Expert Assessment

of the Flue Gas Treatment Process Implemented in the Delfzijl (NL) Waste Incineration Plant

Issued by:

Prof. Dr.-Ing. Rudi Karpf

Officially appointed and sworn expert in
combustion process engineering; flue gas treatment, analysis and measuring

November 2015

Client:	EEW Energy from Waste Delfzijl B.V. Oosterhorn 38 9936 HD Farmsum The Netherlands
Contact:	Horst Bieber Phone: +31 596 67 42 1 Mobile: +49 160 5388506 Email Horst.Bieber@eew-energyfromwaste.com
Plant concerned:	Delfzijl Waste-to-Energy Plant Oosterhorn 38 9936 HD Farmsum The Netherlands
Plant section under review:	Flue gas treatment systems
Operator:	EEW Energy from Waste Delfzijl B.V. Oosterhorn 38 9936 HD Farmsum The Netherlands
Expert:	Prof. Dr.-Ing. Rudi Karpf[1] Ohlengasse 3 35423 Lich Germany Phone +49 6404 65 81 64 Fax +49 6404 65 81 65 Email rudi.karpf@ete-a.de
Task:	Expert assessment of the flue gas treatment processes implemented in the Delfzijl waste incineration plant
Translation:	Translation from German to English by Wolfram Baur (Freier Übersetzer (BDÜ)) Goethestr. 91 45130 Essen (Germany) Phone +49 201 43737-11 Fax +49 201 43737-20 wbaur@techtranslations.net

Lich, 28 November 2015

Prof. Dr.-Ing. Rudi Karpf

[1]Officially appointed and sworn expert in combustion process engineering and flue gas treatment, analysis and measuring; appointed by the Giessen-Friedberg Chamber of Industry and Commerce. Member of the national expert panel appointed by the UBA (German Federal Environment Agency) for the amendment of the Reference Documents on Best Available Techniques (BAT) for Waste Incineration.

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Abbreviations

BAT	Best Available Technique
DeNOx	Denitrification
Eco	Economizer
HOK	Rotary hearth furnace lignite coke, sometimes also referred to as “activated lignite” (the abbreviation HOK derives from the German designation “Herdofen Aktiv-Koks”)
LCV	Lower Calorific Value
CED	Cumulative Energy Demand
CED_P	Cumulative energy demand – Production
CED_U	Cumulative energy demand – Use
CED_D	Cumulative energy demand – Disposal
RD BAT	Reference Document on Best Available Techniques
SCR	Selective Catalytic Reduction
SD	Spray Dryer

1 Task assigned

EEW Energy from Waste operates a waste incineration plant for commercial and domestic waste and refuse-derived fuels at the Oosterhorn Delfzijl industrial park, in the Dutch province of Groningen. The very high demand for electric and thermal energy in the neighbouring chemical park is an important advantage of the plant site.

The Delfzijl waste-to-energy plant consists of two incineration lines which are identical in design; both lines together can incinerate up to 384,000 metric tons of waste per year to generate electric power and steam. The generated steam (max. 148 metric tons per hour) is supplied to industrial enterprises in the vicinity. Flue gases are treated in a multi-stage emission control system, comprising a two-stage dry sorption process and a catalytic nitrogen oxide reduction process.

To meet the increased energy demand of the neighbouring industrial plants, there are plans to build a third incineration line, identical in design to the two existing lines. In the permitting context, an assessment of the existing flue gas treatment system has been required, which is the subject matter of the present expert opinion.

The assessment of the flue gas treatment process (design) implemented at the Delfzijl plant is carried out by taking current best available techniques (BAT) as a reference for assessing the emission values achieved in the past. Furthermore, the energy efficiency aspect of the flue gas treatment process is assessed on the basis of the cumulative energy demand, by comparison with a comparable wet flue gas treatment process.

Fig. 1: *Aerial view of the Delfzijl industrial zone* [1]

2 Plant description

The plant description below is intended to provide an insight into the process technology implemented in the plant, the plant technical data, and the emission values achieved.

2.1 Plant design

As the focus of this expert assessment is on the flue gas treatment system, the combustion and energy conversion systems in the narrower sense (boiler, turbine) are left out of the consideration.

As illustrated in Fig. 2, the flue gas treatment system is based on a two-stage process designed to achieve the lowest possible emission values. The first stage consists merely of a dry sorption process, in which sodium bicarbonate ($NaHCO_3$) is blown into the flue gas flow which leaves the boiler at a temperature of approx. 230 °C; in this stage, the majority of the acidic flue gas constituents SO_3, SO_2, HCl, HF are removed. The fly ash and the reaction salts produced are separated in a fabric filter. Thereafter, the nitrogen oxides (NOx) are reduced in a catalytic process stage referred to as the selective catalytic reduction (SCR) system at a process temperature of approx. 230 °C. A diluted aqueous solution of ammonia (24% ammonia liquor) is used as the reducing agent and spray-injected into the flue gas flow upstream from the catalyst.

The second stage consists of another dry sorption process stage with a fabric filter; this time, however, the dry sorption process is based on normal hydrated lime ($Ca(OH)_2$) and proportioning of activated lignite coke (HOK). The main role of this second stage is to reduce the amounts of heavy metals (especially mercury) and dioxins and furans in the flue gases, by adsorption on activated coke. Furthermore, the remaining acidic flue gas constituents are removed in this stage. For this separation process to be effective, it is necessary to cool the flue gas down by means of an economizer (Eco) to a temperature of approx. 140 °C. Besides ensuring favourable separation conditions, this temperature reduction also provides a significant improvement of the energy efficiency of the overall plant. The heat capacity recovered in this process amounts to 4,500 kW.

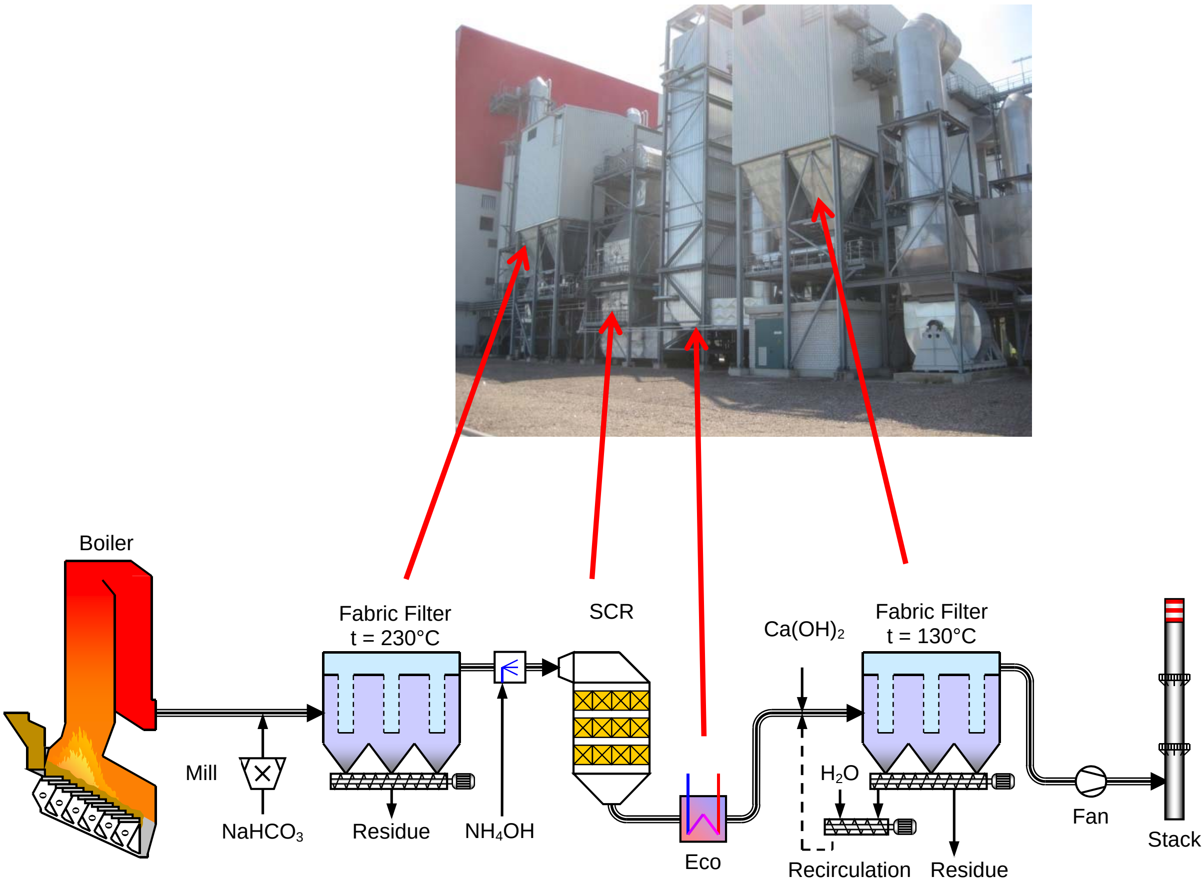

Fig. 2: *Simplified process flow diagram of the flue gas treatment system in the Delfzijl waste incineration plant* [1]

2.2 Technical data of the plant

The data given below have been extracted from the operation manual provided by LAB (manufacturer of the flue gas treatment system) and from operation records of the plant operator EEW Energy from Waste Delfzijl B.V.

Table 1: *Operating and design data, extracted from the operation manual issued by the plant manufacturer LAB*

PROCESS PARAMETER	UNIT	RATED LOAD	MAX.	MIN.	100% AUXILIARY BURNER OPERATION
Volume flow at boiler outlet	m^3/h, std moist	111,495	132,872	63,309	93,000
Volume flow at boiler outlet	m^3/h, std dry	99,431	109,101	53,566	82,000
N_2	wt%	70.76	66.46	68.88	71.95
O_2	%	7.70	7.23	5.10	5.41
CO_2	wt%	10.72	8.42	10.63	15.43
Moisture	wt%	10.82	17.89	15.39	7.20
Temperature at boiler outlet	°C	230	230	230	230
Pressure at boiler outlet	mbar	-6,8	-19,0	-2,5	-1,8
Temperature at Eco outlet	°C	$\geq$ 140	$\geq$ 140	$\geq$ 140	$\geq$ 140

Table 2: *Concentration of noxious gases / emission values in 2014* [2]

Process Parameter	Unit	Value measured downstream from first fabric filter	Value measured downstream from catalyst	Value measured at stack	Value required by permit
Particulate matter	mg/m³	< 1	< 1	< 0.1	5
C_{ges}	mg/m³			< 0.1	10
HCl	mg/m³	< 115	< 115	< 1	8
SO_2	mg/m³	< 30	< 30	< 5	40
NO_x	mg/m³	350	< 70	< 70	70
Hg	mg/m³			< 0.005	0.02
CO	mg/m³			< 10	30
NH_3	mg/m³			< 3	5
Flue gas temperature	°C	230	230	> 135	

2.3 Operating experience, emission values achieved to date

The first of the two existing waste incineration lines at the Oosterhorn 38, 9936 HD Farmsum site has been in operation since 2010, i.e. operating experience from five years is now available. No noteworthy trouble with the plant has been reported and the systems feature a very high level of effectiveness and availability. The performance of the multi-stage flue gas treatment system is documented on the basis of the 2014 operating records (cf. Figures 3 – 5 and Appendix I)).

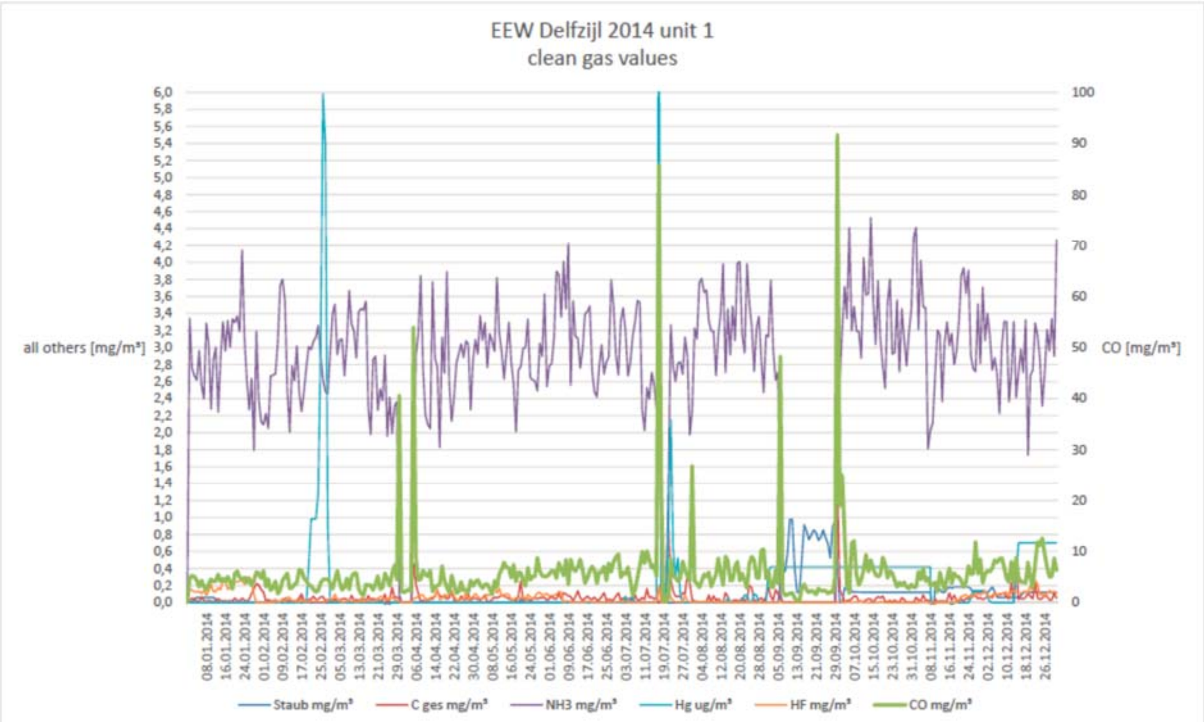

Fig. 3: *Emissions from the Delfzijl waste incineration plant, Line 1, in 2014* [2]

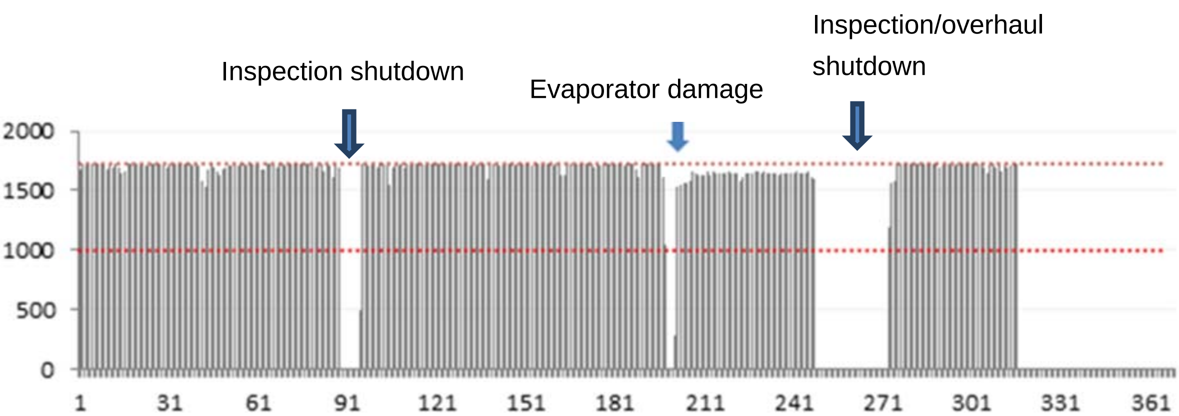

Fig. 4: *Steam load curve of the Delfzijl waste incineration plant, Line 1, in 2014* [2]

From the steam load curve (Fig. 4) it can be seen that an inspection was carried out in March and a major inspection/overhaul in September/October. In July, an unscheduled downtime was caused by tube damage in the evaporator part of the boiler; the fire in the furnace was extinguished by the escaping water. These factors gave rise to increased emission values, especially of carbon monoxide (CO), which finds its reflection in the emission peaks in Figure 3. In normal operation in line with the specifications, the emission values were always far below the required emission limits.

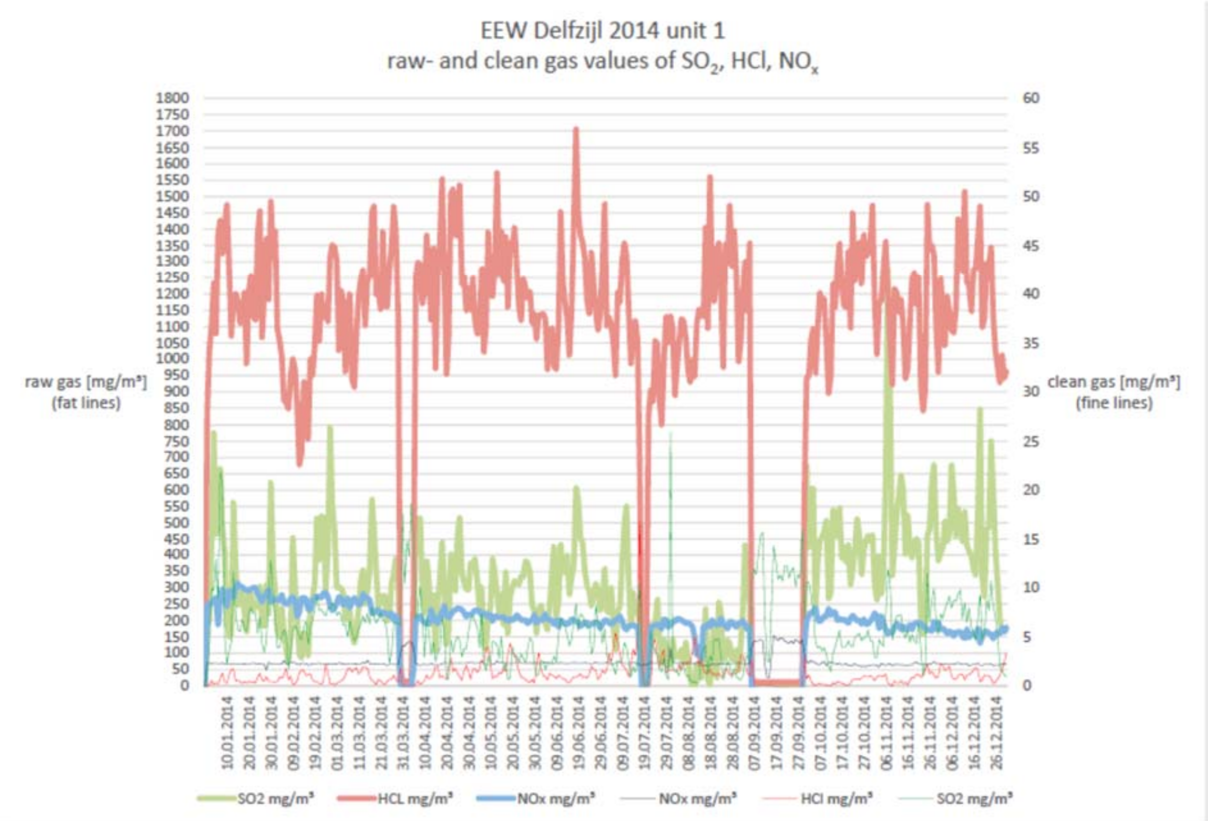

Fig. 5: *Raw and clean gas values of SO_2, HCl, HF at the Delfzijl waste incineration plant, Line 1, in 2014* [2]

3 Assessment of the existing/proposed flue gas treatment systems with reference to the BAT

In the following sections, the design of the existing and proposed flue gas treatment systems in the Delfzijl waste incineration plant is compared with and discussed with reference to the information provided in the *Reference Document on the Best Available Techniques for Waste Incineration* [3] (referred to below as RD BAT) in the document version of August 2006 which is still valid. In this context, the subchapters 4.3 (*Energy recovery*) and 4.4 (*Flue gas treatment*) in Chapter 4 (*Techniques to consider in the determination of BAT*) of the RD BAT are relevant.

3.1 Energy recovery

In Chapter 4.3.1 *Optimisation of overall energy efficiency and energy recovery, pages 284 and 285 (Achieved environmental benefits)* of the RD BAT it is pointed out that the plant should be designed and executed for optimum energy recovery, adapted to the energy demand structure. Exactly this has been implemented in the chosen process structure of the flue gas treatment systems in the Delfzijl plant. Owing to the fact that the two flue gas treatment stages needing high flue gas temperatures – dry sorption using sodium bicarbonate ($NaHCO_3$), followed by catalytic nitrogen oxide reduction – are the first two stages in the configuration, recuperative flue gas cooling and associated recovery of waste heat are possible without detriment to the treatment process. Such recuperative flue gas cooling from approx. 230 °C to 140 °C is integrated into the water/steam cycle of the boiler.

The “cross-media effects” aspect (RD BAT, page 286), i.e. the necessity to find the right balance between energy efficiency and emission control technology, was considered and implemented in an exemplary manner in Delfzijl. Although process stages such as fabric filters and selective catalytic NOx reduction, which the RD BAT characterizes as being very energy-intensive technologies, are employed, no disadvantages result for the overall energy balance (cf. Section 4 below).

Furthermore, in Chapter 4.3.2 of the RD BAT, *Energy loss reduction: flue gas losses* (pages 290 and 291) measures are identified which reduce the amount of heat leaving the plant with the flue gas. As mentioned above, this aspect has been duly considered as regards the operating temperatures required and the design and arrangement of the different flue gas process stages of the existing and proposed flue gas treatment systems in such a manner that it is possible to do without energy-intensive flue gas reheating.

RD BAT Chapter 4.3.6 *Reduction of overall process energy consumption* explicitly mentions aspects and sources of significant process energy consumption. Most of the consumption sources mentioned there, such as

- flue gas reheating for specific process stages (e.g. SCR),
- flue gas reheating to reduce plume visibility, and
- use of a wet flue gas treatment process

have not been implemented in the Delfzijl plant, and the plant thus meets the energy efficiency requirements specified in the RD BAT to a very large extent.

In this chapter of the RD BAT it is also pointed out that the lower the emission limit values applied, the more energy is consumed by the flue gas treatment system. While this will probably be true for many existing plants, it is not applicable to the plant design chosen for the Delfzijl plant (cf. Section 4 below).

3.2 Flue gas treatment

Chapter 4.4.1 of the RD BAT, *Factors to consider when selecting flue-gas treatment systems*, placed right at the beginning of RD BAT Chapter 4.4, *Flue-gas treatment*, describes energy optimisation criteria which should be taken into account when defining the plant design concept. Chapter 4.4.1.2 *Energy optimisation* (page 318) points out the need to arrange the different process stages in line with their required process temperatures, avoiding additional input energy requirements (e.g. for flue gas reheating). As already mentioned in Section 3.1 above, these requirements are fully met by the design of the existing and proposed flue gas treatment systems in Delfzijl.

The second fabric filter stage in the Delfzijl plant configuration performs exactly those functions described in RD BAT Chapter 4.4.2.2, *Application of an additional flue gas polishing system, such as*

- separation of dust/fine dust,
- effective adsorption of heavy metals, specifically mercury,
- effective adsorption of dioxins/furans, and
- separation of acid noxious gas constituents (HCl, HF, SO_3, SO_2).

For the separation of the noxious gas constituents, in comparison with a wet scrubbing process as described in RD BAT Chapter 4.4.3.1 *Wet scrubbing systems* (pages 230-233), the following assessment is given. While dry and conditioned dry sorption processes remove several noxious gas components, such as acidic constituents, dust, heavy metals etc., simultaneously, this is not possible in the case of a wet flue gas treatment system. This means that the process configuration for comparable requirements is much more complex and thus much more energy intensive than in the case of a dry or conditioned dry process. Of course, wet flue gas scrubbing systems have a high selective separation capacity for halogens (HCl, HF) and SO_2. To a small extent, a wet scrubber can also separate dust, which then needs to be removed from the system in the form of sludge. According to the RD BAT, a 70 % separation of dioxins/furans can be achieved by proportioning activated carbon to the scrubbing water; however, the author of this expert opinion has no answer to the question on which separation mechanism this dioxin/furan separation effectiveness is based, because dioxins/furans are hydrophobic. The author rather assumes that this separating effect is due to adsorption processes occurring at the surfaces of scrubber materials used, such as plastic/rubber. Separation of mercury is basically possible in the so-called wet acidic scrubber stage. An effective and high separation performance crucially depends on the availability of sufficient amounts of halogenic reaction partners (ligands) for the formation of mercury complexes. However, the separation of mercury is subject to the requirement for suitable process control to ensure that sufficient ligands (HCl) are available in dissolved form in the scrubbing water at any time; in addition, there is the risk of metallic mercury (Hg°) being released from ionic mercury (Hg^{2+}), e.g. as a consequence of SO_2 peak concentrations. The removal of Hg° is then only possible in an effective manner with sufficient capacity by adsorption to special activated carbon. In the process design in Delfzijl, two-stage mercury removal has been implemented in the form of the two dry sorption stages, in which the tail-end sorption stage with its lower temperature functions as the actual mercury sink. To ensure a high Hg removal performance and cope with Hg peak concentrations even if metallic mercury (Hg°) is present, brominated activated carbon is added to the flue gas.

If the process configuration of the existing/proposed flue gas treatment systems in the Delfzijl plant is examined in the light of the most significant cross-media effects listed in Chapter 4.4.3.1 of the RD BAT (page 332), the following assessment can be given:

- *lowest reagent consumption rates*

  The first treatment stage (dry sorption using $NaHCO_3$), in which most of the acidic noxious gas constituents are removed, operates at a stoichiometric factor of 1.0 – 1.1, which is comparable to that of wet scrubbers (1.0).

- *lowest solid residue production rates*

  Due to the fact that the dry sorption process is operated at a stoichiometric factor of approx. 1.0 – 1.1, comparable amounts of residue are produced. However, there is a difference in the fact that in an <u>effluent free</u> wet process energy is required for evaporation of the scrubbing water and production of a solid residue.

- *higher water consumption*

  No water is used in the entire process chain, i.e. the process conserves water resources.

- *production of an effluent that requires management*

  No effluent is produced, i.e. compared to a wet scrubbing process no burden results in this respect for the environment in general or for a marine environment. On page 333 of the RD BAT, the use of a wet scrubber is recommended only where salty waste waters can be discharged without environmental impacts.

- *increased plume visibility*

  Since the process applied is a purely dry process, it does not give rise to a visible plume.

- *PCDD/F build up (memory effect) on scrubber plastic components requires addressing*

  There is no PCDD/F build up which could have an impact on the emission value. Dioxins/furans are removed in a three stage process:

- by fly ash removal (PCDD/F bonded to particles) in the first dry sorption stage,
- catalytic destruction of PCDD/F at the SCR catalysts, and
- adsorption to carbon-containing adsorbent in the second dry sorption stage.

• *if input temperature is too high the material used in the wet scrubber may be destroyed*

Thermal overstressing of materials is ruled out due to the selected process stages and arrangement of the different stages in the process sequence.

The achievable HCl, HF and SO_2 emission values specified in Chapters 4.4.3.1 (page 330) and 4.4.3.4 (page 342) of the RD BAT for a wet process and for a dry process using sodium bicarbonate, respectively, differ only in the HF emission value (wet process < 0.5 mg/m³; $NaHCO_3$ process < 1.0 mg/m³). However, since $NaHCO_3$ is used in the first dry sorption stage while hydrated lime is used in the second dry sorption stage of the Delfzijl plant, the reduction of HF to levels << 0.5 mg/m³ is ensured in the second stage at the latest.

By opting for a catalytic nitrogen oxide reduction (DeNOx) process, the best available technique has been chosen. Owing to the optimum arrangement of the DeNOx system in the process sequence, there is no need for an energy-intensive reheating of flue gases. By placing the DeNOx system downstream from the first dry sorption stage it is ensured that the catalysts can be operated with dust-free flue gas and without a risk of catalyst poisoning (e.g. sulphatization).

4 Energy efficiency assessment and comparison with a comparable wet flue gas treatment process in terms of cumulative energy demand

Energy efficiency is playing an ever more important role, whether in the climate discussion and the anthropogenic CO_2 emissions discussed in that context or in the field of conservation of natural resources. Therefore, in this section two different processes are assessed and compared with regard to their energy efficiencies; the two processes are comparable as regards their emission control performance and the achievement of a defined emission level. In order to ensure comparability, an energy balance is calculated on the basis of the cumulative energy demand (CED), considering both the energy consumed in production and operation of the plant and equipment, and the energy that will be consumed for disposal of the plant and equipment after a service life of 20 years.

By definition [5], the cumulative energy demand (CED) describes the total primary energy input which can be attributed and assigned to the production (CED_P), use (CED_U) and disposal (CED_D) of any goods or services.

$$CED = CED_P + CED_U + CED_D$$

4.1 Wet flue gas treatment process used as reference

Since in the discussions on the conceptual design of the flue gas treatment systems in Delfzijl the design of the existing (dry) flue gas treatment systems competes with a wet flue gas treatment process, the energy efficiency of the dry emission control process implemented in Delfzijl is assessed against the reference of a comparable wet process. Other single-stage processes, such as conditioned dry sorption processes using hydrated lime, which are likewise used downstream from waste incineration plants, in principle also perform excellently in terms of emission control performance, but they are not economically efficient if pollutant concentrations are high and comparable emission limit values must be complied with.

In general, wet and dry flue gas treatment processes can be characterized and distinguished as follows:

Table 3: *Characteristics of wet and dry air pollution control systems* [6]

Feature	Wet processes	Dry processes
Additives (Type and quantity)	Lime slurry or NaOH, low additive consumption (stoichiometric factor 1.0 to 1.1)	CaO, $CaCO_3$, $Ca(OH)_2$, higher additive consumption (stoichiometric factor 1.6 to > 2); $NaHCO_3$ (stoichiometric factor 1.1 to 1.5)
Residue volume and type	Small volumes of residues, possibility to recover recyclable materials such as gypsum, NaCl	Larger volumes of residues, depending on stoichiometry, residues need to be disposed/placed in landfills
Residue reduction measures	Recovery of recyclable materials (gypsum, NaCl)	Minimized additive input due to optimized process conditions; selection of additives
Pollution control performance depending on gas flow, pollutant concentration and pollutant properties	Selective removal of pollutants, high removal performance for acidic noxious gas constituents; a preliminary dust removal stage and an additional adsorption stage will normally be necessary	Simultaneous removal of acidic noxious gas constituents on an alkaline neutralization agent and of heavy metals, PCDD/F if adsorbents with large surface areas (e.g. HOK, activated carbon, clay minerals) are used
Removal selectivity	High selectivity	No selective removal
Energy demand	Higher demand	Low demand
Space requirements	Large space required, many plant components	Small space required, fewer plant components
Cost and effort	Larger effort, multi-stage system, waste water treatment (evaporation) required; higher costs	Smaller effort and lower costs

The configuration of the wet scrubbing system chosen for reference purposes is shown in Fig. 6; it is based on the process and emission conditions at the Delfzijl plant.

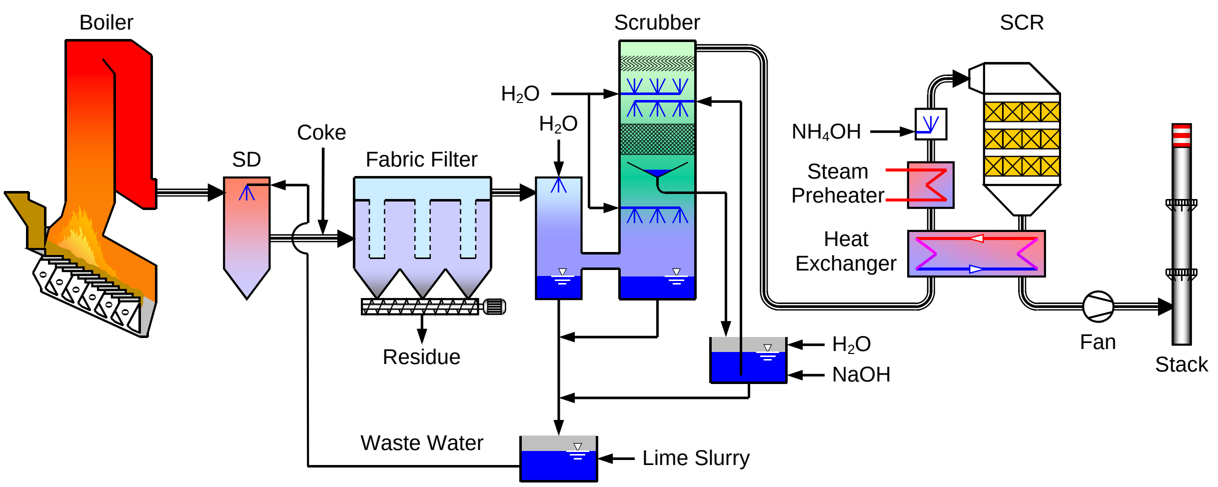

Fig. 6: *Two-stage wet scrubbing process, spray dryer, fabric filter and SCR system*

This means that a catalytic process for nitrogen oxide reduction and waste water-free operation are also assumed for the wet scrubbing process. This results in the configuration of the wet emission control process shown in Fig. 6, with a two-stage scrubber and tail-end SCR system for nitrogen oxide reduction. The waste water produced is evaporated in a spray dryer (SD) and the reaction salts are removed as dry residue in the downstream fabric filter. The fabric filter likewise performs the function of fly ash removal and, by addition of activated carbon, the function of dioxin/furan and mercury separation.

4.2 Determination of the cumulative energy demand

For determination of the cumulative energy demand for production and disposal of the various components of the flue gas treatment systems for the two process variants, the mass and energy balances were compiled on the basis of the boundary conditions described in Chapter 2.2. Applying the specific energy input in the different materials and taking into consideration the energy expended in erection/dismantling and transport it was possible to calculate the cumulative energy demand components CED_P and CED_D. The values calculated are given in the Annex [Appendix II].

For determination of the cumulative energy demand for the operation of the systems (CED_U), the relevant interdependencies as regards the consumables required (cf. Fig. 7), such as hydrated lime, sodium bicarbonate, compressed air and general electrical loads were analysed and calculation approaches for mass and energy assessments derived on the basis of practical experience.

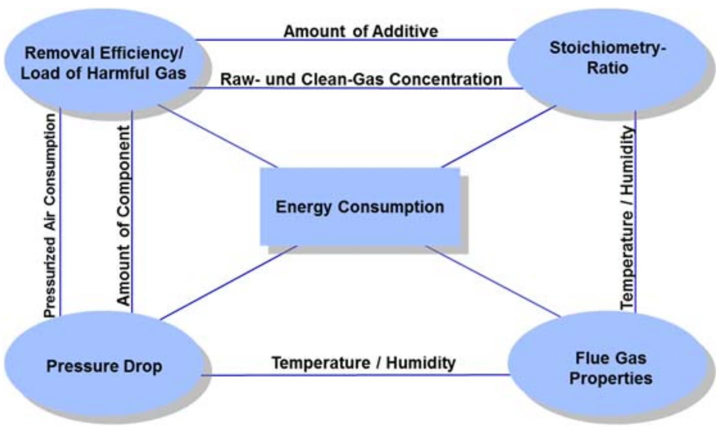

Fig. 7: *Network structure diagram of influencing factors for energy demand in flue gas treatment systems* [4]

As in both process types most of the energy is consumed for the removal of the acidic noxious gas components (HCl, HF, SO_2), the balancing has been done for a noxious gas concentration of 1,300 mg/m³ HCl and 500 mg/m³ SO_2, as can be considered typical of the Delfzijl plant. From the energy and mass balances, the values given in Table 4 have been calculated:

Table 4: *CED_U for the Delfzijl system and wet scrubber (HCl raw gas 1,300 mg/m³; SO2 raw gas 500 mg /m³)*

Device	Energy accrual via	Unit	2-stage dry system (Delfzijl)	Wet system
Electrical Energy	Compressed air	[kW]	66	107
	ID fan	[kW]	433	596
	Other devices	[kW]	100	162
	Total	[kW]	599	865
	$CED_{U\text{-electricity}}$	[kJ/h]	4,981,284	7,193,340
	$CED_{U\text{-electricity}}$	MJ	39,850,272	57,546,720
Additives	$Ca(OH)_2$	[kg/h]	41	122
	$NaHCO_3$	[kg/h]	527	-
	NaOH	[kg/h]	-	160
	Lignite coke	[kg/h]	47	47
	NH_3	[kg/h]	19	19
	$CED_{Ca(OH)2}$	[kJ/h]	149,144	442,726
	CED_{NaHCO3}	[kJ/h]	3,740,280	-
	CED_{NaOH}	[kJ/h]	-	1,120,700
	$CED_{lignite\ coke}$	[kJ/h]	1,771,900	1,786,980
	CED_{NH3}	[kJ/h]	657,400	657,400
	$CED_{U\text{-additive}}$	[kJ/h]	6,318,724	4,007,806
	$CED_{U\text{-additive}}$	MJ	50,549,792	32,062,448
Water	m_{H2O}	[kg/h]	-	8,621
	CED^2_{H2O}	[kJ/h]	-	-
Thermal energy	Heat	[kJ/h]	-	5,639,058
	$CED_{NG(eq)}$	[kJ/h]	-	5,695,449
	$CED_{NG(eq)}$	MJ		45,563,589
Residue	$m_{res.}$	[kg/h]	619	494
Transport	$CED_{U\text{-transport}}$	[kJ/h]	766,662	515,661
	$CED_{U\text{-transport}}$	MJ	6,133,296	4,125,288
CED_U		**[kJ/h]**	12,066,670	17,412,256
Energy offtake		[kJ/h]	13,202,286	-
CED energy offtake		[kJ/h]	17,162,972	-
CED energy offtake		MJ	-137,303,774	-
$CED_{U\text{-effective}}$		**[kJ/h]**	**-5,096,302**	**17,412,256**
$CED_{U\text{-effective}}$		**MJ**	**40,770,414.40**	**139,298,044.64**
$CED_{U\text{-effective}}$		**[MW]**	**-1.42**	**4.84**

[2] The CED for the medium water was not considered

The balance study of the individual cumulative energy demands shows that the CED_P and the CED_D each account for less than 1 percent of the total CED and, in comparison with the CED_U can almost be neglected (cf. also Figs. 8 and 9, and Appendix II).

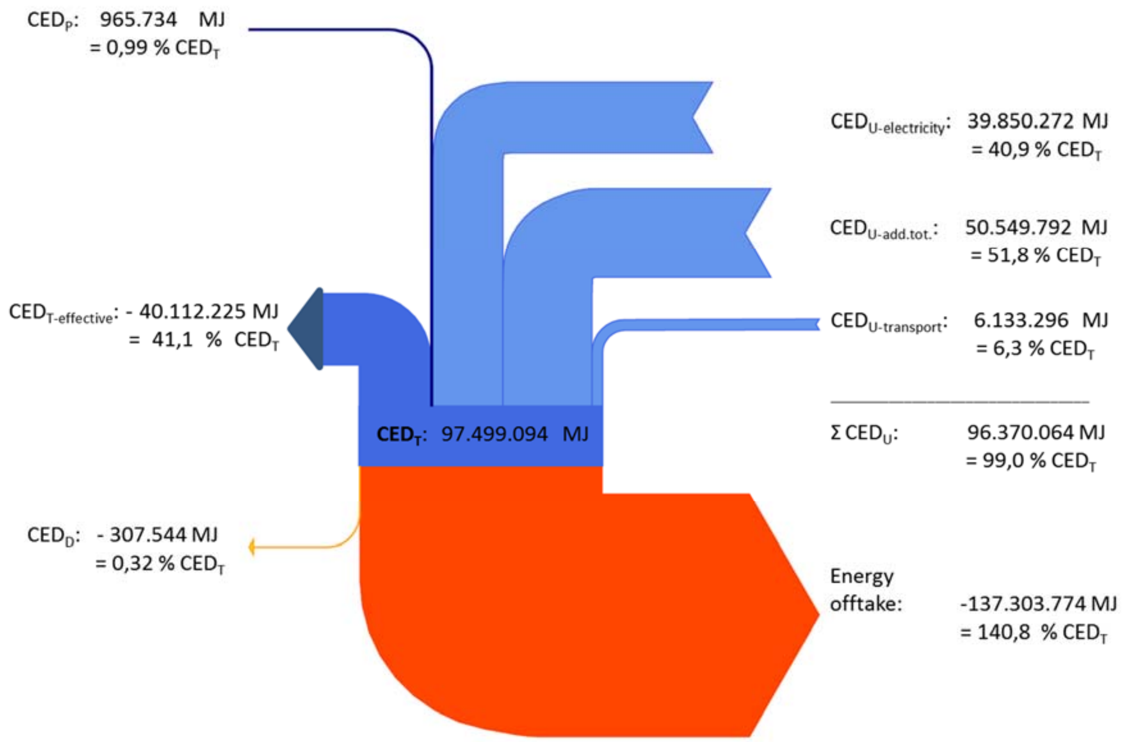

Fig. 8: *Sankey diagram: Total CED for the existing and proposed flue gas treatment in Delfzijl, reference period 8000 h*

As can easily be seen from Fig. 8, a cumulative energy offtake of almost 137,304 GJ results for the process design of the existing Delfzijl plant, which is due to the recovery of energy by means of the heat exchanger (external economizer) between the SCR system and the second dry sorption stage. The amount of energy of approx. 140,000 GJ corresponds to approx. 38,889 MWh and, with reference to the assumed annual operation time of 8,000 hours, to a capacity of 4.86 MW.

The wet flue gas treatment system in contrast, with its cumulative energy demand for operation (CED_U) of 140,000 GJ, almost consumes the same amount of energy as is recovered from the existing flue gas treatment system in the form of usable energy in Delfzijl. This means that in a direct comparison with a wet flue gas treatment system, the use of the two-stage dry sorption process (Delfzijl) will save a total net amount of approx. 280,000 GJ in energy per year, which is equivalent to a capacity of approx. 9.7 MW.

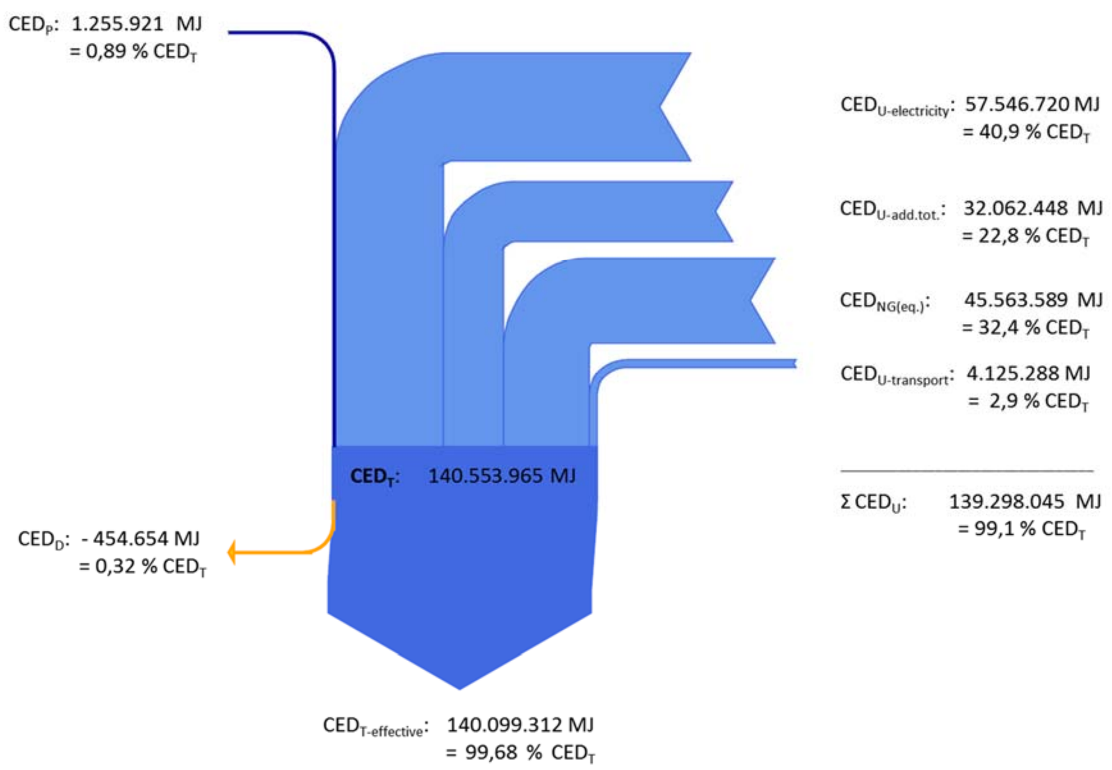

Fig. 9: *Sankey diagram: Total CED for a wet based flue gas treatment system, reference period 8000 h*

5 Summary and conclusion

The present expert opinion aims at providing an objective assessment of the conceptual designs of the existing and proposed flue gas treatment systems. Thanks to the fact that operating experience from five years is available, it is fundamentally possible to verify the effectiveness of the flue gas treatment system on the basis of the emission values achieved.

Since the *Reference Document on the Best Available Techniques for Waste Incineration* is gaining ever more importance due to recent European legislation and the permitting requirements to be derived from that legislation for plants of that type, the chosen flue gas treatment concept has been assessed against the yardstick of the requirements described in this Reference Document. The analysis of the design of the flue gas treatment system in the light of the requirements described in the *Reference Document on the Best Available Techniques for Waste Incineration* shows that with the design implemented and proposed in Delfzijl, these requirements are fully satisfied. Moreover, the experience gained in Delfzijl has shown that even stricter requirements than those described in the Reference Document can be met, thereby defining a new state of the art.

Table 5 provides a summary view of a qualitative comparison of the flue gas treatment system design chosen in Delfzijl and a comparable wet process.

Table 5: *Qualitative comparison of characteristics of the dry flue gas treatment system in Delfzijl and a comparable wet scrubbing process*

Criterion	Delfzijl dry flue gas treatment process	Wet scrubbing process
Emission level	0	0
Volume of residues produced	0/-	+
Water consumption	+	- -
Wastewater production	+	- -
Energy consumption	+	- -
Waste heat recovery	+	- -
Consumables consumption	0/-	+
Complexity	+	- -
0 neutral; + positive; - somewhat negative; - - very negative		

Especially as regards energy efficiency, to which tremendous importance is attributed today, Delfzijl can be considered a role model and is way ahead of the documented state of the art. Due to the optimum configuration and coupling of the individual process stages, and to the recuperative energy recovery, in comparison with a comparable process (e.g. a wet scrubbing process), net energy savings of approx. 9.7 MW are calculated on the basis of the cumulative energy demand for the flue gas treatment system alone. This means that a considerable amount of primary energy is saved; if, for instance natural gas H (LCV = 11 kWh/m³) is used for thermal energy input, a total of 7.07[3] million m³ per year of natural gas H can be saved. This primary energy saving is equivalent to 19,133 metric tons of avoided CO_2 emissions[4] per year.

From an expert point of view, it is recommended to build and operate the flue gas treatment system for the third incineration line in the Delfzijl waste incineration plant, which is pending approval, identically in terms of design and process configuration to the flue gas treatment systems of the existing two incineration lines.

[3] Without consideration of combustion efficiency
[4] CO_2 equivalents on the basis of the summary of greenhouse gas emissions as CO_2 equivalent emissions including upstream chains (data source: GEMIS 4.18, year 2013) 246 g/kWh_{LCV}

6 References

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[2] Operation data and operation records of EEW Energy from Waste Delfzijl B.V., Oosterhorn 38, 9936 HD Farmsum, Netherlands

[3] EUROPEAN COMMISSION; Reference Document on the Best Available Techniques for Waste Incineration, August 2006

[4] Karpf, R.; Emissions-related energy indicators for flue gas treatment systems in waste incineration; TK Verlag Karl Thomé-Kozmiensky, ISBN 978-3-944310-14-5, Neuruppin 2014

[5] VDI Standard 4600. Cumulative energy demand – Terms, definitions, methods of calculation. Berlin : Beuth-Verlag, 2012. ICS 01.040.27, 27.100

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7 Annex

Appendix I Jahres-Emissionswerte Delfzijl

Datum: 23.11.15

E.ON Energy from Waste

Jaarrapport concentratie emissies lijn 12 voor het Jaar 14
Statistiek lijn 11 vanaf Maand 01.14 t/m 1.01.14

KKS Eenheid	Debiet 12 12HNE20CF901 m3/h	Temp. 12 12HNE20CT001 °C	Druk 12 12HNE20CP001 mbar	Vocht 12 12HNE20CM001 Vol%	O2 12 12HNE20CQ001 Vol%	Stof 12 12HNE20CQ002 mg/Nm3	HCL 12 12HNE20CQ003 mg/Nm3	NOx 12 12HNE20CQ005 mg/Nm3	CO 12 12HNE20CQ009 mg/Nm3	CO10 12 12HNE20CQ009 mg/Nm3	SO2 12 12HNE20CQ004 mg/Nm3	C-tot12 12HNE20CQ006 mg/Nm3
EGW 100% dag gemidd.						5.0	8.0	100	30	-	40	10
EGW 97% dag gemidd.						-	-	-	50	-	-	-
EGW 100% mnd gemidd.						-	-	100	-	-	-	-
EGW 100% 1/2h gemidd.						15.0	60	400	150	-	200	20
EGW 97% 1/2h gemidd.						5.0	8.0	180	-	-	40	10
EGW 95% 10min gemidd.						-	-	-	-	150	-	-
Max niet beschikbaar						10	10	10	10	10	10	10
1.01.14	99959	139.73	1003.55	15.26	6.63	0.02	0.02	67.12	4.06	4.06	1.60	0.11
1.02.14	103538	141.19	997.55	15.59	7.06	0.04	0.02	66.59	3.54	3.54	2.24	0.10
1.03.14	105336	140.93	1024.41	15.20	7.10	0.01	0.19	66.12	3.65	3.65	3.35	0.07
1.04.14	105281	141.44	1021.69	14.54	7.18	0.01	0.08	65.12	3.14	3.14	2.45	0.10
1.05.14	101787	140.30	1023.00	14.68	7.17	0.01	0.09	67.73	2.52	2.52	0.97	0.08
1.06.14	73836	101.26	1028.76	11.15	10.35	0.00	0.00	66.81	2.00	2.00	1.34	0.07
1.07.14	98605	140.85	1021.47	15.97	6.28	0.01	0.62	68.00	2.23	2.23	0.40	0.05
1.08.14	104239	142.36	1014.53	15.49	6.88	0.01	0.08	67.05	1.82	1.82	0.69	0.07
1.09.14	102568	141.49	1029.89	15.45	6.83	0.07	0.09	65.57	1.49	1.49	0.70	0.06
1.10.14	97201	140.86	1019.72	16.20	5.99	0.10	0.01	63.26	2.62	2.62	0.49	0.04
1.11.14	101172	141.44	1014.91	15.98	6.60	0.13	0.13	62.39	2.50	2.50	5.02	0.05
1.12.14	101618	141.15	1021.43	15.82	6.60	0.17	0.64	63.01	4.39	4.39	5.88	0.06
Laagste waarde	73836	101.26	997.55	11.15	5.99	0.00	0.00	62.39	1.49	1.49	0.40	0.04
Hoogste waarde	105336	142.36	1029.89	16.20	10.35	0.17	0.64	68.00	4.39	4.39	5.88	0.11
Gemiddelde t/m 31.12.14	99588	137.78	1018.42	15.13	7.03	0.05	0.16	65.70	2.85		2.13	0.07
% MW <= EGW Dag						100.00	100.00	100.00	100.00		100.00	100.00
% MW <= EGW 100% Mnd								N				
% MW <= EGW 100% 1/2h						100.00	100.00	100.00	99.98		99.99	100.00
% MW <= EGW 97% 1/2h						100.00	99.98	99.93			99.67	100.00
% MW <= EGW 95% 10min										99.98		
aantal Dag > EGW						0	0	0	0	0	0	0
aantal 1/2h > EGW 100%						0	0	0	4		2	0
aantal 1/2h > EGW 97%						0	1	2			37	0
aantal 10min > EGW 95%										10		
Bedrijfsuren RGR						8458	8458	8458	8458	8458	8458	8458
Metingen (aantal)						16892	16844	16844	16844	50525	16844	16844
Onderhoud (aantal 1/2h)						2	40	40	40		40	40
Storing (aantal 1/2h)						21	31	31	31		31	31
geen daggemidd. (o/s)						0	5	5	5		5	5
Beschikbaarheid % AMS				99.0	99.0	99.9	99.6	99.6	99.6	99.6	99.6	99.6

(N)Geen meetwaarden (M)Onderhoud (S)Storing (U)uit bedrijf (V)vervangingswaarde (X)Geen Gemiddelde

E.ON Energy from Waste

Datum: 23.11.15

Jaarrapport concentratie emissies lijn 12 voor het Jaar 14
Statistiek lijn 11 vanaf Maand 01.14 t/m 31.12.14

KKS Eenheid	HG 12 12HNE20CQ008 mg/Nm3	NH3 12 12HNE20CQ010 mg/Nm3	HF 12 12HNE20CQ011 mg/Nm3	T NBZ 12 11HBK20CT901 °C
EGW 100% dag gemidd.	20	5	0.5	850
EGW 97% dag gemidd.	50	-	-	-
EGW 100% mnd gemidd.	-	-	-	-
EGW 100% 1/2h gemidd.	30	-	-	-
EGW 97% 1/2h gemidd.	-	-	1	-
EGW 95% 10min gemidd.		-	-	-
Max niet beschikbaar	10	10	10	10
1.01.14	0.00	0.29	0.00	1143.92
1.02.14	1.21	0.10	0.00	1120.32
1.03.14	1.10	0.55	0.00	1129.35
1.04.14	0.13	1.45	0.00	1139.29
1.05.14	0.13	2.54	0.00	1138.37
1.06.14	0.56	0.24	0.00	1145.91
1.07.14	0.03	2.12	0.00	1159.83
1.08.14	0.99	1.06	0.00	1145.90
1.09.14	0.41	2.20	0.00	1163.78
1.10.14	0.66	2.99	0.00	1190.62
1.11.14	0.00	1.78	0.00	1183.13
1.12.14	0.00	2.60	0.02	1177.84
Laagste waarde	0.00	0.10	0.00	1120.32
Hoogste waarde	1.21	2.99	0.02	1190.62
Gemiddelde t/m 31.12.14	0.43	1.54	0.00	1153.87
% MW <= EGW Dag	100.00	100.00	100.00	100.00
% MW <= EGW 100% Mnd				
% MW <= EGW 100% 1/2h	99.89	98.24	100.00	
% MW <= EGW 97% 1/2h	99.85	98.23	100.00	
aantal Dag > EGW	0	0	0	0
aantal 1/2h > EGW 100%	18	296	0	
aantal 1/2h > EGW 97%	12	298	0	
Bedrijfsuren RGR	8458	8458	8458	8458
Metingen (aantal)	16844	16693	16844	50676
Onderhoud (aantal 1/2h)	42	40	40	0
Storing (aantal 1/2h)	0	31	31	0
geen daggemidd. (o/s)	3	5	5	0
Beschikbaarheid % AMS	99.8	99.6	99.6	100.0

(N)Geen meetwaarden (M)Onderhoud (S)Storing (U)uit bedrijf (V)vervangingswaarde (X)Geen Gemiddelde

Datum: 23.11.15

E.ON Energy from Waste

Jaarrapport concentratie emissies lijn 11 voor het Jaar 14
Statistiek lijn 11 vanaf Maand 01.14 t/m 1.01.14

KKS Eenheid	Debiet 11 11HNE10CF901 m3/h	Temp. 11 11HNE10CT001 °C	Druk 11 11HNE10CP001 mbar	Vocht 11 11HNE10CM001 Vol%	O2 11 11HNE10CQ001 Vol%	Stof 11 11HNE10CQ002 mg/Nm3	HCL 11 11HNE10CQ003 mg/Nm3	NOx 11 11HNE10CQ005 mg/Nm3	CO 11 11HNE10CQ009 mg/Nm3	CO10 11 11HNE10CQ009 mg/Nm3	SO2 11 11HNE10CQ004 mg/Nm3	C-tot11 11HNE10CQ006 mg/Nm3
EGW 100% dag gemidd.						5.0	8.0	100	30	-	40	10
EGW 97% dag gemidd.						-	-	-	50	-	-	-
EGW 100% mnd gemidd.						-	-	100	-	-	-	-
EGW 100% 1/2h gemidd.						15.0	8.0	400	150	-	200	20
EGW 97% 1/2h gemidd.						5.0	10	180	-	-	40	10
EGW 95% 10min gemidd.						-	-	-	-	150	-	-
Max niet beschikbaar						10	10	10	10	10	10	10
1.01.14	99994	146.75	1007.38	15.75	6.60	0.00	0.53	67.83	4.44	4.44	7.78	0.03
1.02.14	102843	147.69	1004.62	15.62	6.73	0.00	0.72	67.85	3.84	3.84	6.12	0.01
1.03.14	98363	140.38	1018.25	14.72	7.27	0.00	0.92	67.48	3.95	3.95	6.22	0.01
1.04.14	84605	124.95	1017.04	13.12	8.22	0.00	1.13	67.84	4.21	4.21	4.60	0.04
1.05.14	96349	143.47	1017.95	15.93	5.94	0.00	1.76	69.38	5.00	5.00	3.49	0.02
1.06.14	95717	143.49	1021.41	16.22	5.82	0.00	1.09	69.56	6.43	6.43	4.81	0.03
1.07.14	93981	134.48	1018.36	14.43	7.16	0.00	2.75	69.55	6.96	6.96	2.61	0.07
1.08.14	90590	142.83	1014.72	16.39	5.54	0.00	1.85	67.86	5.82	5.82	1.80	0.03
1.09.14	66541	51.92	1022.62	4.76	16.33	0.02	2.21	71.64	10.94	10.94	2.34	0.28
1.10.14	94667	141.53	1016.35	16.17	5.69	0.16	0.41	66.78	6.93	6.93	4.92	0.02
1.11.14	99294	142.67	1013.79	16.15	6.18	0.15	0.81	66.04	4.97	4.97	5.97	0.04
1.12.14	100834	142.14	1016.98	15.79	6.31	0.16	1.28	66.02	6.86	6.86	6.80	0.08
Laagste waarde	66541	51.92	1004.62	4.76	5.54	0.00	0.41	66.02	3.84	3.84	1.80	0.01
Hoogste waarde	102843	147.69	1022.62	16.39	16.33	0.16	2.75	71.64	10.94	10.94	7.78	0.28
Gemiddelde t/m 31.12.14	93631	133.58	1015.80	14.68	7.22	0.04	1.20	67.88	5.52		4.99	0.04
% MW <= EGW Dag						100.00	100.00	100.00	99.69		100.00	100.00
% MW <= EGW 100% Mnd								N				
% MW <= EGW 100% 1/2h						100.00	100.00	100.00	99.89		100.00	100.00
% MW <= EGW 97% 1/2h						100.00	99.93	99.97			99.67	99.99
% MW <= EGW 95% 10min										99.78		
aantal Dag > EGW						0	0	0	1	0	0	0
aantal 1/2h > EGW 100%						0	0	0	14		0	0
aantal 1/2h > EGW 97%						0	10	5			36	1
aantal 10min > EGW 95%										106		
Bedrijfsuren RGR						7918	7918	7918	7918	8736	7918	7918
Metingen (aantal)						15825	15732	15732	15731	48752	15732	15732
Onderhoud (aantal 1/2h)						0	70	70	70		70	70
Storing (aantal 1/2h)						9	32	32	31		32	32
geen daggemidd. (o/s)						0	8	8	[illegible]		8	8
Beschikbaarheid % AMS				98.4	98.4	99.9	99.4	99.4	99.3	93.0	99.4	99.4

(N)Geen meetwaarden (H)Onderhoud (S)Storing (U)uit bedrijf (V)vervangingswaarde (X)Geen Gemiddelde

E.ON Energy from Waste

Datum: 23.11.15

Jaarrapport concentratie emissies lijn 11 voor het Jaar 14
Statistiek lijn 11 vanaf Maand 01.14 t/m 31.12.14

KKS Eenheid	HG 11 11HNE10CQ008 mg/Nm3	NH3 11 11HNE10CQ010 mg/Nm3	HF 11 11HNE10CQ011 mg/Nm3	T NBZ 11 11HBK20CT901 °C
EGW 100% dag gemidd.	20	5.0	0.5	≥50
EGW 97% dag gemidd.	50	-	-	-
EGW 100% mnd gemidd.	-	-	-	-
EGW 100% 1/2h gemidd.	30	-	-	-
EGW 97% 1/2h gemidd.	-	-	1.0	-
EGW 95% 10min gemidd.		-	-	-
Max niet beschikbaar	10	10	10	10
1.01.14	0.00	2.95	0.17	1176.97
1.02.14	0.72	2.81	0.01	1169.80
1.03.14	0.02	2.89	0.03	1181.51
1.04.14	0.02	2.84	0.07	1190.62
1.05.14	0.02	2.98	0.09	1198.45
1.06.14	0.15	3.19	0.02	1194.53
1.07.14	0.75	2.94	0.01	1179.02
1.08.14	0.18	3.29	0.00	1198.69
1.09.14	0.05	3.09	0.00	1167.07
1.10.14	0.11	3.34	0.00	1164.59
1.11.14	0.05	3.18	0.03	1193.06
1.12.14	0.08	2.91	0.12	1190.12
Laagste waarde	0.00	2.81	0.00	1164.59
Hoogste waarde	0.75	3.34	0.17	1198.69
Gemiddelde t/m 31.12.14	0.18	3.03	0.05	1185.09
% MW <= EGW Dag	100.00	99.69	100.00	100.00
% MW <= EGW 100% Mnd				
% MW <= EGW 100% 1/2h	99.97	96.37	100.00	
% MW <= EGW 97% 1/2h	99.95	96.37	99.99	
aantal Dag > EGW	0	1	0	0
aantal 1/2h > EGW 100%	3	564	0	
aantal 1/2h > EGW 97%	4	564	0	
Bedrijfsuren RGR	7918	7918	7918	7918
Metingen (aantal)	15731	12170	15732	47403
Onderhoud (aantal 1/2h)	18	70	70	0
Storing (aantal 1/2h)	1	32	32	0
geen daggemidd. (o/s)	1	8	8	0
Beschikbaarheid % AMS	99.9	99.4	99.4	100.0

(N)Geen meetwaarden (M)Onderhoud (S)Storing (U)uit bedrijf (V)vervangingswaarde (X)Geen Gemiddelde

Appendix II

CED_P calculated for the 2-stage dry system (Delfzijl) and the wet system

Components	Unit	2-stage dry system (Delfzijl)	Wet system
Spray absorber	[MJ]		2,438,461
Fabric filters	[MJ]		5,074,060
Sorption filter lime	[MJ]	5,464,297	
Sorption filter Bicar	[MJ]	5,411,729	
Scrubber	[MJ]		5,514,464
Heat exchanger	[MJ]		3,606,306
SCR	[MJ]	7,407,107	7,407,107
ID fan	[MJ]	486,831	486,831
Flue duct	[MJ]	464,772	511,249
Compressor station	[MJ]	79,938	79,938
Total	[MJ]	**19,314,674**	**25,118,416**

CED_D for the 2-stage dry system (Delfzijl) and the wet system

Components	Unit	2-stage dry system (Delfzijl)	Wet system
Spray absorber	[MJ]		-859,165
Fabric filters	[MJ]		-1,675,535
Sorption filter lime	[MJ]	-1,795,493	
Sorption filter Bicar	[MJ]	-1,777,560	
Scrubber	[MJ]		-2,033,926
Heat exchanger	[MJ]		-1,930,539
SCR	[MJ]	-2,306,343	-2,306,343
ID fan	[MJ]	-71,907	-71,907
Flue duct	[MJ]	-160,839	-176,923
Compressor station	[MJ]	-38,738	-38,738
Total	[MJ]	**-6,150,881**	**-9,093,078**

Total CED for the 2-stage dry system (Delfzijl) and the wet system ($CED_{U\text{-effective}}$ for HCl raw gas 1,300 mg m³; SO_2 raw gas 500 mg/m³) and a reference period of 8000 h

CED	Unit	2-stage dry system (Delfzijl)	Wet system
CED_P	[MJ]	965,733.69	1,255,920.81
$CED_{U\text{-effective}}$	[MJ]	-40,770,414.40	139,298,044.64
CED_D	[MJ]	307,544.06	454,653.92
Total	[MJ]	40,112,224.76	140,099,311.53
Total	[GJ]	40,112.22	140,099.31