless)
$K = k_l K_{eq} k_g/(K_{eq} k_g + k_l)$	(*Ibid*, p.4.3-10)	where	K = Overall mass transfer coefficient (m/s)
			4.25E-06 m/s
$C_L = QC_O/(KA+Q)$	(*Ibid*, p.4.3-10)	where	C_L = Sulphide concentration in the liquid phase (g/m^3)
			0.428 g/m^3
$N = 10^6 KC_L A$	(*Ibid*, p.4.3-10)	where	N = Sulphide emission (ug/s)
			3636.96 ug/s
			Sulphide emission rate (ug/m^2-s)
			1.82 ug/m^2-s

3. Summary

Sources of sulphide	Emission rate (ug/m^2-s)	Emission (ug/s)
Inlet work	3.95	708.14
Aerobic digester facility building	3.95	1274.65
Sludge dewatering and storage facility building	3.95	1310.06
Sludge thickeners	3.95	3.10
SBR tanks	3.95	3098.11
Emergency storage tank	1.82	3636.96