

Annex A1 - Gaseous Emission Calculation

SUMMARY OF EMISSION INVENTORY

Operation / Restoration (within 500m from the boundary of the Extension)

Emission Source	X	Y	Z	Diameter	Height	Temp	Temp	Velocity	Emission Rate (g/s)				
				(m)	(m)	(oK)	(oC)	(m/s)	NO2	CO	SO2	Vinyl chloride	Benzene
HAECO	846000	815724	6.7	14.7 (equivalent diameter) (stack area = 169m ²)	40	325	52	16.4 (for NO2 & SO2); 12 (for CO)	21.2	23.9	1.9	-	-
(reference to HAECO EIA, 1995; confirmed by HAECO that the emission rate, type of engine used in HAECO EIA Report are still valid in January 2008)													
Flare1	846570	814618	6.7	3.8	25	1123	850	12.24	0.31	3.91	0.22	2.61E-04	4.14E-04
Flare2	846570	814612	6.7	3.8	25	1123	850	12.24	0.31	3.91	0.22	2.61E-04	4.14E-04
Thermal oxidizer	846525	814670	6.7	1.12	9.76	444.6	171.6	17.5	0.10	1.22	0.07	8.15E-05	1.29E-04
LFG Generator	846531	814610	6.7	0.305	28	727	454	48.6	0.11	1.72	0.176	6.26E-06	8.22E-05

Aftercare Phase (within 500m from the boundary of the Extension)

Source	X	Y	Z	Diameter	Height	Temp	Temp	Velocity	Emission Rate (g/s)				
				(m)	(m)	(oK)	(oC)	(m/s)	NO2	CO	SO2	Vinyl chloride	Benzene
HAECO	846000	815724	6.7	14.7 (equivalent diameter) (stack area = 169m ²)	40	325	52	16.4 (for NO2 & SO2); 12 (for CO)	21.2		1.9		
(reference to HAECO EIA, 1995; confirmed by HAECO that the emission rate, type of engine used in HAECO EIA Report are still valid in January 2008)								12		23.9			
Flare1	846570	814618	6.7	3.8	25	1123	850	12.24	0.31	3.91	0.22	2.61E-04	4.14E-04
Flare2	846570	814612	6.7	3.8	25	1123	850	12.24	0.31	3.91	0.22	2.61E-04	4.14E-04
LFG Generator	846531	814610	6.7	0.305	28	727	454	48.6	0.11	1.72	0.176	6.26E-06	8.22E-05

BASIC INFORMATION

LFG to LTP	3125	m3/hr	(peak)
LFG to gen. set	1500	m3/hr	(refer to existing SENT Landfill)
LFG to Flare (total)	20000	m3/hr	(design total capacity of flares)
LFG to Flare (each)	10000	m3/hr	(no. of flare = 2, at 83.8oC)
Exhaust gas flowrate of each flare @ 850oC	499582	m3/hr	(provided by engineer and estimated based on 10,000 m3/hr of LFG & 850oC)

FLARE (with a total of 20,000 m3/hr of LFG to flare)

(For Operation/Restoration & Aftercare Phases)

Air Pollutant	Emission limit		
NOx	0.06	lb/mmBTU	(emission in raw LFG @ 83.8oC, reference to the flare in existing SENT landfill)
NO2	0.012	lb/mmBTU	(20% of NOx ----> NO2)
CO	0.15	lb/mmBTU	(emission in raw LFG @ 83.8oC, reference to the flare in existing SENT landfill)
SO2	1.55	mg/m3	(in exhaust gas at 850oC, see detailed SO2 calculation below)
Benzene (inlet)	5.6	ppm	(max. benzene concentration measured at the inlet of flare at existing SENT Landfill @ 83.8oC & 1atm, reference to the monitoring data of existing SENT Landfill in 2006)
	14.91	mg/m3	(5.6 ppm x (12x6+6)/(22.414x(273+83.8)/(273))), @ 83.8oC)
Vinyl chloride (inlet)	4.4	ppm	(max. vinyl chloride concentration measured at the inlet of flare at existing SENT Landfill @ 83.8oC & 1atm, reference to the monitoring data of existing SENT Landfill in 2006)
	9.39	mg/m3	(4.4ppm x (12x2+3+35.5)/(22.414x(273+83.8)/(273))), @ 83.8oC)

Landfill gas energy	0.0207	(mmBTU/m3)	(provided by existing SENT Landfill operator)
Total LFG energy in each flare	207.0	mmBTU/hr	(0.0207 x landfill gas flowrate = 10,000 m3/hr)
lb ----> g	453.6		
Stack diameter	3.8	m	
Stack height	25	m	
Exit temp	850	oC	
Exhaust flowrate at 850oC	499582	m3/hr	
Exit velocity	12.24	m/s	

Air pollutant	Emission Rate at Exhaust		
NOx	1.56	g/s	(0.06 lb/mmBTU x 207 mmBTU/hr x 453.6 g/lb/3600)
NO2	0.31	g/s	(NOx emission rate x 0.2)
CO	3.91	g/s	(0.15 lb/mmBTU x 207 mmBTU/hr x 453.6 g/lb/3600)
SO2	0.22	g/s	(refer to detailed SO2 emission rate calculation below)
Benzene	4.14E-04	g/s	(14.91 mg/m3 x 10,000 m3/hr / 1000 / 3600 x (1-0.99), 99% VOC removal efficiency should be required with reference to Contract Specification)
Vinyl chloride	2.61E-04	g/s	(9.39 mg/m3 x 10,000 m3/hr / 1000 / 3600 x (1-0.99), 99% VOC removal efficiency should be required with reference to Contract Specification)

Air pollutant	Emission Concentration at exhaust, 850oC		
NOx	11.28	mg/m3	(NOx emission rate / exhaust flowrate)
NO2	2.26	mg/m3	(NOx emission rate x 0.2)
CO	28.19	mg/m3	(CO emission rate / exhaust flowrate)
SO2	1.55	mg/m3	(refer to detailed SO2 emission rate calculation below)
Benzene	2.98E-03	mg/m3	(Benzene emission rate / exhaust flowrate)
Vinyl chloride	1.88E-03	mg/m3	(Vinyl chloride emission rate / exhaust flowrate)

THERMAL OXIDIZER of LTP (with 3,125 m3/hr of LFG to LTP)

(For Operation/Restoration Phase Only)

Air Pollutant	Emission limit		
NOx	0.06	lb/mmBTU	(emission in LFG @ 83.8oC, same as that in flare)
NO2	0.012	lb/mmBTU	(20% of NOx ----> NO2)
CO	0.15	lb/mmBTU	(emission in LFG @ 83.8oC, same as that in flare)
SO2	3.9	mg/m3	(at exhaust flowrate, 850oC, see detailed SO2 calculation below)
Benzene (inlet)	14.91	mg/m3	(same as that in flare)
Vinyl chloride (inlet)	9.39	mg/m3	(same as that in flare)

Landfill gas energy	0.0207	(mmBTU/m3)	(provided by existing SENT Landfill operator)
Total LFG energy in stack	64.7	mmBTU/hr	(0.0207 x landfill gas flowrate = 3,125)
lb ----> g	453.6		
Stack diameter	1.12	m	(reference to the thermal oxidizer at existing SENT Landfill)
Stack height	9.76	m	(reference to the thermal oxidizer at existing SENT Landfill)
Exit temp	171.6	oC	(reference to the thermal oxidizer at existing SENT Landfill)
Raw LFG flowrate	3125	m3/hr	
Exit velocity	17.5	m/s	(reference to the thermal oxidizer at existing SENT Landfill)
Exhaust flowrate @ 171.6oC	62068	m3/hr	(17.5 m/s x 3.1416 x (1.12/2) ²)

Air pollutant	Emission Rate at Exhaust		
NOx	0.49	g/s	(0.06 lb/mmBTU x 64.7 mmBTU/hr x 453.6 g/lb/3600)
NO2	0.10	g/s	(NOx emission rate x 0.2)
CO	1.22	g/s	(0.15 lb/mmBTU x 64.7 mmBTU/hr x 453.6 g/lb/3600)
SO2	0.07	g/s	(refer to detailed SO2 emission rate calculation below)
Benzene	1.29E-04	g/s	(14.91 mg/m3 x 3125 m3/hr / 1000 / 3600 x (1-0.99), 99% VOC removal efficiency should be required with reference to Contract Specification)
Vinyl chloride	8.15E-05	g/s	(9.39 mg/m3 x 3125 m3/hr / 1000 / 3600 x (1-0.99), 99% VOC removal efficiency should be required with reference to Contract Specification)

Air pollutant	Emission Concentration at exhaust, 171.6oC		
NOx	28.4	mg/m3	(NOx emission rate / exhaust flowrate)
NO2	5.67	mg/m3	(NOx emission rate x 0.2)
CO	70.91	mg/m3	(CO emission rate / exhaust flowrate)
SO2	3.90	mg/m3	(refer to detailed SO2 emission rate calculation below)
Benzene	7.51E-03	mg/m3	(Benzene emission rate / exhaust flowrate)
Vinyl chloride	4.73E-03	mg/m3	(Vinyl chloride emission rate / exhaust flowrate)

LFG GENERATOR **(For Operation/Restoration & Aftercare Phases)**

LFG consumption	1500	m3/hr	(given by Engineer)
LFG energy	0.0207	mmBTU/m3	(provided by existing SENT Landfill operator)
	31.05	mmBTU/hr	(1500 m3/hr x 0.0207 mmBTU/m3)
NOx emission factor at exhaust	0.14	lb/mmBTU	(AP-42, Table 3.1-1, http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s01.pdf)
CO emission factor at exhaust	0.44	lb/mmBTU	(AP-42, Table 3.1-1, http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s01.pdf)
SO2 emission factor at exhaust	0.045	lb/mmBTU	(AP-42, Table 3.1-2b, http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s01.pdf)
Benzene emission factor at exhaust	2.10E-05	lb/mmBTU	
Vinyl chloride emission factor at exhaust	1.60E-06	lb/mmBTU	
No. of stack	1		
Stack diameter	0.305	m	(reference to the generator design in the existing SENT Landfill)
Stack height	28	m above ground	
Exit temp.	454	oC	(reference to the generator design in the existing SENT Landfill)
	727	oK	
Exit velocity	48.6	m/s	(reference to the generator design in the existing SENT Landfill)
Exit flowrate	3.55	m3/s	(reference to the generator design in the existing SENT Landfill)
lb ----> g	453.6		

Air pollutant	Emission Rate at Exhaust		
NOx emission rate	0.55	g/s	(NOx emission factor x LFG energy (mmBTU/hr))
NO2 emission rate	0.110	g/s	(20% of NOx ----> NO2)
CO emission rate	1.721	g/s	(CO emission factor x LFG energy (mmBTU/hr))
SO2 emission rate	0.176	g/s	(SO2 emission factor x LFG energy (mmBTU/hr))
Benzene emission rate	8.22E-05	g/s	(Benzene emission factor x LFG energy (mmBTU/hr))
Vinyl chloride emission rate	6.26E-06	g/s	(Vinyl chloride emission factor x LFG energy (mmBTU/hr))

Detailed calculation of SO2 emission (Reference to USEPA AP-42 for H2S concentration)

<u>Fling</u>			
H2S concentration (in ppm) in raw LFG	35.5	ppm	(USEPA AP-42, Section 2.4, Table 2.4-1, http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf)
Molecular weight of H2S	34		
Flowrate of LFG	10000	m3/hr	
Conc of H2S (in g/m3) in raw LFG @ 83.8oC	0.04	g/m3	(ppm x MW / (22.414x(273+83.8)/(273)) / 1000)
Mass of H2S	0.1	g/s	(conc of H2S (in g/m3) x LFG flowrate)
Mole ratio of H2S / SO2	1:1		(2H2S + 3O2 ----> 2SO2 + 2H2O)
molecular weight of SO2	64		
Mass of SO2	0.22	g/s	(mass of H2S x (64 / 34))
Exhaust flowrate at 850oC	499582	m3/hr	
Emission concentration of SO2 at exhaust (850oC)	1.55	mg/m3	(mass of SO2 / exhaust flowrate)

<u>Thermal oxidizer</u>			
H2S concentration (in ppm) in raw LFG	35.5	ppm	(USEPA AP-42, Section 2.4, Table 2.4-1, http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf)
Molecular weight of H2S	34		
Flowrate of LFG	3125	m3/hr	
Conc of H2S (in mg/m3) in raw LFG @ 83.8oC	0.04	g/m3	(ppm x MW / (22.414x(273+83.8)/(273)) / 1000)
Mass of H2S	0.04	g/s	(conc of H2S (in g/m3) x LFG flowrate)
Mole ratio of H2S/SO2	1:1		(2H2S + 3O2 ----> 2SO2 + 2H2O)
Molecular weight of SO2	64		
Mass of SO2	0.1	g/s	(mass of H2S x (64 / 34))
Exhaust flowrate at 171.6oC	62068	m3/hr	
Emission concentration of SO2 at exhaust (171.6oC)	3.9	mg/m3	(mass of SO2 / exhaust flowrate)