Appendix 3.3

Calculation of Emissions from Stacks of HSKEPP

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Appendix 3.3 Calculation of Emission Rate of the Stacks of HSKEPP

CHP1

Peak Exhaust Flow rate (standard condition, dry)= 4,029 Nm3/hr at 273K

Actual Flow rate (actual condition, wet)= 7,540 m3/hr at 453K

Parameter	Oa (%)	Os (%)	%H2O	Ta (K)	Ts (K)	Hourly Average Emission Limit (mg/Nm^3, dry)	Emission Rate* (g/s)	*Remarks*
RSP	5	6	11	453	273	15	**0.0179**	*[1] [3]*
Carbon Monoxide	5	5	11	453	273	650	**0.7275**	*[2] [4]*
NO_x	5	5	11	453	273	250	**0.2798**	*[2] [4]*
SO_2	5	6	11	453	273	50	**0.0597**	*[1] [3]*
Methane	5	6	11	453	273	150	**0.1792**	*[1] [3]*
HCl	5	6	11	453	273	10	**0.0119**	*[1] [3]*
HF	5	6	11	453	273	1	**0.0012**	*[1] [3]*
Formaldehye (CH2O)	5	6	11	453	273	14	**0.0167**	*[3] [5]*

CHP2

Peak Exhaust Flow rate (standard condition, dry)= 4,029 Nm3/hr at 273K

Actual Flow rate (actual condition, wet)= 7,540 m3/hr at 453K

Parameter	Oa (%)	Os (%)	%H2O	Ta (K)	Ts (K)	Hourly Average Emission Limit (mg/Nm^3, dry)	Emission Rate* (g/s)	*Remarks*
RSP	5	6	11	453	273	15	**0.0179**	*[1] [3]*
Carbon Monoxide	5	5	11	453	273	650	**0.7275**	*[2] [4]*
NO_x	5	5	11	453	273	250	**0.2798**	*[2] [4]*
SO_2	5	6	11	453	273	50	**0.0597**	*[1] [3]*
Methane	5	6	11	453	273	150	**0.1792**	*[1] [3]*
HCl	5	6	11	453	273	10	**0.0119**	*[1] [3]*
HF	5	6	11	453	273	1	**0.0012**	*[1] [3]*
Formaldehye (CH2O)	5	6	11	453	273	14	**0.0167**	*[3] [5]*

CHP3

Peak Exhaust Flow rate (standard condition, dry)= 4,029 Nm3/hr at 273K

Actual Flow rate (actual condition, wet)= 7,540 m3/hr at 453K

Parameter	Oa (%)	Os (%)	%H2O	Ta (K)	Ts (K)	Hourly Average Emission Limit (mg/Nm^3, dry)	Emission Rate* (g/s)	*Remarks*
RSP	5	6	11	453	273	15	**0.0179**	*[1] [3]*
Carbon Monoxide	5	5	11	453	273	650	**0.7275**	*[2] [4]*
NO_x	5	5	11	453	273	250	**0.2798**	*[2] [4]*
SO_2	5	6	11	453	273	50	**0.0597**	*[1] [3]*
Methane	5	6	11	453	273	150	**0.1792**	*[1] [3]*
HCl	5	6	11	453	273	10	**0.0119**	*[1] [3]*
HF	5	6	11	453	273	1	**0.0012**	*[1] [3]*
Formaldehye (CH2O)	5	6	11	453	273	14	**0.0167**	*[3] [5]*

Remarks:

Oa : Oxygen concentration at actual condition
Os : Oxygen concentration at reference condition
Ta : Temperature at actual condition
Ts : Temperature at reference condition

All Hourly emission limits are referenced at standard air condition (i.e. 273K, 101,325 Pa, 0%H_2O), and at oxygen content as shown under column Os (%)
*Emission Rate is calculated by Peak Exhaust Flow Rate (at 273K, 101,325 Pa, 0%H_2O) *Hourly Average Emission Limit/3600/1000, with corrections of oxygen content where actual (Oa) and reference (Os) conditions differ.

Appendix 3.3 Calculation of Emission Rate of the Stacks of HSKEPP

Remarks:

Unit CHP exhaust flow rate calculation based on supplier information:

CHP supplier exhaust flow rate (at 0% v/v water vapor) = 3,297 Nm^3/hr (dry)

CHP supplier exhaust flow rate (at 11% v/v water vapor) = 3,718 Nm^3/hr (wet)

CHP supplier equipment model rated power = 851kWe

CHP power output designed = 800kWe

Maximum exhaust flow from CHP = 800/851 x 3,718 x 1.3^ = 4,544 Nm^3/hr (wet)

4,544Nm^3/hr equivalent power output of CHP = 800 x 1.3 = 1,040kWe (max)

^1.3 factor applied to accommodate variation in biogas production during operation

Actual Exhaust Flow rate conversion from standard condition

CHP exhaust at standard condition: 4,544 Nm3/hr (273K , 101,325 Pa, wet)

CHP exhaust at actual condition (453K, ^101,325 Pa): 4,544 x 453 / 273 x 101,325 / 101,325 = 7,540 m3/hr = 2.09m3/s (wet)

^Assume air pressure is same as standard condition.at altitude of exhaust discharge point.

Moisture concentration correction factor from references condition to actual condition

moisture content in exhaust as per supplier : 3,297 Nm3/hr (dry exhaust) / 3,718 Nm3/hr (wet exhaust) = 11.3%

dry exhaust to wet exhaust pollutant concentration correction factor : (1-11.3%) = 0.887

For dry exhaust flow : 4,544 x (3,297/3,718) = 4,029 Nm3/hr (dry) (for emission rate calculation)

Oxygen concentration correction factor from references condition to actual condition

Only adopted for emission rates referenced at oxygen concentrations different from the actual condition

actual oxygen concentration in exhaust : 5% (condition adopted in air models)

referenced oxygen concentration in exhaust : 6% as per emission rate references of RSP, SO2, Methane, HCl and HF

referenced oxygen concentration in exhaust : 5% as per emission rate references of CO and NO3

oxygen correction factor : (20.9-5)/(20.9-6) = 1.067 (applicable for RSP, SO2, Methane, HCl and HF only)

Example pollution emission rate for CHP

RSP : 4029Nm3/hr x 15mg/Nm3 x 1.067 /3,600s/1,000g/kg = 0.0179g/s

NO3 : 4029Nm3/hr x 250mg/Nm3 x 1 /3,600s/1,000g/kg = 0.2798g/s

Formaldehyde emission estimate

Formaldehyde emission based on research paper (reference no. [5]) = 14 g/GJ

Formaldehyde emission of the designed CHP = 800 kWe x 1.3 x 14 g/GJ = 0.01456 g/s

Formaldehyde emission concentration (dry exhaust) = 0.01456 g/s / (4,029 Nm^3 / 3,600 s) = 0.01301 g/Nm^3 = 13.01 mg/Nm^3, dry

Formaldehyde emission limit = 14 mg/Nm^3 (round up from 13.01 mg/Nm^3)

Formaldehyde emission rate for modelling = 14mg/Nm^3 x 4,029Nm^3/hr = 56.4 g/hr =0.0157 g/s

with correction factor for O2 content in exhaust 0.0157 x (20.9-5) / (20.9-*6) = 0.0167g/s

* Assume oxygen concentration at 6% for referenced formaldehyde emission rate

References

[1] Agreement No. CE 7/2008 (EP) Organic Waste Treatment Facilities, Phase I - Feasibility Study Table 3.5

[2] CHP Supplier's information

[3] The emission limit refers to an oxygen content of 6% and dry basis.

[4] The emission limit refers to an oxygen content of 5% and dry basis.

[5] Valerio Paolini, Francesco Petracchini, Marco Segreto, Laura Tomassetti, Nour Naja & Angelo Cecinato (2018) Environmental Impact of Biogas: A short review of current knowledge, Journal of Environmental Science and Health, Part A, 53:10, 899-906, DOI: 10.1080/10934529.2018.1459076

Appendix 3.3 Calculation of Emission Rate of the Stacks of HSKEPP

Emissions from Boiler (BO)

Maximum biogas to be utilized in Boiler	=	374	m^3/hr	(a) 35°C (0%H_2O), w/ 60% CH_4 content (Provided by the engineer according to the sludge treatment process)
No. of exhaust from the Boiler	=	1		
Standard Condition	=	0	C°	at 101,325 Pa
	=	273	K	(b)
Temperature of Biogas	=	35	C°	at 101,325 Pa
	=	308	K	(c)
By Ideal Gas Law, V1/V2 = T1/T2	=	0.88636	$Nm^3/m3$	(d) = (b) / (c)
Estimated biogas (CH_4) to be burned in boiler	=	224.4	m^3/hr	at actual condition (e) =(a) x 60% CH_4 content 35°C
	=	198.90	Nm^3/hr	at standard condition (f) = (e) x (d)

Boiler Emission

Exhaust flow rate at standard condition at 273K (dry)	2,999	Nm^3/hr
Exhaust flow rate at actual condition at 453K (wet)	5,611	m^3/hr

Parameter	Oa (%)	Os (%)	%H2O	Ta (K)	Ts (K)	Emission Limit for Boiler Exhaust (mg/ Nm^3, dry)	Emission Rate (g/s)	Remarks
RSP	5	6	11	453	273	15	**0.0133**	*[1] [3]*
Carbon Monoxide	5	5	11	453	273	650	**0.5415**	*[2] [4]*
NO_x	5	5	11	453	273	250	**0.2083**	*[2] [4]*
SO_2	5	6	11	453	273	50	**0.0444**	*[1] [3]*
Methane	5	6	11	453	273	150	**0.1333**	*[1] [3]*
HCl	5	6	11	453	273	10	**0.0089**	*[1] [3]*
HF	5	6	11	453	273	1	**0.0009**	*[1] [3]*
Formaldehyde (CH2O)	5	6	11	453	273	14	**0.0124**	*[3] [5]*

Note

All Hourly emission limits are referenced at standard air condition (i.e. 273K, 101,325 Pa, 0%H_2O), and at oxygen content as shown under column Os (%)
*Emission Rate is calculated by Peak Exhaust Flow Rate (at 273K, 101,325 Pa, dry) *Hourly Average Emission Limit/3600/1000, with corrections of oxygen content where actual (Oa) and reference (Os) conditions differ.

Given CHP and boiler emissions are both generated from combustion of the same biogas generated at the effluent polishing plant, the emission rates are considered comparable. Therefore, CHP emission limit of the respective pollutants are used to estimate those in the boiler emissions.

Appendix 3.3 Calculation of Emission Rate of the Stacks of HSKEPP

CHP Exhaust gas flow rate to CH_4 consumption (flow rate proportion based on CHP supplier information)

CHP exhaust flow rate per unit : 3,297 Nm^3/hr (273K, 101,325 Pa, dry - 0% moisture concentration)
CHP exhaust flow rate per unit : 3,718 Nm^3/hr (273K, 101,325 Pa, wet - 11% moisture concentration)
CHP Biogas consumption rate per unit 361 Nm^3/hr (273K, 101,325Pa, dry, without oxygen)
Biogas methane content : 60% v/v
CH_4 flow : 361 x 0.6 = 217Nm^3/hr - i.e. 217Nm^3/hr CH_4 is consumed to produce 3,718 Nm^3/hr (wet) exhaust gas as per supplier
Exhaust (wet) to CH_4 flow ratio : 3,718 / 217 = 1:17 (a)
above ratio adopted to prorate boiler exhaust flow rate with reference to biogas consumption rate.

Boiler Exhaust flow rate estimate

Boiler biogas maximum demand: 374 m^3/hr (308K, 101,325 Pa, dry, without oxygen)
(provided by the Engineer, based on sludge treatment process requirements)
CH_4 consumed by boiler : 374 x 60% x 0.88636 = 198.90 Nm^3/hr (273K, 101,325 Pa dry, without oxygen)
Using ratio from (a) : Wet boiler exhaust flow rate at standard condition
198.90 x 17 = 3,381.3Nm^3/hr (273K, 101,325 Pa, wet)
Wet boiler exhaust flow rate at actual condition
3,381.3 / 273K x 453K x 101,325/101,325 = 5,611 m^3/hr = 1.56 m^3/s (453K, 101,325 Pa, wet)
Dry boiler exhaust flow rate at standard condition
3,381.3 x (3,297 / 3,718) = 2,999 Nm^3/hr (273K, 101,325 Pa, 0% moisture)
^Assume air pressure is equivalent to standard condition.at altitude of exhaust discharge point.

Emission rate for boiler calculations

Boiler RSP emission rate = 15 x 2,999 x (20.9-5) / (20.9-6) / 3,600s / 1,000g/kg = 0.0133 g/s
Boiler Carbon Monoxide emission rate = 650 x 2,999 x (20.9 - 5) / (20.9 - 5) / 3,600s / 1,000 kg/kg = 0.5415 g/s
Boiler NO_3 emission rate = 250 x 2,999 x (20.9 - 5) / (20.9-5) / 3,600s / 1,000 kg/kg = 0.2083 g/s
Boiler SO_2 emission rat e= 50 x 2,999 x (20.9 - 5) / (20.9 - 6) / 3,600s / 1,000 kg/kg = 0.0444 g/s
Boiler Methane emission rate = 150 x 2,999 x (20.9 - 5) / (20.9 - 6) / 3,600s / 1,000 kg/kg = 0.1333 g/s
Boiler HCL emission rate = 10 x 2,999 x (20.9 - 5) / (20.9 - 6) / 3,600s / 1,000 kg/kg = 0.0089 g/s
Boiler HF emission rate = 1 x 2,999 x (20.9 - 5) / (20.9 - 6) / 3,600s / 1,000 kg/kg = 0.0009 g/s
Boiler Formaldehyde (CH2O) emission rate = 14 x 2,999 x (20.9 - 5) / (20.9 - 6) / 3,600s / 1,000 kg/kg = 0.0124 g/s

References

[1] Agreement No. CE 7/2008 (EP) Organic Waste Treatment Facilities, Phase I - Feasibility Study Table 3.5
[2] CHP Supplier's information
[3] The emission limit refers to an oxygen content of 6% and dry basis.
[4] The emission limit refers to an oxygen content of 5% and dry basis.
[5] Valerio Paolini, Francesco Petracchini, Marco Segreto, Laura Tomassetti, Nour Naja & Angelo Cecinato (2018) Environmental Impact of Biogas: A short review of current knowledge, Journal of Environmental Science and Health, Part A, 53:10, 899-906, DOI: 10.1080/10934529.2018.1459076

Appendix 3.3 Calculation of Emissions from Stacks of HSKEPP

Emission Sources Listing in AERMOD

Description	Source ID	Type	X	Y	Height (mAG)	Exit Temp (K)	Exit Velocity (m/s)	Stack Diameter (m)	Working Hours	RSP Emission Rate (g/s)	FSP Emission Rate (g/s) [2]	NOx Emission Rate (g/s)	SO2 Emission Rate (g/s)	CO Emission Rate (g/s)
biogas engine	CHP1	POINTCAP	816332.00	834094.00	46.00	453.00	13.17	0.45	0000 - 2400	1.792E-02	1.792E-02	2.798E-01	5.972E-02	7.275E-01
biogas engine	CHP2	POINTCAP	816338.00	834092.00	46.00	453.00	13.17	0.45	0000 - 2400	1.792E-02	1.792E-02	2.798E-01	5.972E-02	7.275E-01
biogas engine	CHP3	POINTCAP	816343.00	834088.00	46.00	453.00	13.17	0.45	0000 - 2400	1.792E-02	1.792E-02	2.798E-01	5.972E-02	7.275E-01
fire tube boiler	BO	POINTCAP	816332.00	834098.00	46.00	453.00	12.40	0.40	0000 - 2400	1.333E-02	1.333E-02	2.083E-01	4.445E-02	5.415E-01

Description	Source ID	Type	X	Y	Height (mAG)	Exit Temp (K)	Exit Velocity (m/s)	Stack Diameter (m)	Working Hours	Methane Emission Rate (g/s)	HCL Emission Rate (g/s)	HF Emission Rate (g/s)	Formaldehyde Emission Rate (g/s)
biogas engine	CHP1	POINTCAP	816332.00	834094.00	46.00	453.00	13.17	0.45	0000 - 2400	1.792E-01	1.194E-02	1.194E-03	1.672E-02
biogas engine	CHP2	POINTCAP	816338.00	834092.00	46.00	453.00	13.17	0.45	0000 - 2400	1.792E-01	1.194E-02	1.194E-03	1.672E-02
biogas engine	CHP3	POINTCAP	816343.00	834088.00	46.00	453.00	13.17	0.45	0000 - 2400	1.792E-01	1.194E-02	1.194E-03	1.672E-02
fire tube boiler	BO	POINTCAP	816332.00	834098.00	46.00	453.00	12.40	0.40	0000 - 2400	1.333E-01	8.890E-03	8.890E-04	1.245E-02

Description	Source ID	Non-AQO Pollutant Emission Rate (g/s) [1]	Scaling Factor for Cumulative Concentration [1]			
			Mechane	HCL	HF	Formaldehyde (CH2O)
biogas engine	CHP1	1.000E+00	1.792E-01	1.194E-02	1.194E-03	1.672E-02
biogas engine	CHP2	1.000E+00	1.792E-01	1.194E-02	1.194E-03	1.672E-02
biogas engine	CHP3	1.000E+00	1.792E-01	1.194E-02	1.194E-03	1.672E-02
fire tube boiler	BO	7.443E-01	1.792E-01	1.194E-02	1.194E-03	1.672E-02

Remarks

1. A single non-AQO AERMOD model is employed for Methane, HCL, HF and Formaldehyde. Respective scaling factor is applied to the model output to obtain the emission rate shown in P.3.
   e.g. Methane emission rate of CHP1 = 1 x 1.792E-01 = 1.792E-01
   Methane emission rate of BO = 7.443E-01 x 1.792E-01 = 1.333E-01.
2. RSP emission rate is adopted for FSP emission as a conservative approach.
3. No dry deposition applied for RSP and FSP.

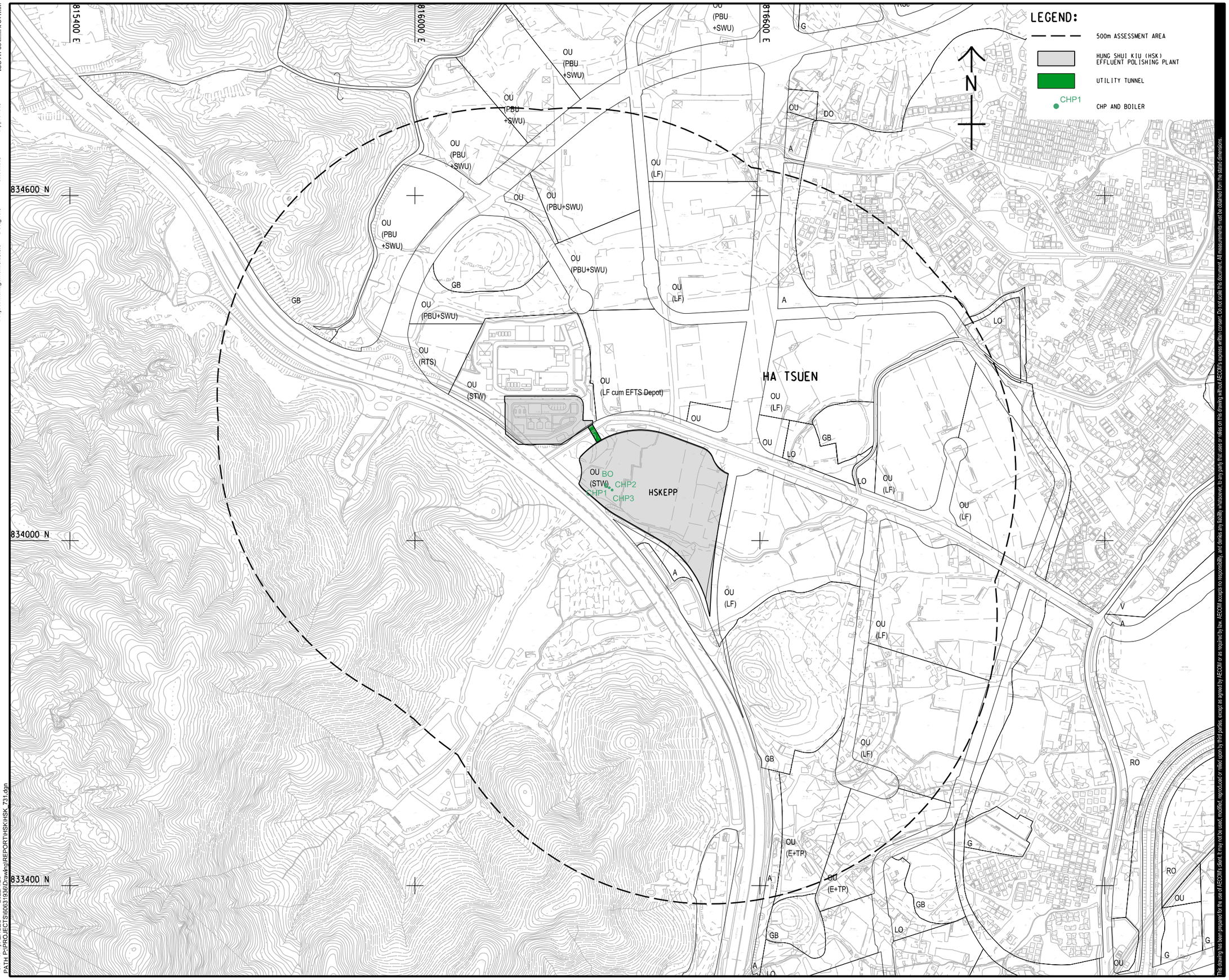
ISO A1 594mm x 841mm

Approved:

Checked:

Designer:

Project Management Initials:



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AECOM

PROJECT
項目

HUNG SHUI KIU EFFLUENT POLISHING PLANT AND YUEN LONG SOUTH EFFLUENT POLISHING PLANT - INVESTIGATION

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ISSUE/REVISION
修訂

I/R 修訂	DATE 日期	DESCRIPTION 內容摘要	CHK. 核核

STATUS
階段

SCALE 比例
A1 1 : 3000

DIMENSION UNIT 尺寸單位
METRES

KEY PLAN
索引圖

PROJECT NO. 項目編號
60631936

CONTRACT NO. 合約編號
CE 6/2019 (DS)

SHEET TITLE
圖紙名稱

LOCATION OF CHP AND BOILER

SHEET NUMBER
圖紙編號

60631936/APPENDIX 3.3.1