Appendix 3.4 Calculation of Emission from Stacks of YLSEPP

Emissions from CHP in YLSEPP

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 from CHP for Modelling (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]*
Formaldehyde (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 from CHP for Modelling (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]*
Formaldehyde (CH2O)	5	6	11	453	273	14	**0.0167**	*[3] [5]*

Remarks:

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

*: Emission Rate = Peak Flow Rate*Hourly Average Emission Limit/3600/1000

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 for YLSEPP = 800kWe
Maximum exhaust flow from CHP at YLSEPP = 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 (273K , 101,325 Pa): 4,544 Nm^3/hr (wet)
CHP exhaust at actual condition (453K, ^101,325 Pa): 4,544 x 453 / 273 x 101,325 / 101,325 = 7,540 m^3/hr = 2.09m^3/s
^Assume air pressure is same as standard condition.at altitude of exhaust discharge point.

Moisture concentration correction factor (for emission rate estimation)

moisture content in exhaust as per supplier : 3,297 Nm^3/hr (dry exhaust) / 3,718 Nm^3/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 * (3,297 / 3,718) = 4,029 Nm^3/hr (dry)

Oxygen concentration correction factor (for emission rate estimation)

actual oxygen concentration in exhaust : 5% (same for CO and NO_x at referenced/ standard condition)
standard oxygen concentration in exhaust : 6% (for RSP, SO2, Methane, HCl and HF)
oxygen correction factor : (20.9-5)/(20.9-6) = 1.067 (for RSP, SO2, Methane, HCl and HF)

Example RSP pollution emission rate for CHP

4,029Nm^3/hr x 15mg/Nm^3 x 1.067 /3,600s/1,000g/kg = 0.0179g/s

Formaldehyde emission estimate

Formaldehyde emission based on research paper (reference no. [5]) = 14 g/GJ
Formaldehyde emission of the designed YLSEPP 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 O_2 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 level refers to an oxygen content of 6% and dry basis.
[4] The emission level 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 3.4 Calculation of Emission from Stacks of YLSEPP

Emissions from Boiler (BO) in YLSEPP

Maximum biogas to be utilized in Boiler	=	215	m^3/hr	(a) at 35°C w/ 60% CH_4 content based on sludge treatment process requirements
No. of exhuast 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	=	0.886	m^3/ m^3	(d) = (b) / (c)
Estimated methane (CH_4) to be burned in boiler	=	129	m^3/hr	at actual condition (e) =(a) x 60% CH_4 content 35°C
	=	114	Nm^3/hr	at standard condition (f) = (e) x (d)
	=	0.032	Nm^3/s	(g) = (f) / 3600s

Boiler Emission

Exhaust flow rate at standard condition at 273K (dry)	1,726	Nm^3/hr
Exhaust flow rate at actual condition at 453K (wet)	3,230	m^3/hr

Parameter		Emission Limit for Emission from Boiler (mg/ Nm^3, dry)	Emission Rate from Boiler for Modelling (g/s)	Remarks
RSP	=	15	**0.0077**	*Provided by engineer*
Carbon Monoxide	=	650	**0.3116**	*Provided by engineer*
NO_x	=	250	**0.1199**	*Provided by engineer*
SO_2	=	50	**0.0256**	*Provided by engineer*
Methane	=	150	**0.0767**	*Provided by engineer*
HCl	=	10	**0.0051**	*Provided by engineer*
HF	=	1	**0.0005**	*Provided by engineer*
Formaldehyde (CH2O)	=	14	**0.0072**	*Provided by engineer*

Note
1. The hourly average emission limit pollutant concentrations are adopted based on standard air conditions.

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

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 (dry exhaust at 0% moisture concentration)
CHP exhaust flow rate per unit : 3,718 Nm^3/hr (wet exhaust at 11% moisture concentration)
CHP Biogas consumption rate per unit 361 Nm^3/hr
Biogas methane content : 60% v/v (provided by the Engineer)
CH4 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)
Exhaust (dry) to CH_4 flow ratio : 3,297 / 217 = 1:15 (b)
above ratios (a) and (b) adopted for boiler exhaust flow and for emission rate estimate, respectively.

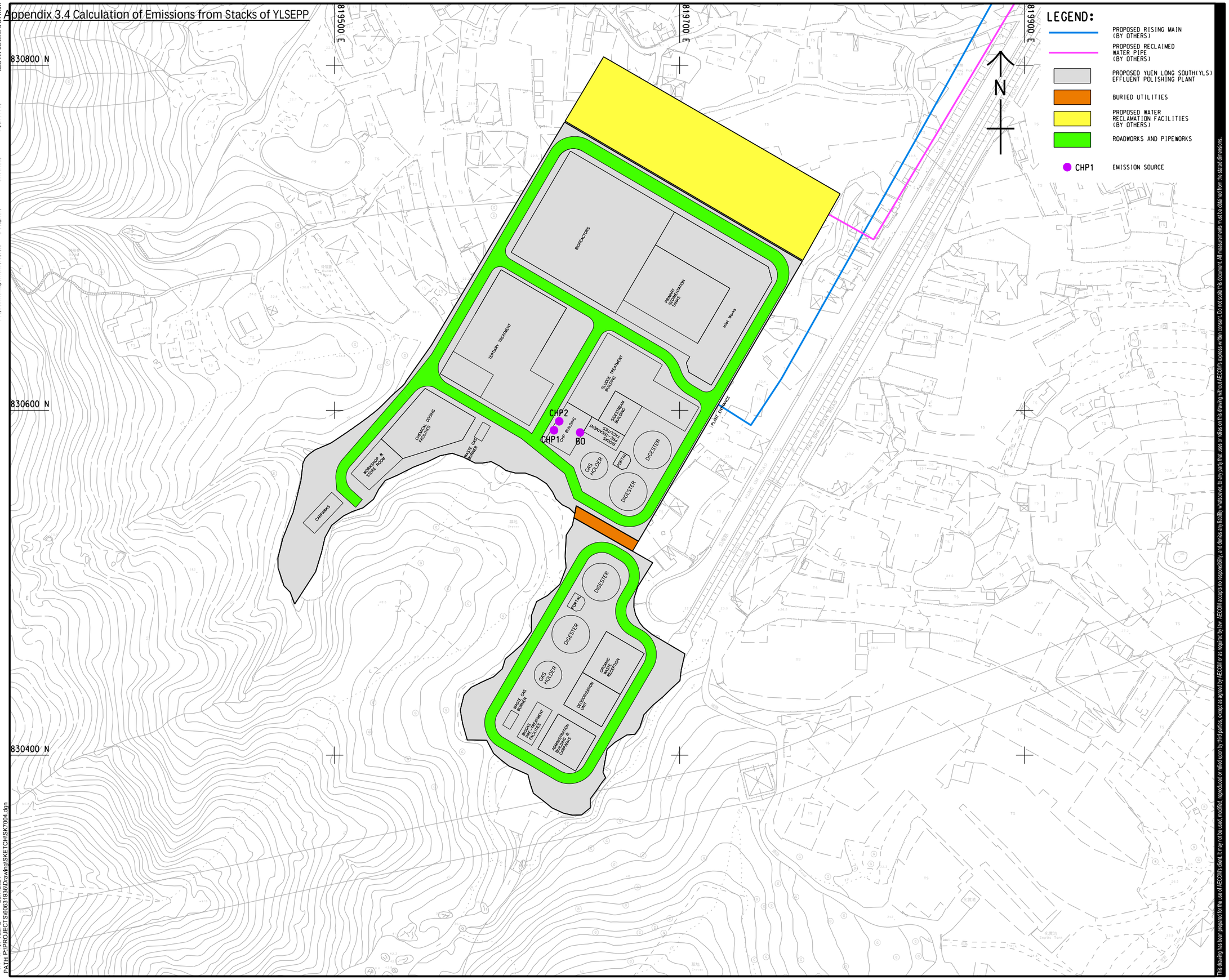
Boiler Exhaust flow rate estimate
Boiler biogas maximum demand: 215 m3/hr (provided by the Engineer, based on sludge treatment process requirements)
CH4 consumed by boiler : 215 x 60% x 0.886 = 114.5 Nm^3/hr
Using ratio from (a) : Wet boiler exhaust flow rate at standard condition (273K, 101,325 Pa): 114.5 x 17 = 1,947 Nm^3/hr (wet)
Wet boiler exhaust flow rate at actual condition (453K, 101,325 Pa): 1,947 / 273K x 453K x 101,325/101,325 = 3,231 m3/hr = 0.90 m^3/s (wet)
Using ratio from (b) : Dry boiler exhaust flow rate at standard condition (273K, 101,325 Pa, 0% moisture) = 1,947 x (3,297 / 3,718) = 1,726 Nm^3/hr (dry)
^Assume air pressure is equivalent to standard condition.at altitude of exhaust discharge point.

Example for RSP emission rate for boiler
RSP emission concentration as per CHP estimate : 15 mg/Nm^3
Boiler RSP emission rate = 15 x 1,726 x (20.9-5)/(20.9-6) / 3,600s / 1,000g/kg = 0.0077 g/s

Emission Sources Listing in Aermod

Source ID	Fuel Type	Type	X	Y	Height (mAG)	Exit Temp. (K)	Exit velocity (m/s)	Stack Diameter (m)	RSP Emission Rate[1]	FSP Emission Rate[1]	NO_x Emission Rate[1]	SO_2 Emission Rate[1]	CO Emission Rate[1]	Methane Emission Rate[1]	HCL Emission Rate[1]	HF Emission Rate[1]	Formaldehyde Emission Rate[1]	Remarks
CHP1	Biogas	POINTCAP	819637.00	830598.00	21.0	453.0	13.17	0.45	1.79E-02	1.79E-02	2.80E-01	5.97E-02	7.28E-01	1.79E-01	1.19E-02	1.19E-03	1.67E-02	No dry deposition applied for RSP & FSP
CHP2	Biogas	POINTCAP	819632.00	830589.00	21.0	453.0	13.17	0.45	1.79E-02	1.79E-02	2.80E-01	5.97E-02	7.28E-01	1.79E-01	1.19E-02	1.19E-03	1.67E-02	No dry deposition applied for RSP & FSP
BO	Biogas	POINTCAP	819642.00	830591.00	21.0	453.0	12.69	0.30	7.67E-03	7.67E-03	1.20E-01	2.56E-02	3.12E-01	7.67E-02	5.12E-03	5.12E-04	7.16E-03	No dry deposition applied for RSP & FSP

Remarks:
1. Emission rate of point source and volume source is in gram per second (g/s)



ISO A1 594mm x 841mm

Approved:

Checked:

Designer:

Project Management Initials:

Plot File by: YaoFB
PATH: P:\PROJECT\S60631936\Drawing\SKETCH\SK7004.dgn
28/7/2021

AECOM

PROJECT
項目

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

CLIENT
客戶

渠務署
Drainage Services Department

CONSULTANT
工程顧問公司

AECOM Asia Company Ltd.
www.aecom.com

SUB-CONSULTANTS
分判工程顧問公司

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 : 1000

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 EXHAUST POINT

SHEET NUMBER
圖紙編號

60631936/SK7004

Technical Description

Cogeneration Unit

Grid Parallel with Island Operation
no special Grid Code

Biogas

Electrical output	851	kW el.
Thermal output	982	kW

Emission values

NOx	< 250 mg/Nm³ (5% O2)	< 95 mg/Nm³ (15% O2)
CO	< 650 mg/Nm³ (5% O2)	< 250 mg/Nm³ (15% O2)

0.01 Technical Data (at module)

			100%	75%	50%
Power input	[2]	kW	2,167	1,648	1,148
Gas volume	*)	Nm³/h	361	275	191
Mechanical output	[1]	kW	876	657	438
Electrical output	[4]	kW el.	851	636	420
Recoverable thermal output					
~ Intercooler 1st stage	[9]	kW	167	92	30
~ Lube oil		kW	105	97	80
~ Jacket water		kW	252	219	178
~ Exhaust gas cooled to 180 °C		kW	458	347	254
Total recoverable thermal output	[5]	kW	982	755	542
Total output generated		kW total	1,833	1,391	962
Heat to be dissipated (calculated with Glykol 37%)					
~ Intercooler 2nd stage		kW	59	42	26
~ Lube oil		kW	---	---	---
~ Surface heat	ca. [7]	kW	73	~	~
Spec. fuel consumption of engine electric	[2]	kWh/kWel.h	2.55	2.59	2.73
Spec. fuel consumption of engine	[2]	kWh/kWh	2.47	2.51	2.62
Lube oil consumption	ca. [3]	kg/h	0.26	~	~
Electrical efficiency			39.3%	38.6%	36.6%
Thermal efficiency			45.3%	45.8%	47.2%
Total efficiency	[6]		84.6%	84.4%	83.8%
Hot water circuit:					
Forward temperature		°C	90.0	85.4	81.0
Return temperature		°C	70.0	70.0	70.0
Hot water flow rate		m³/h	42.2	42.2	42.2
Fuel gas LHV		kWh/Nm³	6		

*) approximate value for pipework dimensioning
[ ] Explanations: see 0.10 - Technical parameters

All heat data is based on standard conditions according to attachment 0.10. Deviations from the standard conditions can result in a change of values within the heat balance and must be taken into consideration in the layout of the cooling circuit/equipment (intercooler; emergency cooling; ...). In the specifications in addition to the general tolerance of ±8 % on the thermal output a further reserve of +5 % is recommended for the dimensioning of the cooling requirements.

0.02 Technical data of engine

Manufacturer		
Engine type		
Working principle		4-Stroke
Configuration		V 70°
No. of cylinders		16
Bore	mm	135
Stroke	mm	170
Piston displacement	lit	38.93
Nominal speed	rpm	1,500
Mean piston speed	m/s	8.50
Length	mm	2,852
Width	mm	1,457
Height	mm	1,800
Weight dry	kg	4,200
Weight filled	kg	4,690
Moment of inertia	kgm²	8.97
Direction of rotation (from flywheel view)		left
Radio interference level to VDE 0875		N
Starter motor output	kW	7
Starter motor voltage	V	24

Thermal energy balance

Power input	kW	2,167
Intercooler	kW	226
Lube oil	kW	105
Jacket water	kW	252
Exhaust gas cooled to 180 °C	kW	458
Exhaust gas cooled to 100 °C	kW	572
Surface heat	kW	40

Exhaust gas data

Exhaust gas temperature at full load	[8]	°C	486
Exhaust gas temperature at bmep= 13.5 [bar]		°C	~ 490
Exhaust gas temperature at bmep= 9 [bar]		°C	~ 510
Exhaust gas mass flow rate, wet		kg/h	4,760
Exhaust gas mass flow rate, dry		kg/h	4,421
Exhaust gas volume, wet		Nm³/h	3,718
Exhaust gas volume, dry		Nm³/h	3,297
Max.admissible exhaust back pressure after engine		mbar	60

Combustion air data

Combustion air mass flow rate	kg/h	4,387
Combustion air volume	Nm³/h	3,394
Max. admissible pressure drop at air-intake filter	mbar	10