Feasibility Study Lowering NO_x Emissions of OVCs at Groningen Production Locations

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EXECUTIVE SUMMARY

The customized regulation for NOx emissions (‘maatwerkvoorschrift voor NOx emissies’, May 2019) of the Overhead Vapour Combustor (F-5001) at the Groningen facilities grants an emission limit of 250 mg/Nm3 at 3%-v O_2 concentration. In addition, it requires a cost effectiveness analysis for NO_x reduction to the current limit in article 5.44 of the Activiteitenbesluit of 70 mg/Nm3 at 3%-v O_2.

The current emission satisfies the permitted emission limit of 250 mg/Nm3 at 3%-v O_2 concentration, but not the emission limit prescribed by the Activiteitenbesluit.

The objective of this study is to look for feasible methods to reduce the NO_x emission to comply with the emission limit of 70 mg/Nm3 at 3%-v O_2. With:

- An average flue gas flow of 3900 Nm3/h
- Average 75 mg/Nm3 NO_x emission at actual O_2 concentration (160 mg/Nm3 at 3%-v O_2 after deduction for the measurement inaccuracy)
- Assuming 8256 hours of operation/year (94%)

the NO_x emission to be removed yearly is around 1,64 tons NO_x/year. The required removal efficiency is around 68%.

The Selective Catalytic Reduction (SCR) method gives the most assurance to reduce the NO_x below the limit of the Activiteitenbesluit. The major drawback of the SCR is the complexity of the system in design, engineering, installation, and operation leading to higher health and safety risks, and higher costs.
Burner replacement for a low NO_x burner is the option with the lowest health and safety risks and cost potential to reduce the NO_x emission, although the required removal efficiency to below the limit of 70 mg/Nm3 @ 3%-v O_2 is very uncertain. A new low NO_x burner in combination with Flue Gas Recirculation may effectively achieve higher NO_x emission reduction.

According to article 2.7 of Activiteitenbesluit, reducing NO_x is considered cost effective (“Afwegingsgebied”) when the cost is 5 to 20 €/kg reduced NO_x. None of the identified options achieves this cost effectiveness at the time of this study.

1 OVERHEAD VAPOUR COMBUSTOR (OVC)

1.1 Introduction

The customized regulation for NOx emissions (‘maatwerkvoorschrift voor NOx emissies’, May 2019) of the Overhead Vapour Combustor (F-5001) at the Groningen facilities grants an emission limit of 250 mg/Nm3 at 3%-v O2 concentration. In addition, it requires a cost effectiveness analysis for NO_x reduction to the current limit in article 5.44 of the Activiteitenbesluit of 70 mg/Nm3 at 3%-v O_2.

The OVC (F-5001) is installed on the clusters for the regeneration of glycol, and it also functions as an afterburner for the off-gas produced.

After gas / liquid separation in a high pressure separator (V-5001) and flash vessel (V-5002), the rich glycol is distilled in a reboiler column (C-5001) to obtain lean glycol. Glycol is heated in the reboiler at 123 °C by the OVC. During this process the overhead vapours which are released at the top of the column are treated to remove liquids and mercury, and then routed to the burner. The OVC uses the combination of the overhead vapour from glycol regeneration, the off-gas from the production water/natural gas condensate (WaCo) storage vessels, and the extern fuel gas as fuel.

The proportion of these components depends on the WaCo production and the amount of glycol used, which both depend on the gas production.

The temperature in the OVC is kept between 850 and 900 °C for maximum destruction of aromatic hydrocarbons by regulating the fuel gas flow and the quench air flow. The temperature measured in the OVC is in general 850 °C, except for TJM at around 875 °C.

1.2 Emission Performance

Emission measurements were performed at the various locations and showed that the NO_x emission (calculated as NO_2 according to NEN-EN 15259) varies between 190 and 250 mg/Nm3 at 3%-v O_2 (≈ 160 to 220 mg/Nm3 at 3%-v O_2 after deduction for the inaccuracy). The average emission value proved to be around 200 mg/Nm3 at 3%-v O_2 (≈ 160 mg/Nm3 at 3%-v O_2 after deduction for the inaccuracy) which is equivalent to around 75 mg/Nm3 at actual O_2 concentration.

The current emission therefore satisfies the permit emission limit of 250 mg/Nm3 at 3%-v O2 concentration, but not the emission limit of 70 mg/Nm3 at 3%-v O_2 prescribed by article 5.44 of the Activiteitenbesluit.

1.3 Optimization of the current burner

On another NAM location (L09) with a similar system, a low NO_x emission (<80 mg/Nm3 at 3%-O_2) has been achieved. The burner is also supplied by Frames. This may be due to the contribution of the wet off-gas on L09 location. Since the gas from Groningen’s field contains more mercury, the overhead vapours on Groningen clusters must be dried to remove the mercury using the carbon filter. It is thus not possible to use wet off-gas on Groningen clusters. Another reason for this is that the off gas used in the furnace of L09 contains a lot less heavier hydrocarbons and the furnace also uses a much lower off gas to natural gas ratio.

In 2014, tests have been done on cluster Spitsbergen (SPI) to test the influence of temperature and fuel gas compositions in the burner on the NO_x emission. The results were not as expected, with the lowest NO_x emission achieved at a higher temperature (950 °C) in the burner.

The NO_x level was around 120 mg/Nm3 at 3%-v O_2 at this high temperature. Based on the test results in 2014, it seems unlikely that the NO_x emission can be significantly lowered.

1.4 Required NOx reduction

The objective of this study is to look for feasible methods to reduce the NO_x emission to comply with the emission limit of 70 mg/Nm3 at 3%-v O_2. With:

- An average flue gas flow of 3900 Nm3/h (see also Appendix 1)
- Average 75 mg/Nm3 NO_x emission at actual O_2 concentration (160 mg/Nm3 at 3%-v O_2 after deduction for the measurement inaccuracy)
- Assuming 8256 hours of operation/year (94%)

the NO_x emission to be removed yearly is around 1,64 tons NO_x/year. The required removal efficiency is around 68%.

2 TECHNICAL FEASIBILITY STUDY

2.1 Available technologies to reduce NO_x emission

NO_x emissions from combustion are primarily in the form of NO, which is thermally formed according to Zeldovich mechanisms:

$$N_2 + O \rightarrow NO + N$$

$$N + O_2 \rightarrow NO + O$$

$$N + OH \rightarrow NO + H$$

Prompt or inherent NO_x formation is not expected since the fuel does not contain nitrogen components. The amount of NO_x thermally formed thus depends on the amount of air (the concentrations of O_2 and N_2), temperature and residence time. There are various methods available to reduce the NO_x emission, which can be classified in the following principles:

- By reducing the peak temperature or by reducing the residence time at peak temperature. Reduction of peak temperature is achieved by avoiding the ideal stoichiometric ratio since higher temperatures may generate thermal formation of NO_x.
- Post combustion treatment, such as catalytic reduction or non-catalytic reduction.

2.1.1 Reduction of peak temperature or reducing the residence time at peak temperature

Examples of methods that are based on this principle are [ref. 2]:

1. Flue gas recirculation (FGR): Recirculation of cooled flue gas reduces temperature by lowering the oxygen concentration and diluting the heat. The flue gas leaving the reboiler may be an option for the cooled flue gas. A new burner will be required for this purpose. Ref. 3 mentions that a recirculation of 30% may reduce NOx emission as high as 70%, and this will require very tight control systems to maintain flame stability. See figure 1.
2. Air staging: Results in staged combustion, avoiding high peak temperature in the flame. Possibly NO_x reduction up to 99% may be achieved. For this method, a new burner needs to be installed to accommodate the longer flame.
3. Fuel staging: Results in staged combustion, avoiding high peak temperature in the flame. A possible NO_x reduction up to 50% has been reported. This is not enough for the required NO_x reduction.
4. Low NO_x burner (LN): A low NO_x burner provides a stable flame with several zones to prevent high peak temperatures in the flame. The basic characteristic of a low NOx burner is that the air/fuel mixing and combustion both take place in successive steps. Possibly an NO_x reduction up to 60% may be achieved.
5. Fuel reburning (staged combustion): Fuel can be added in a secondary combustion stage (i.e. fuel staging) or added in the recirculated fuel gas (FGR). The added fuel will partially react with NO_x to form molecular nitrogen. Burning of the added fuel is completed by adding air or over-fire-air (i.e. air staging). This is a combination of several techniques, resulting in a possible reduction in NO_x emission up to 76%.
6. Injection of water/steam: Injection of water/steam will reduce the peak temperature. Modifications on the burner will be required.
7. Optimization of Air/Fuel ratio: Supplying excess air will reduce the residence time at peak temperature. However, the concentration of N_2 and O_2 will also increase, leading to a higher NO_x formation rate. The NO_x reduction is the net of these 2 effects. This method is based on

permanent monitoring and control of the relevant combustion parameters. The amount of excess air is minimized to minimize the forming of NO_x.
Optimization of Air/Fuel ratio is limited for the OVC due to its function as an incinerator, where a large amount of excess air is required for a complete combustion of the BTEX components. Furthermore, a large excess of air is also required in the OVC to cool the flue gas below the design temperature of the OVC (1100 °C).

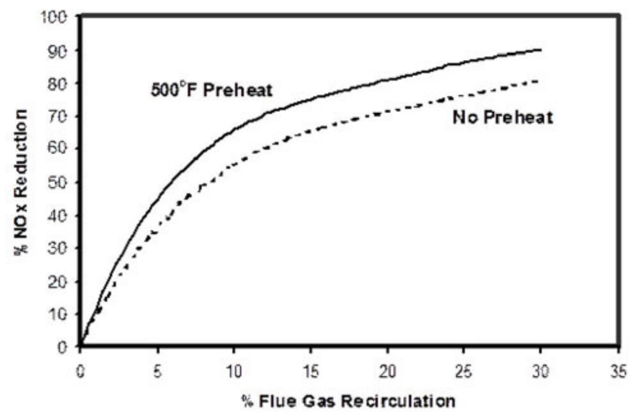

Figure 1. Percentage of NO_x reduction as a function of percentage of flue gas recirculation for boilers [ref. 3].

2.1.2 Post Combustion Treatment

Examples of methods that are based on this principle are:

8. Selective Catalytic Reduction (SCR): SCR uses catalyst to consume injected ammonia or urea to reduce NO_x. An NO_x reduction up to 94% has been reported. A catalyst bed will be required for this method. A drawback is the possible slip-through of ammonia or urea to the flue gas. The catalyst life time is limited.
9. Selective Non-catalytic Reduction (SNCR): SNCR uses the injection of ammonia or urea in a temperature region between 900°C and 1050 °C. Ammonia or urea is ionized in this temperature region. This temperature window is important, since outside this window the ammonia may slip through, or worse more NO_x is generated. This option requires an injection skid for ammonia or urea, a new burner and a good temperature control.

2.2 Comparison of the potential technologies

Of all the methods described above, a comparison matrix was prepared based on the possible NO_x reduction, the health and safety risks, the environmental and commercial risks and resulting technical complexity and expected capex and opex impact. The comparison matrix was prepared by Jacobs Consultancy and GLTplus (see Appendix 2). Table 1 shows the resulting selection matrix from the comparison scores.

	Rank on	Achieve NO_x removal	Health/ Safety Risks	Environm. Risks	Commercial Risks	Technical Complexity	Costs	Overall Rank *
1	Flue gas recirculation (FGR)	5	5	8	1	2	3	3
2	Air staging	1	3	5	3	4	6	4
3	Fuel staging	No	-	-	-	-	-	-
4	Low NOx burner	6	1	1	5	1	1	1
5	Fuel reburning	4	3	1	3	4	4	5
6	Water injection	7	5	6	5	4	4	7
7	Optimize A/F ratio	7	2	6	5	2	2	6
8	SCR	1	7	4	1	7	7	2
9	SNCR	1	7	4	1	7	7	2
* Overall rank is based on weighted comparison scores prepared by Jacobs Consultancy and GLTplus (see Appendix 2)								

Table 1. Selection matrix for NO_x reduction technologies.

A low NO_x burner ranks highest based on the scores, specifically on HSE, reduced technical complexity and proven design. However, it has not been confirmed by vendors that the required 68% removal efficiency can be achieved. This option will require extensive engineering and testing if satisfying results can be achieved.
The S(N)CR is ranked slightly lower and is considered as the most promising option to reduce the NO_x emission to the required limit without affecting the incineration process of aromatic components. The major drawbacks of the SCR are the extensive design and control of the ammonia/urea injection, and the possible ammonia/urea emissions. The ammonia/urea emission is currently not included in the environmental permit.

For a low NO_x burner (LN), an additional NO_x reduction may be achieved by combining it with flue gas recirculation. This option is considered less complex than the S(N)CR method. However, this option is not certain to achieve the emission limit 70 mg/Nm3 @ 3%-v O_2. Furthermore, there is also the possibility that the BTEX emission will increase due to lower flame temperature and different air/fuel ratio. Benzene emission is not allowed to increase when reducing the NO_x emission since benzene is classified as a substance of very high concern ('zeer zorgwekkende stof', ZZS). This must be thoroughly clarified with vendors.

3 COST ESTIMATES

Based on the feasibility evaluation of the technologies and selection matrix in the previous chapter, the cost estimates for the following options are presented in this chapter:

1. Selective catalytic reduction (SCR)
2. Low NOx burner
3. Low NOx burner in combination with flue gas recirculation (FGR)

The cost estimates were initially prepared by Jacobs Consultancy and GLTplus (Appendix 2). Some corrections have been made.

A general remark: For options 1 and 3, modifications of the stack will be required. See Figure 2.

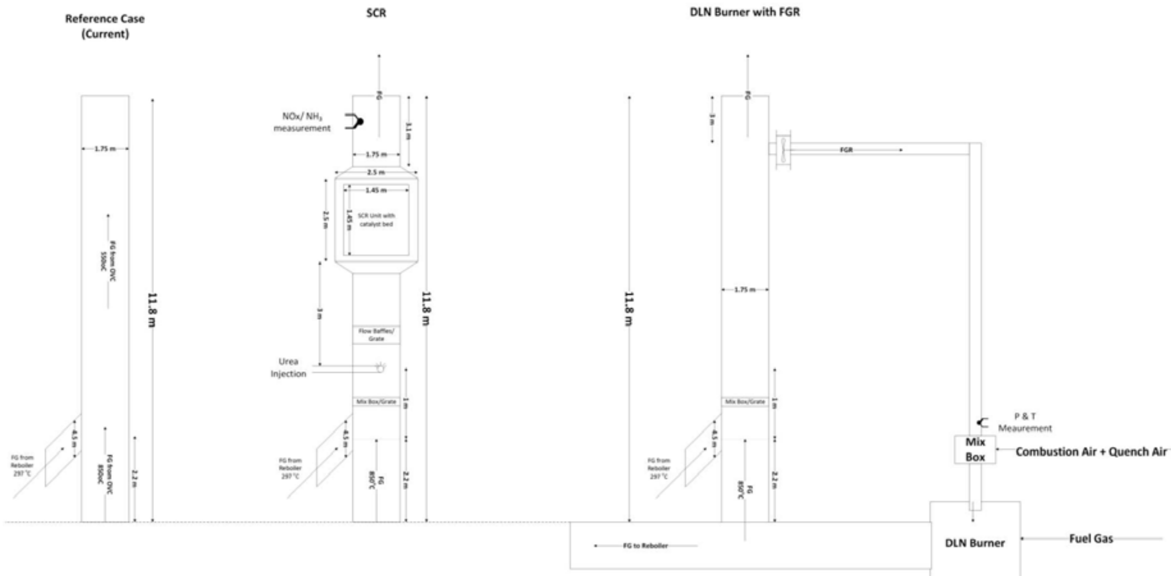

Figure 2. Modifications required on the stack

For all three options the following is considered:

- that the production of Groningen gas fields is stopped in 10 years
- time to execution of modification is minimum two years including project design, procurement and modification execution, and permitting request and allocation
- a depreciation period of maximum 8 years is used in the calculations
- estimate is chosen in line with earlier study work and very optimistic: depreciation times for the production locations are much shorter since they will be decommissioned earlier
- an interest rate of 10% as mentioned in the Activiteitenbesluit

3.1 Selective Catalytic Reduction

The flue gas of 850 °C from the OVC is sent in part to the glycol reboiler, and in part to the stack, and both are mixed again at the bottom of the stack. The flue gas returning from the glycol reboiler has a temperature around 200 °C. The measured temperature in the stack becomes around 500 °C due to this mixing. The catalyst bed works at a temperature around 450 °C and can thus be placed in the stack.

For the SCR, the following modifications will be required:

- a mix box/grate in the stack to have homogenous flue gas across the stack before urea is injected
- an urea injection unit
- an injection point of urea in the stack
- another grate after the injection point of urea in the stack to have a homogenous mixture before entering the catalyst bed
- a new stack section with a catalyst bed
- an ammonia/urea measurement needs to be installed downstream the catalyst bed, in order to prevent/monitor ammonia/urea slip-through.

Several considerations for the SCR:

- Fine dust and particulates from the flue gas and stack are expected to cause fouling of the catalyst bed and block the catalyst surface. This should be discussed further with SCR vendors.
- Flue gas inlet temperature for the SCR should be in the range of 450 to 500 °C. However, there are cases that the flue gas temperature may exceed this temperature (up to 850 °C). To lower the flue gas temperatures at the SCR inlet, cold air may be mixed with the flue gas. This should be further investigated with SCR vendors. This might require additional equipment like fan, ducting, control valves etc.

The estimated CAPEX and OPEX for the SCR option is shown in Table 2.

Capital Expenditure				Annual
Equipment				
SCR reactor unit	euro	349.000	euro	65.418
Catalyst batch	euro	23.000	euro	4.311
New, insulated stack	euro	35.000	euro	6.561
Modifications to OVC	euro	20.000	euro	3.749
Pumping and air compression	euro	30.000	euro	5.623
Piping and Instrumentation	euro	70.000	euro	13.121
Other				
Project costs	euro	200.000	euro	37.489
Total CAPEX (incl. contingency)			euro	177.153
Operating Expenditure				Annual
Utility Use				
Electricity	kWh/year	39.420	euro	1.971
Urea (at 220 EUR per m3)	ton/year	1,0	euro	220
Other				
Catalyst replacement, every	years	5	euro	5.000
Maintenance	%	2	euro	6.980
Insurance	%	1	euro	3.490
Total OPEX			euro	17.661
				Annual
Total Cost			euro	194.814

Basis:		
Catalyst cost	15.000	euro/m3
Depreciation	8	years
Interest	10	%, as per Activiteitenbesluit guideline
Residual value	0	euro
Contingency	30	%
Method	Annuity	

Table 2. Estimated CAPEX and OPEX for Selective Catalytic Reduction (+/-50%)

The resulting annual CAPEX is estimated to be around 177 k€/year. The OPEX is estimated around 18 k€/year. The total cost is then 195 k€/year.
This corresponds to 195 k€/year / 1,64 tons NO_x reduction/year ≈ 119 €/kg NOx reduction.

3.2 Low NO_x burner (without Fuel Gas Recirculation)

As stated previously an NO_x reduction up to 60% may be achieved by decommissioning of the existing burner and installation of a new low NO_x burner.

Contacts with vendors have resulted in the following estimates:

a) Frames is the vendor of the current burners (including the glycol regeneration package unit). Frames advice is to replace the current burner with a new low NO_x burner (by a special burner vendor). The estimated cost for a new burner, some modification of the OVC, and changes in the process control is around 375 k€. The performance of the new burner has however still to be verified by the burner vendor and tested. The resulting reduction in NO_x emission is uncertain.

b) Saacke is confident to be able to reduce the NO_x emission to less than 100 mg/Nm3 at 3%-v O_2 with its swirl burner system, which will avoid temperature peaks in the flame. Saacke also expects that the combustion of aromatic compounds will not be adversely affected. The impact on plant lay out is expected not to be a problem since the flame formed by the swirl burner is short. Saacke has given an estimate of 100 k€ - 150 k€ per unit.

A third vendor was contacted without response.
As confirmed by the vendors, this option will require extensive engineering and testing for satisfying results. This will result in a significant cost increase. And it has not been confirmed by vendors that the required 68% removal efficiency can be achieved.

For the cost estimate for a new burner, the worst case estimated price given by Saacke (150 k€/burner) is used.

The estimated CAPEX and OPEX for the LN option is shown in Table 3.

Capital Expenditure				Annual
Equipment				
Decommisioning old burner	euro	12.000	euro	2.249
New burner	euro	150.000	euro	28.117
Other				
Project costs	euro	50.000	euro	9.372
Total CAPEX (incl. contingency)			euro	51.660
Operating Expenditure				Annual
Utility Use				
Electricity	kWh/year	39.420	euro	0
Other				
Maintenance	%	2	euro	3.000
Insurance	%	1	euro	1.500
Total OPEX			euro	4.500
				Annual
Total Cost			euro	56.160
Basis:				
Decommisioning old burner estimated at 10 to 12% of low NO_x burner CAPEX				
Depreciation	8	years		
Interest	10	%, as per Activiteitenbesluit guideline		
Residual value	0	euro		
Contingency	30	%		
Method	Annuity			

Table 3. Estimated CAPEX and OPEX for a low NOx burner without Flue Gas Recirculation (+/-50%)

The resulting annual CAPEX is estimated to be 51,6 k€/year. The OPEX is estimated 4,5 k€/year. The total cost is then around 56 k€/year.
This corresponds to 56 k€/year / 1,64 tons NO_x reduction/year ≈ 34 €/kg NOx reduction.

3.3 Low NO_x Burner with Flue Gas Recirculation (FGR)

A low NO_x burner in combination with FGR may effectively achieve higher NO_x emission reduction than replacing the burner without FGR. The following modifications will be required for this option:

- Decommissioning of the existing burner and installation of a new low NO_x burner
- Installation of a circulation line for the flue gas to the burner
- Implementing control instruments
- Installation of mix box and fans for FGR
- Stack modifications

The estimated CAPEX and OPEX for the LN option is shown in Table 4.

Capital Expenditure				Annual
Equipment				
Decommisioning old burner	euro	12.000	euro	2.249
New burner	euro	100.000	euro	18.744
Fan, mix box, instruments	euro	55.000	euro	10.309
Stack modifications	euro	25.000	euro	4.686
Piping and insulation	euro	50.000	euro	9.372
Other				
Project costs	euro	100.000	euro	18.744
Total CAPEX (incl. contingency)			euro	83.338
Operating Expenditure				Annual
Utility Use				
Electricity	kWh/year		euro	937
Other				
Maintenance	%	2	euro	3.100
Insurance	%	1	euro	1.550
Total OPEX			euro	5.587
				Annual
Total Cost			euro	88.925

Basis:
Decommisioning old burner estimated at 10 to 12% of low NOx burner CAPEX
OPEX electricity estimated at 5% of annual low NOx burner CAPEX
Maintenance and insurance estimated on burner and rotating equipment

Depreciation	8	years
Interest	10	%, as per Activiteitenbesluit guideline
Residual value	0	euro
Contingency	30	%
Method	Annuity	

Table 4. Estimated CAPEX and OPEX for a low NOx burner with Flue Gas Recirculation (+/-50%)

The resulting annual CAPEX is estimated to be 83 k€/year. The OPEX is estimated 5,5 k€/year. The total cost is then around 89 k€/year.
This corresponds to 89 k€/year / 1,64 tons NO_x reduction/year ≈ 54 €/kg NO_x reduction.

4 CONCLUSIONS

The customized regulation for NO_x emissions ('maatwerkvoorschrift voor NOx emissies', May 2019) of the OVC's at the Groningen facilities requires a cost effectiveness analysis for NO_x reduction to the current limit in article 5.44 of the Activiteitenbesluit of 70 mg/Nm3 at 3%-v O_2.

The Selective Catalytic Reduction (SCR) method gives the most assurance to reduce the NO_x below the limit of the Activiteitenbesluit. The major drawback of the SCR is the complexity of the system in design, engineering, installation, and operation leading to higher health and safety risks, and higher costs.
The low NO_x burner is the option with the lowest health and safety risks and cost potential to reduce the NO_x emission, although the required removal efficiency to below the limit of 70 mg/Nm3 @ 3%-v O_2 is very uncertain. A low NO_x burner in combination with Flue Gas Recirculation may effectively achieve higher NO_x emission reduction.

Most viable solutions	Est. €/kg NOx reduction	Remark
Selective Catalytic Reduction	119	HSE risks
A low NOx burner	34	Success very uncertain
A low NOx burner with flue gas recirculation	54	

Table 5. Cost effectiveness comparison most viable solutions

According to article 2.7 of Activiteitenbesluit, reducing NO_x is considered cost effective ("Afwegingsgebied") when the cost is 5 to 20 €/kg reduced NO_x. None of the identified options achieves this cost effectiveness at the time of this study.

5 References

1. Activiteitenbesluit milieubeheer (https://wetten.overheid.nl)
2. Technical Bulletin: Nitrogen Oxides (NOx), Why and How They are Controlled, EPA 456/F-99-006R
3. Process Engineering Technical Guidelines: NOx Reduction, Intern Jacobs report TG 590.01, 7 Aug 2004.

6 Appendices

1. Stookproef location Zuiderpolder 2021

zpd stookproef
14072021.pdf

2. Comparison study prepared by Jacobs Consultancy and GLTplus

Lowering NOx in
OVC - evaluation SC