Ministry of Environment of Denmark
Environmental
Protection Agency

Advanced catalytic bags for combined abatement of NOx and particulate matter in biomass boilers

- Et MUDP projekt

MUDP Report

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Miljøteknologisk Udviklings- og Demonstrationsprogram

Projektet, som er beskrevet i denne rapport, er støttet af Miljøteknologisk Udviklings- og Demonstrationsprogram, MUDP, som er et program under Miljøministeriet, der støtter udvikling, test og demonstration af miljøteknologi.

MUDP investerer i udvikling af fremtidens miljøteknologi til gavn for klima og miljø i Danmark og globalt, samtidig med at dansk vækst og beskæftigelse styrkes. Programmet understøtter dels den bredere miljødagsorden, herunder rent vand, ren luft og sikker kemi, men understøtter også regeringens målsætninger inden for klima, biodiversitet og cirkulær økonomi.

Det er MUDP’s bestyrelse, som beslutter, hvilke projekter der skal modtage tilskud. Bestyrelsen betjenes af MUDP-sekretariatet i Miljøstyrelsen.

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Denne slutrapport er godkendt af MUDP, men det er alene rapportens forfatter/projektlederen, som er ansvarlige for indholdet. Rapporten må citeres med kildeangivelse.

Contents

1. Resume in Danish

Nærværende projekt har haft til formål at teste en specielt udviklet filterpose med SCR (DeNOx) belægning for kombineret reduktion af partikelemission og NO_x i fuld skala på et biomassefyret kraftværk. Denne posetype har tidligere været anvendt i andre sammenhænge hvor der ikke optræder alkaliske elementer i nævneværdig grad, som udgør en potentiel risiko for DeNOx funktionen.

Combi-poserne kan være en attraktiv ”drop-in” måde at opgradere biomasseanlæg til at opnå reduceret NO_x emission væsentlig mere effektivt end med traditionelle SCR reaktorsystemer, forudsat naturligvis at poserne har en fornuftig levetid og funktion i biomasse røggas.

Afprøvning i fuld skala og under realistiske driftsforhold blev foretaget på Snetterton REP, et 50 MW_e halmfyret kraftværk i UK opført af BWSC og idriftsat 2017. På netop dette anlæg var røggastemperatur i filterinstallation tilpas høj, ligesom ammoniakdosering var tilgængelig ifm. et eksisterende SCR anlæg.

De nye katalytiske filterposer leveret af Haldor Topsøe, blev indsat i ét af 8 filterkamre i foråret 2019, sammen med nye konventionelle poser i de 7 øvrige kamre, og har siden kørt parallelt under normale drift forhold. Periodevis (senest marts 2021 efter næsten 2 års drift) er enkelte poser, både nye og konventionelle, taget ud for inspektion og analyse, ligesom driftsforhold har være observeret løbende.

Hovedresultatet har været at de nye katalytiske poser mht. installation, tryktab, rensning, mekanisk holdbarhed og partikeludskillelse har fungeret fuldt på højde med traditionelle poser. Laboratorieanalyser af poser undervejs har vist at den katalytiske belægning, som sidder på en indvendig pose, ikke er blevet påvirket negativt af alkaliske elementer, som er blevet tilbageholdt i tilstrækkeligt omfang af yderposer.

DeNOx aktivitetstests har også demonstreret at DeNOx aktiviteten, bortset fra en tilsyneladende indledende mindre reduktion, er intakt efter 2 års drift og uden nævneværdig negativ trend. Disse observationer svarer til traditionelle SCR reaktorer og tyder på en praktisk levetid væsentlig længere end 2 år selv under biomasse røggas eksponering.

Det var oprindelig forudset også in-situ at demonstrere NO_x reduktion ved injektion af ammoniak før kammer indeholdende de katalytiske poser. Installation herfor blev etableret, men af forskellige praktiske grunde viste det sig vanskeligere end forudset og med Covid-19 restriktioner var det ikke muligt i tide at få etableret NH_3 dosering. Dette er dog ikke afgørende for den succesfulde demonstration, da DeNOx aktiviteten er konstateret intakt vha. laboratorie tests og i øvrigt er kendt fra tidligere applikationer.

Som et resultat af denne praktiske test anses løsningen nu for tilstrækkeligt demonstreret til at blive tilbudt til biomasse fyrede og lignende kraftværker som måtte stå overfor et behov for at reducere NO_x emissionen. Dette er i mellemtiden blevet højaktuelt for en række anlæg alene i UK som følge af fornyelse af deres miljøtilladelse med Bref guidelines som rettesnor.

Mange af disse anlæg anvender pt. udelukkende SNCR teknologi (injektion af ammoniak eller urea direkte i fyrringrum), hvilket er langt mindre effektivt end SCR teknologi og med begrænset reduktionseffektivitet der kan komme til kort overfor nye skærpede NO_x krav.

Hidtil har dette kunnet indebære behov for en kompleks traditionel SCR installation som kan være svær og omkostningskrævende at etablere på et bestående anlæg. Katalytiske poser kan nu tilbydes som et alternativ for indsættelse i bestående posefiltre med mindre omfattende tilhørende anlægsmodifikationer.

Derudover kan samme løsning også vise sig attraktiv for nye anlæg der forlods dimensioneres for Bref emissionsbegrænsninger.

2. Introduction

Cogeneration plants, waste incineration plants and similar plants meet increasingly stringent requirements for emissions.

Many plants today can only reduce NO_x emissions to the required levels by adding ammonia (NH_3) directly into the boiler for so-called SNCR (selective non-catalytic reduction) - this allows for around 40-65% NO_x removal.

Stricter NO_x emission requirements mean that SNCR either require excessive ammonia dosing or is not sufficient, and therefore SCR (selective catalytic reduction) becomes necessary. Dedicated SCR reactors for NO_x reduction is a well-known technology but require substantial investments to be implemented in an existing flue gas treatment facility. Furthermore, it is often required to raise the flue gas temperature before the SCR since most plants operate filters with lime injection for SOx removal around 140 ˚C and then cooled again not to lose efficiency. This and the increased pressure drop caused by the SCR installation, often with complex piping due to space limitations, increases the operating expenses.

Haldor Topsøe has in collaboration with FLSmidth developed a filter bag which functionally is a combined filter bag and SCR catalyst. This CataFlex™ filter bag works as a drop-in solution for systems with fabric filters for dust removal. Installation of CataFlex catalytic filter bags enables the reduction of NO_x levels directly across the filter bag, whereby a separate investment-heavy SCR reactor and associated piping system can be avoided. The catalyst is the same as used in conventional SCR, and NH_3 injection is required.

Especially on plants where removal rates that can be obtained using SNCR becomes insufficient due to tightening of NOx requirements, CataFlex™ will be able to ensure that the plant can be in compliance with new and stricter requirements for NOx emissions without entailing significant rebuilds like the traditional SCR solution requires.

Using SNCR more intensively to reach lower NO_x values will in many cases also cause unreacted NH_3 to be emitted with the flue gas compromising the emission limits for NH_3, but CataFlex™ will also reduce NH_3 emission.

With a CataFlex™ solution it will be necessary to increase filter temperature to about 185 ˚C or more (if this is not already the case) to avoid excessive ammonium bisulphate fouling and add a new flue gas cooler downstream the filter if efficiency is to be recovered. However, this is usually not problematic and still far less complex than a separate SCR reactor solution.

3. Idea and purpose of the project

The purpose of the project was to demonstrate that catalytic bag filters could be an attractive Technology for biomass-fired power plants.

The catalytic bags in combination with the outer filter bags can reduce both particles and NO_x, at a lower capital investment and Total Cost of Ownership than conventional technologies. One of the main advantages of this technology is that the catalyst is not exposed to dust from the process because it is removed by an outer filter bag. The main reasons for catalysts to be poisoned when used in biomass plants, is that it can be exposed to alkali and alkaline earth metals, which are common poisons for V/TiO_2 deNOx catalysts and present in woody biomass.

At the moment the challenge is to demonstrate the concept and performance of CataFlex™ catalytic bag in full scale. The idea of this project was thus to demonstrate the concept and performance of CataFlex™ on a full-scale biomass-fired power plant, i.e. prove bag lifetime assumptions mechanically and with regard to catalytic NO_x reduction.

BWSC is a global supplier of turn-key power plants and a provider of technical services and often operates the biomass plants they construct. BWSC partly owned and operates the straw and wood chip fired Snetterton Renewable Energy Plant in the UK, which was commissioned in April 2017.

This plant was chosen for the test since it already operated the filter installation at 190 ˚C and have a downstream SCR installation with ammonia dosing facility etc. Other similar plants rely on SNCR and operate filters at 130-140 °C.

The catalytic bags were installed in one of 8 bag filter compartments, which the flue gas passes through in parallel. This way, it can be compared how factors such as mechanical life, catalytic life and filter bag differential pressure are for the catalytic filter bags in direct comparison with the conventional bags in the 7 other chambers.

For the catalytic bags to work with respect to NO_x reduction, NH_3 must be injected locally in front of the chamber with the catalytic bags, so that only this chamber receives NH_3. NH_3 reacts with NO and NO_2 and forms N_2 and water. This is an additional NH_3 injection in addition to the NH_3 injection which already exists in front of the existing downstream SCR.

Plant risks

At Snetterton, the existing DeNO_x SCR reactor will always ensure emissions compliance with regards to NO_x and ammonia, so in the event of lower catalytic performance of the catalytic filter bags, compliance is not at risk. This is also valid for dust emissions as the catalytic filter bags each consist of a conventional bag for standard dust removal, whereas the catalytic NO_x removal is a feature added by an extra layer inside the conventional bag.

In the unlikely event that any or all the catalytic filter bags are damaged, a full spare set of conventional bags was made available on site and they could freely be used during or after the finishing of this trial.

Trial risks

The injected NH_3 in the inlet of one compartment with catalytic filter bags, is at risk of being maldistributed. This will reduce the average catalytic performance

of all catalytic filter bags. This risk has been mitigated by nozzle design and prior NH_3 evaporation for easy mixing.

SO_2 and SO_3 can cause deactivation of the embedded catalyst by formation and condensation of ammonium bisulphate. This risk is the same as in conventional SCR catalysts and since Snetterton has an SCR installed downstream of the fabric filter, measures are already implemented to reduce SO_2 content in the gas by sorbent injection upstream the fabric filter and operational temperature is somewhat higher than usual.

4. Snetterton biomass boiler

Snetterton is a primarily straw fired 50 MW_e power plant located North-East of London. To supplement straw, it is also possible partly to utilize wood chips.

Snetterton was the third plant in a row of similar plants, starting with Sleaford in 2012 and Brigg in between.

Sleaford and Brigg were designed to comply with IED emission limitations, primarily utilizing SNCR for NO_x control, although with a part-stream SCR installation to ensure NO_x control.
Bag filter with upstream lime addition was designed to operate at about 140 ˚C (optimal for the lime SO_2 reduction process) where flue gas in the part stream SCR branch was raised to about 185 ˚C and re-cooled afterwards to about 140 ˚C (not to lose efficiency).

Under these circumstances it would be difficult to test CataFlex™ catalytic bags, since they are intended to operate at a higher temperature to avoid the risk of ABS fouling.

Unlike Sleaford and Brigg, the Snetterton plant was designed when an update of emission limitations (B_{ref}) was expected in the near future. Therefore, the Snetterton flue gas treatment system, including filter, was designed for operation at about 190 ˚C, allowing for a full stream SCR directly down- stream the filter. The flue gas is then cooled to about 140 ˚C after the SCR installation.
This made the Snetterton plant the ideal location for a catalytic bag test under conditions for which these bags are intended.

A DCS screen shot of the Snetterton flue gas train system is included in FIGURE 1 below.

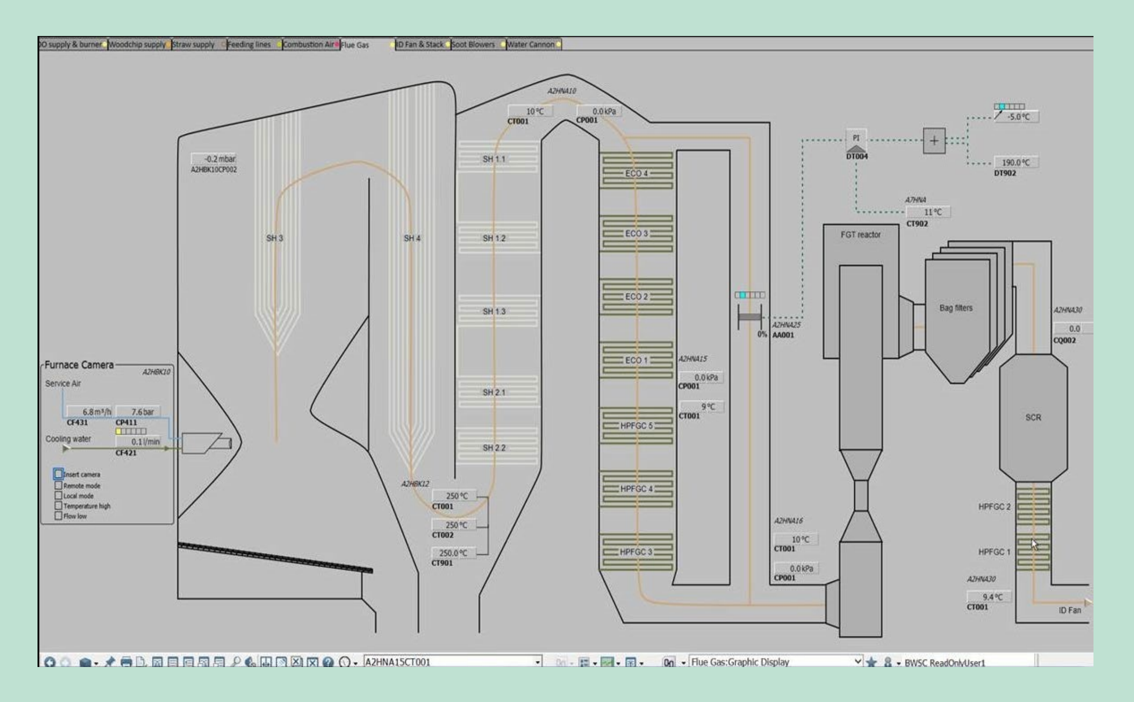


FIGURE 1. Snetterton plant – Flue gas path

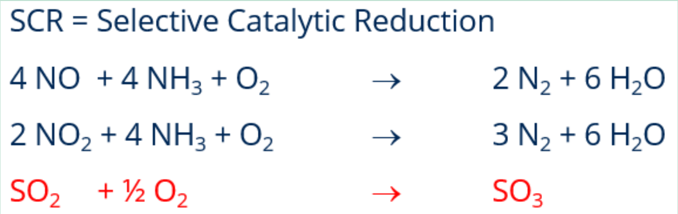
The flue gas treatment system is the grey equipment to the right consisting of: lime venturi mixer and pre-reaction chamber, bag house filter (8 compartments), SCR reactor and finally flue gas cooler element.

5. Topsøe CataFlex^{TM} catalytic bags

The CataFlex™ catalytic bag is used for NO_x removal using NH_3 injection with similar reactions as SCR reactors. The CataFlex™ is a two-layer concept where an inner bag is impregnated with a catalyst, and then mounted inside a normal outer bag made of material decided by the end user. The outer bag is performing the dust removal (and SO_x removal if lime is added to the flue gas upstream the filter), and the catalytic inner bag the removal of the remaining gaseous pollutants, primarily NO_x. The bags are supported by a cage mounted inside the two bags. See FIGURE 2.

FIGURE 2. CataFlex concept

The catalyst used is of the same family as that used in stationary SCR installations (V_2O_5/TiO_2) and the chemical reactions are the same. See FIGURE 3.



SCR = Selective Catalytic Reduction

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 2\,N_2 + 6\,H_2O$$

$$2\,NO_2 + 4\,NH_3 + O_2 \rightarrow 3\,N_2 + 6\,H_2O$$

$$SO_2 + \tfrac{1}{2}\,O_2 \rightarrow SO_3$$

FIGURE 3. Selective Catalytic Reduction

The SO_2 oxidation to SO_3 is an unwanted reaction, and together with temperature and NH_3 content in the gas, it is contributing to determining the lowest acceptable operation temperature for the installation, just as when using a stationary SCR. The amount of SO_2 in the gas can be lowered by injecting lime or similar, thereby lowering the acceptable operation temperature.

The catalyst will also remove dioxin and VOC´s to a certain degree, dependent on temperature and several other factors, see FIGURE 4 for description of the function.

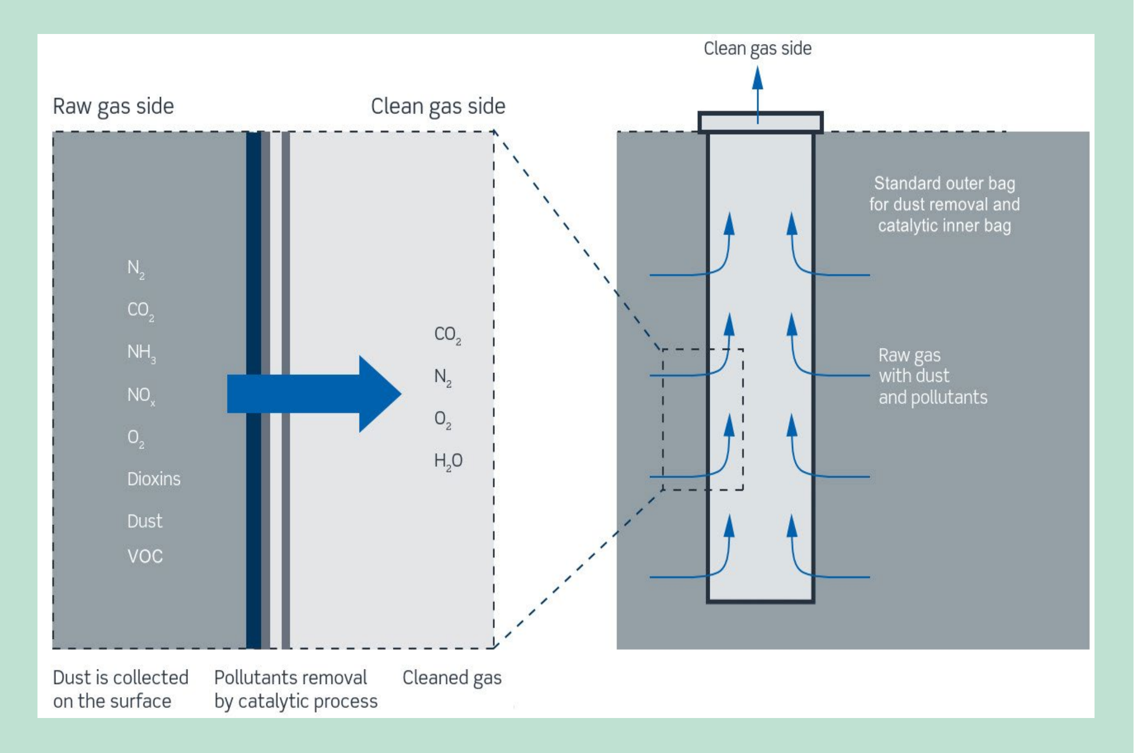


FIGURE 4. CataFlex function

6. Objectives

The objective of the project was to prove that CataFlex™ can be used as an alternative to stationary SCR on biomass fired boilers as shown in FIGURE 5.

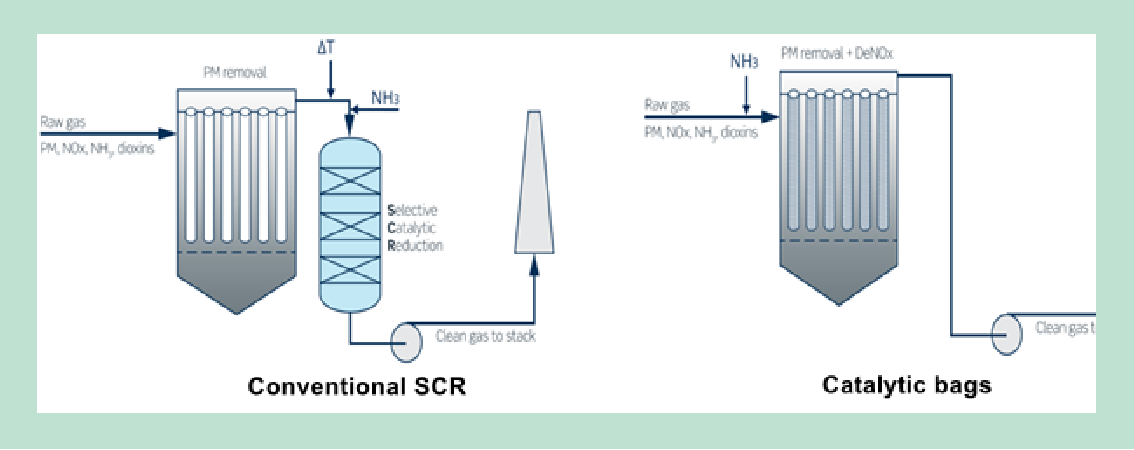


FIGURE 5. Conventional SCR and Catalytic bags

It is a well-known fact, that potassium, which is present in high levels in the fly ash of biomass fired systems, along with sodium, phosphorous, and calcium are catalyst poisons, so a long-time test of catalyst deactivation in a filter where the catalytic bags could be exposed to actual gasses from a biomass boiler was needed.

Because of the CataFlex™ concept, where an outer bag is removing the dust before it can get in contact with the catalytic inner bag, the catalyst is protected more efficiently from the particulate poisons than a conventional hot SCR upstream the filter, so good long-time performance can be expected.

The Fabric Filter on the Snetterton biomass power plant is divided in 8 compartments and the CataFlex™ catalytic bags was installed in one of the 8 compartments. This allows for comparison of factors such as traditional bag lifetime, lifetime of the catalytic bags and differential pressure from catalytic versus standard bags.

As outlined in the MUDP project description, it was the intention to demonstrate the NO_x reduction capability directly on site by dosing NH_3 upstream the filter chamber chosen for the CataFlex test bags.

A lot of effort was spent trying this, but in the end, it was not possible to achieve this partial goal. Fortunately, this is not a serious issue since deactivation/poisoning of the catalyst can be measured by taking a bag out of the filter and measure the NO_x removal activity in the Topsoe R&D laboratories. The mechanics behind deactivation with ABS is well documented by Topsoe from many years of working with both stationary SCR, CataFlex ™ and TopFrax™ catalytic solutions.

The problems faced were of various nature, compounded by limited access to the site during the test period due to Covid-19 travel restrictions.

It was intended to dose a limited amount of pre-evaporated and flue gas mixed ammonia from the existing SCR dosing system in the chosen test chamber, and an installation for this was implemented.

The pressure upstream the filter test chamber (where test NH_3 should be dosed) is higher than at the main point of NH_3 dosing in front of the existing SCR installation.

Nevertheless, the over pressure in the existing NH_3 dosing loop indicated there were sufficient pressure also to drive a limited NH_3 dosing for the test chamber without a costly and complex booster fan.

However, once the system was implemented and started up, it was only possible for a very short period to achieve a NH_3 dosing flow to the test chamber, before being able to make any DeNOx observations.

It was first discovered that the dosing piping system were blocked up by condensate, which could not be drained due to a vacuum condition in the piping.

Having fixed this, it was still not possible to achieve NH_3 dosing due to fouling in the meantime of the injection distribution nozzles (sitting on the dirty side of the filter).

Having eventually also fixed this problem, it was found that there no longer was a positive pressure to drive this NH_3 dosing. This was probably due to a slightly increased pressure drop over the filter, which can also be seen in the pressure drop trend FIGURE 10.

In a final attempt (spring/summer 2021) to achieve NH_3 dosing it was planned to risk throttling the existing main NH_3 dosing, since there were distribution throttling flaps in the existing dosing system. However, when communicating this plan to the operating staff they informed these flaps had been recently removed due to fouling problems, putting the NO_x compliance at risk.

Unfortunately, they could not readily be reinstalled since it was a welded construction, and operation was reluctant to take any risk with the emission compliance by disturbing the main NO_x reduction.

Finally, this part of the project objectives had to be abandoned as time (and budget) was running out.

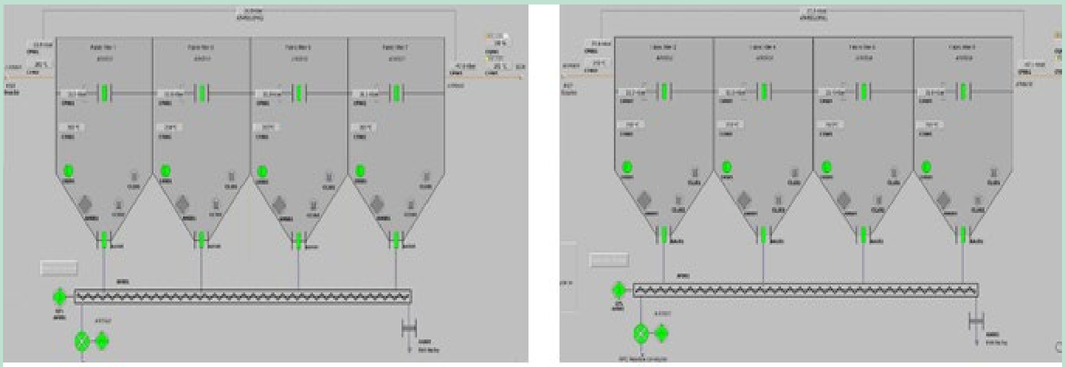
By not injecting ammonia, a reduction in NO_x removal activity by ABS formation can be ruled out, and any sign of deactivation can only be due to poisoning by the components mentioned earlier. This was an important aspect of the project.

7. The Snetterton Fabric Filter – mechanical description

The fabric filter installed at Snetterton has an 8-compartment lay-out as seen in FIGURE 6.

Each compartment has 196 bags, so the total number of bags is 1568. The bags are 8m long.

Numbering of the compartments is from left to right, odd numbers in one side and even numbers in the other.



Fabric Filter compartment 1 to 7

Fabric Filter compartment 2 to 8

FIGURE 6. Fabric filter configuration

8. Installation of the CataFlex^{TM} bags in the filter

196 CataFlex™ catalytic bags were installed in the fabric filter in May 2019. Reference bags without the inner catalyst bag were also installed at this time.

The CataFlex™ catalytic bags were installed in compartment 5, and 8 pcs. reference outer bags were installed in compartment 6 – see FIGURE 7 and FIGURE 8.

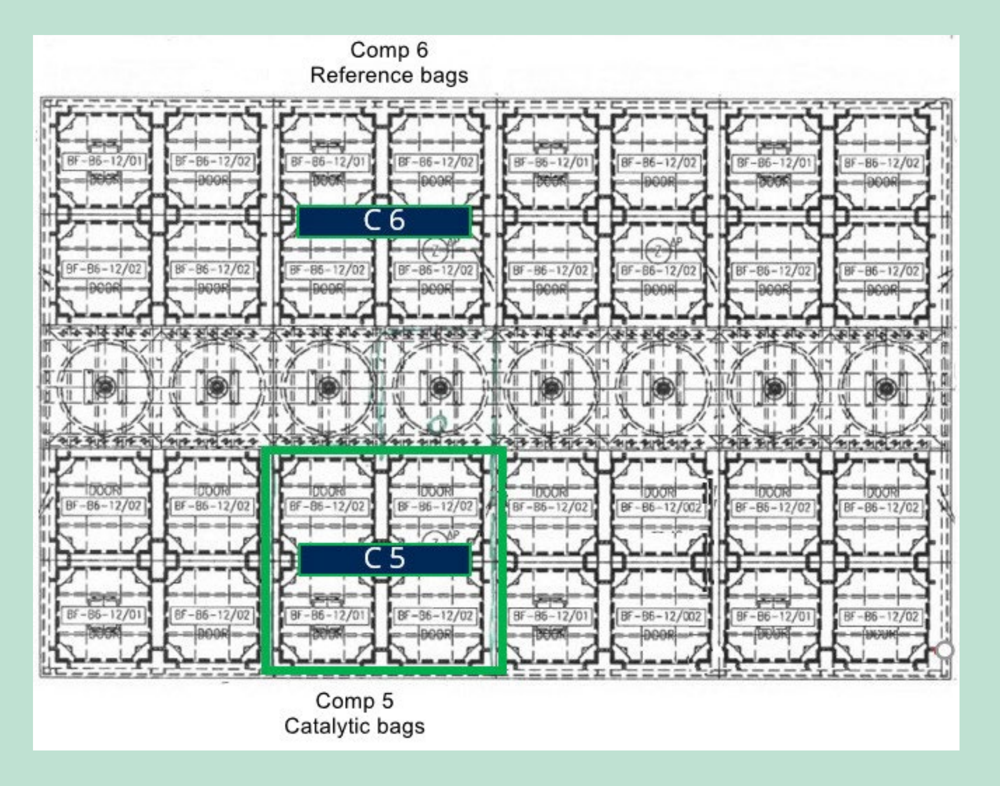
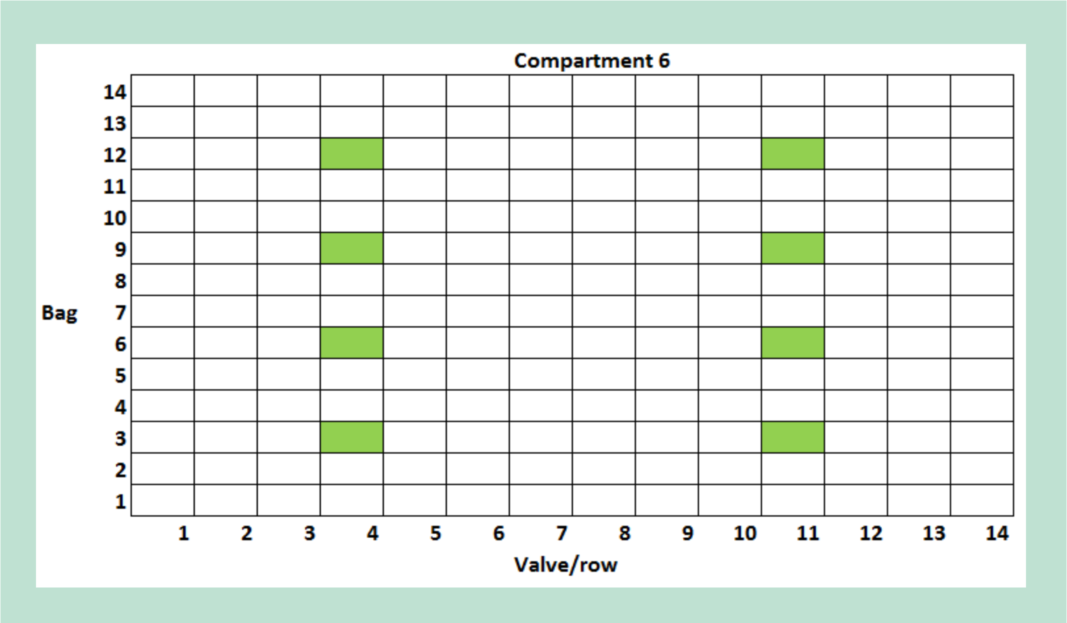


FIGURE 7. Filter seen from above. Compartment 5 and 6



Compartment 6

Bag \ Valve/row	1	2	3	4	5	6	7	8	9	10	11	12	13	14
14														
13														
12				🟩							🟩			
11														
10														
9				🟩							🟩			
8														
7														
6				🟩							🟩			
5														
4														
3				🟩							🟩			
2														
1														

FIGURE 8. Placement of reference bags in compartment 6

9. Plant Data

Data on operation of the filter was collected using the plant control system. The filter was equipped with differential pressure and temperature measurement devices for each individual compartment, which made it possible to compare compartment 5 with the catalytic bags with one of the other compartments with normal bags – see FIGURE 9.

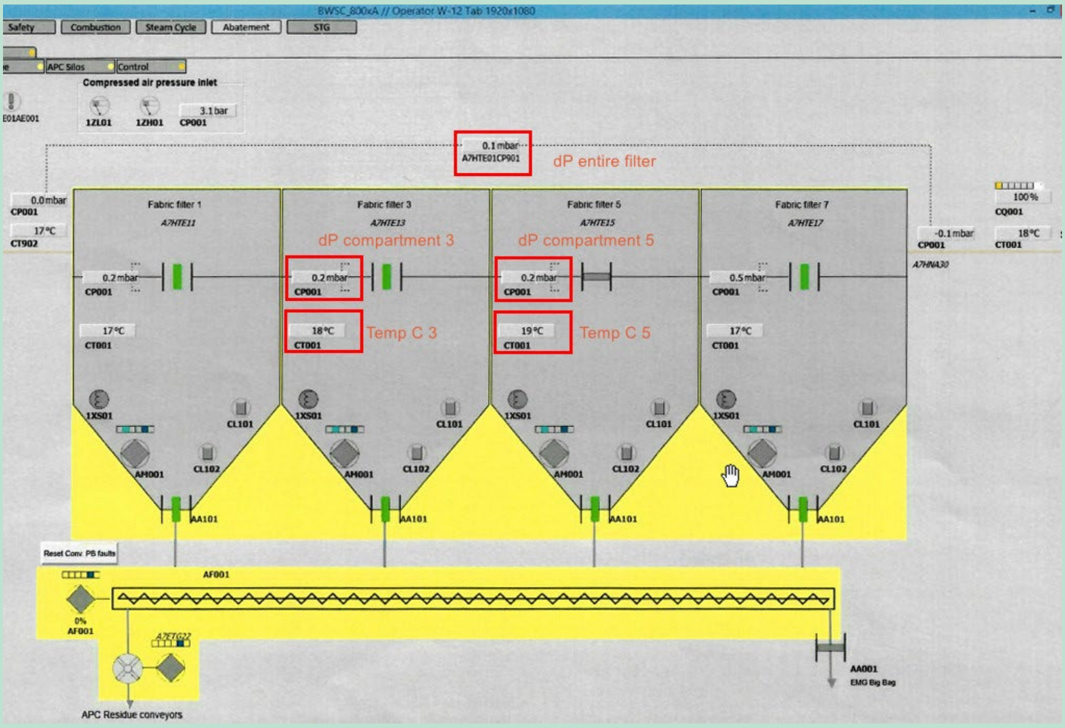


FIGURE 9. dP and temperature measurements compartment 3 and 5

9.1 Comparison between compartment 3 and 5

Data plot below show recorded pressure drop over filter compartment 5 (containing new catalytic bags) and compartment 3 (containing ordinary filter bags, serving as reference for pressure drop) over the initial 4 months operating time.

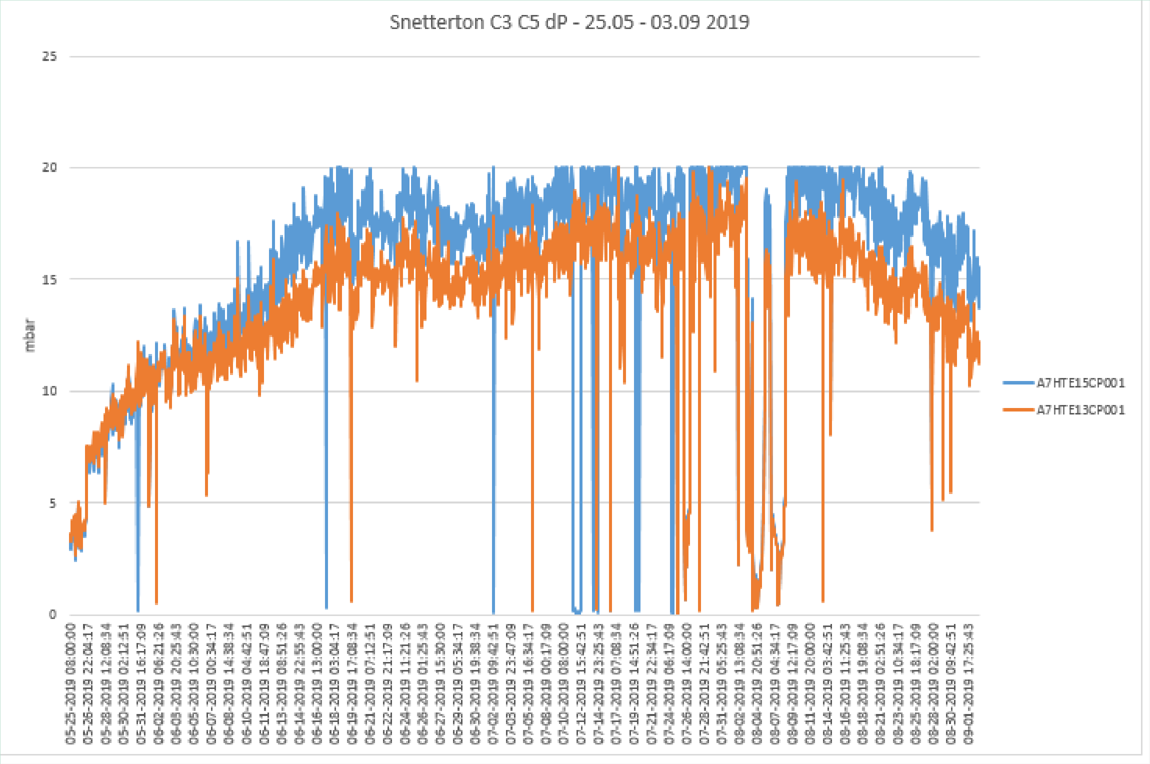


FIGURE 10. Differential pressure compartment 3 and 5. Brown curve is compartment 3 and blue is compartment 5.

As seen (and as could be expected) pressure drop over compartment 5 is slightly higher than compartment 3 after an initial running in period. Extra pressure drop is of the order 2-3 mbar (200-300 Pa), which is rather marginal compared to the overall FG train pressure drop.

This result demonstrate that traditional filter bags can be replaced with catalytic bags one-to-one without significant impact on system pressure drop. In most cases this will allow installation without having to upgrade plant ID-fan (unless this is already operating at its capacity limit).

Data plot shown in Figure 12 shows temperature in compartment 3 and 5, and it can be seen that the normal operation temperature for the filter is between 200 °C and 210 °C.

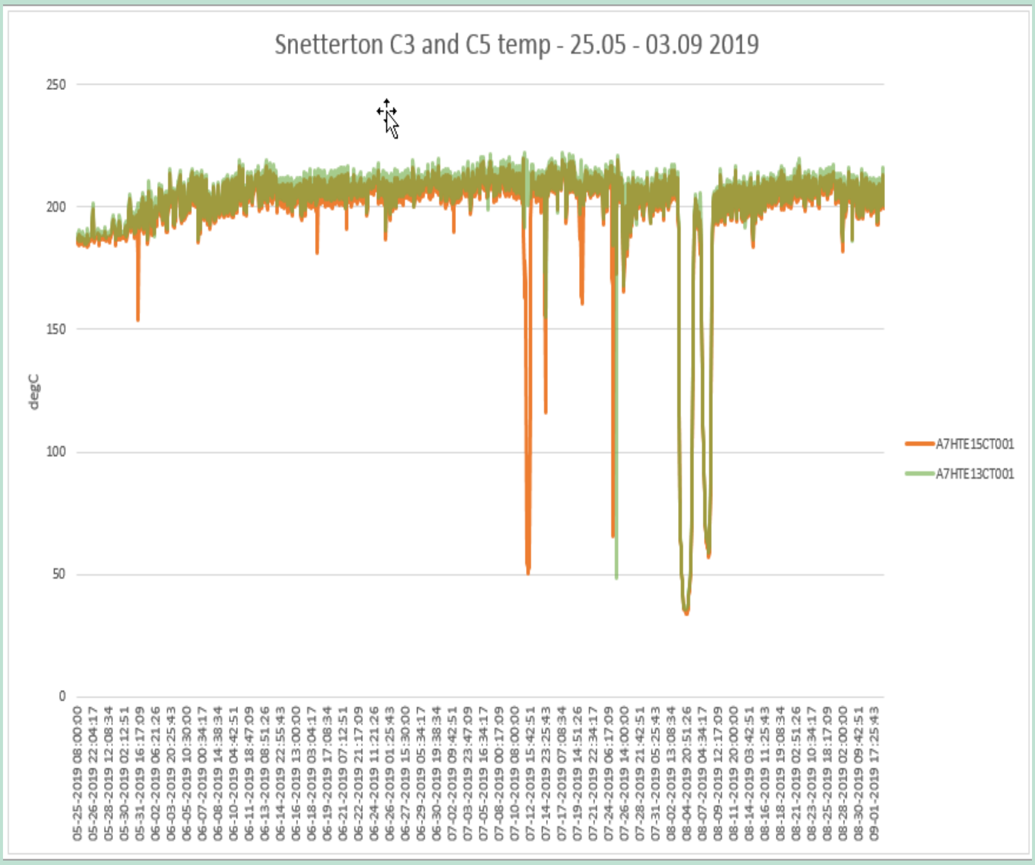


FIGURE 11. Temperature compartment 3 and 5. Green curve is compartment 3 and orange is compartment 5.

10. Laboratory tests and measurements

For the BWSC-Topsøe MUDP project, where a set of catalytic filter bags was installed at the BWSC biomass power plant in Snetterton, England, a series of analyzes have been performed to document possible signs of deterioration of catalytic activity after exposure to flue gasses from the biomass boiler for two years.

The purpose of the analyzes, was to demonstrate that the use of CataFlex™ catalytic filter bags is a suitable deNOx solution for biomass power plants, where the flue gas contains high levels of alkali and alkaline earth metals. These components are common poisons for V/TiO_2 deNOx catalysts. The catalytic activity was determined by extracting bags from the filter at regular intervals, and perform activity analyzes in a Topsøe test unit used for this purpose.

The CataFlex inner filter bags used for this project, were made of fiber glass without PTFE membrane, and were 8 meters in length, same length as the normal outer bags used for dust removal. The CataFlex filter bags were

installed inside the outer bags. Installation of the filters was in May 2019 with subsequent start-up.

10.1 Methods

The CataFlex filter bags have been in operation since May 2019. Samples were taken out in November 2019, July 2020, and March 2021 and sent to Haldor Topsoe. Sample analysis and activity testing of the exposed filter bags was done to evaluate performance after exposure to the biomass power plant flue gas for different periods of time.

The analysis of the bags was done using the following methods:

1. Visual inspection of filter bags to evaluate eventual discoloration of the catalytic inner bag and inspect for signs of dust penetration through the outer bag.
2. Elemental analysis to determine catalyst load and quantify poisons to determine if there had been loss of catalyst, or if signs of alkali and alkaline earth metals could be observed.
3. Activity test of catalytic filter bags to establish deNOx activity relative to that measured on the unused bags. The test unit used for activity test also makes it possible to investigate if changes in pressure drop at a given face velocity can be observed. A rise in pressure drop could indicate presence of small particles or condensated matter inside the bag material.

10.1.1 Visual inspection

The filter bags were visually inspected to evaluate the state of the filter bags. The state of the different filters received were very similar, and it was therefore chosen to show only one set of representative images. The pictures from the visual inspection of exposed filter bags consist of an outer bag with a dusty exterior and an inner CataFlex filter bag with a dust-free interior. Both the outer and inner bag were in a condition as normally seen on bags that have been in operation for this period of time. The outer bag had the expected layer of dust from the boiler and sorbent material from the FGT reactor, and the inner catalytic bag showed no signs of dust having penetrated the outer bag.

FIGURE 12. Pictures from visual inspection of exposed filter bags from Snetterton consisting of an outer bag with a dusty exterior and an inner CataFlex filter bag with a dust-free interior.

Figure 12.A shows the opening/collar of the filters with the catalytic filter bag on the inside.
Figure 12.B shows the dusty exterior of the outer filter bag.
Figure 12.C shows the dusty bottom of the outer filter bag.
Figure 12.D shows a filter cross-section with a dust-free interior for the catalytic inner bag (the dark color is the catalyst layer), compared to the dusty exterior of the outer bag.

10.1.2 Elemental analysis

Elemental analysis of the reference and exposed samples was done to:

1) Quantify the catalyst load from the V and Ti values determined
2) Quantify the presence of catalyst poisons on the samples, relative to the initial values for the reference sample.

The uncoated glass fiber bags are made of SiO_2 and oxides of Al, Na, K, Ca, and Fe, amongst others. Na, K, Mg, and Ca can act as catalyst poisons and it is therefore important to relate the analysis values to those of a reference sample

The sum of V and Ti are slightly higher for the unused sample compared to the exposed samples translating to catalyst loads of 68 g/m^2, 43 g/m^2, 49 g/m^2, and 51 g/m^2, respectively. The measured decrease in Vanadium and Titanium corresponds well with the small decrease in catalytic activity observed in the activity measurements.

The exposed samples are very similar in catalyst loading so no significant decrease over time was observed.

The higher catalyst load of the reference sample can either be due to non-uniformity in the catalytic cloth and/or due to some catalyst being lost during operation for the exposed samples.

The analysis results for Na, K, Mg, Ca, Cl, and P show a rather constant level of these species when compared to the reference sample.

This indicates that the catalyst has not been exposed to any significant amounts of these typical poisons.

However, an increase in the content of SO_4^{2-} is seen from 430 ppm for the reference sample to 3000, 3200, and 3500 ppm for the exposed samples, respectively.

The increased content can be an indicator of sulfate formation ($CaSO_4$, $MgSO_4$, $VOSO_4$) causing surface masking or pore blockage, reducing accessibility to active sites.

A content of 3500 ppm is not alarmingly high and the effect on DeNOx performance is not expected to be severe as also demonstrated by the activity measurements.

10.1.3 Activity measurements

The exposed CataFlex filter bags were tested to compare the deNOx activity and pressure drop to that of the fresh reference sample. All samples were tested under the same conditions and in the same test unit so the results are comparable.

Samples were initially conditioned at 250 °C for 8 hours in a flow of air. The activity was then measured for the following test conditions: 150-200 °C, 400 ppm NO_x, 320 ppm NH_3 (Ammonia -to-NO_x ratio =0.8), 19 vol.% O_2, and 10 vol.% H_2O.

The measurements for the individual samples overlay with each other, so this reflects that the exposed filter bags perform on the same level as the reference sample, which has not been installed in the filter house.

In other words, the catalytic filter bags have not deactivated significantly during 6, 14, or 22 months of operation. The activity reduction seen is normal and within the expected range.

The pressure drop over the catalytic filter bags was also measured during testing, and for all samples it was less than 0.5 mbar @air to cloth ratio 1.0 (m/min) for the inner catalytic bag alone.

Fabric filters with catalytic inner bags installed typically requires a slightly higher cleaning pressure than if only the outer dust bag is installed, but as it is not possible to adjust the cleaning pressure for the individual compartments this cannot be obtained. This is the reason that the difference in differential pressure between the compartments seen in FIGURE 13 is higher than measured in the laboratory.

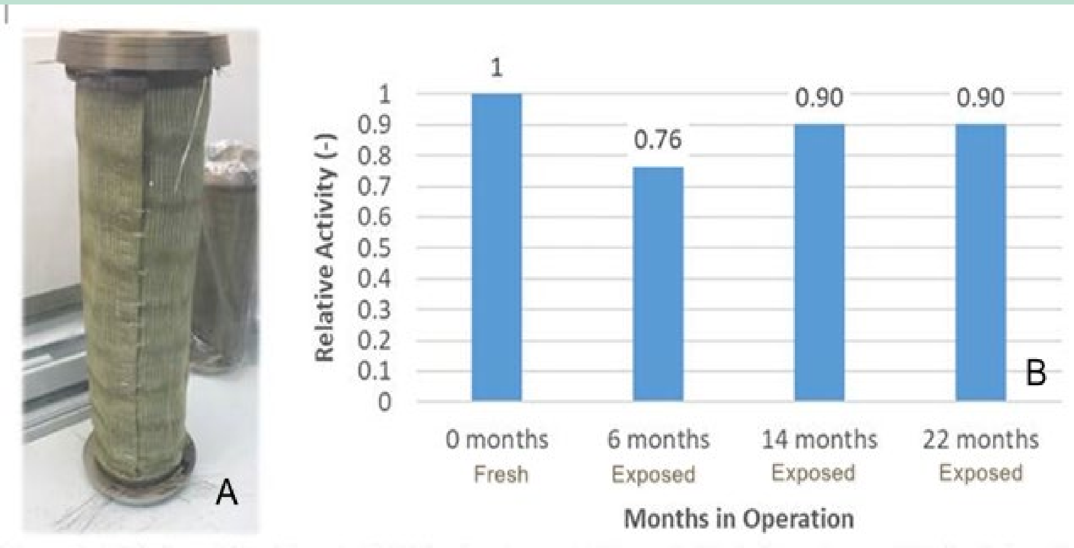


FIGURE 13. A) Picture of how the catalytic filter bag is mounted on a holder before placement in the test unit. B) Results from activity measurement relating relative activity of the exposed filter bags to the reference sample.

11. Conclusion on analyses

Four catalytic filter bags related to the Snetterton MUDP project with BWSC were analyzed and tested: one reference sample, and three exposed samples.

The bags are representative of performance at 0, 6, 14, and 22 months of operation in the filter house of the biomass power plant where a flue gas with a high content of alkali and alkaline earth metals is expected.

An inner bag/outer bag configuration was used, meaning that the catalytic filter bags were placed inside the regular filter bags. This configuration offers increased protection of the catalyst from the dust in the flue gas.

Analysis of the exposed samples confirms this, showing that the catalyst samples did not exhibit an increase in content of Na, K, Mg, Ca, Cl, or P which are expected from the biomass combustion. Furthermore, activity measurements showed little or no decrease in catalytic activity even after 14/22 months of operation.

12. Overall conclusions

Despite the failure to demonstrate DeNOx capability directly by injecting ammonia upstream the catalytic test bags, the test at Snetterton with almost two years of realistic biomass flue gas exposure has demonstrated that the CataFlex concept is a feasible solution to upgrade DeNOx capability of existing biomass power plants without dramatic and costly rebuilding of the flue gas train, where also often available space is a problematic factor.

The test period has demonstrated physical endurance beyond two years of the combi bag system under realistic operating conditions.

Also, pressure drop has been demonstrated to be only marginally higher than for traditional “dust only” bags, and remaining stable over time, indicating that the traditional air pulse cleaning technique is sufficient and effective.

Laboratory analysis has demonstrated that no significant poisoning or DeNOx de-activation has occurred during the nearly 2-year test period, indicating an effective service life well in excess of 2 years, which is at least as good as for traditional SCR installation catalyst fillings.

The DeNOx capacity of the CataFlex bags are well known by Haldor Topsøe from previous works and applications. With no de-activation found from lab analysis/testing the lack of direct on-site demonstration of DeNOx capacity is of no practical concern.

With above results the CataFlex concept is now considered sufficiently proven and documented to be marketed for biomass fired power plants.

Especially for retrofit installations, where plants are facing more stringent emission standards, the CataFlex solution offer many advantages compared to a traditional SCR installation.

13. Market estimate

In UK alone, a series of biomass (straw and wood chip) power plants has been established roughly in the time span 2010 - 2020.

BWSC alone has built 6 such plants, 3 mainly for straw and 3 for virgin wood chips (as well as other plants fired with waste wood or MSW).

Most of these (biomass plants) have been designed in accordance with the IED (Part 2) EU Directive emission limitations, among other a NOx limit of 200 mg/Nm^3 @dry, 6% O_2 (daily and monthly average) for plants with thermal input 100-300 MW_{th} (as Snetterton) or 250 mg/Nm^3 for smaller plants in the range 50-100 MW_{th}.

The “natural” NO_x emission from such plants is of the order 300 – 400 mg/Nm^3, so the reduction required to meet IED limits are limited and have in most cases been achieved with SNCR technology alone and a traditional FGD filter facility operated at around 140 ˚C (optimum for use of ordinary lime)..

An exception has been Sleaford and Brigg, with a part stream SCR installation to secure IED NO_x compliance and involving FG heating and cooling in the SCR branch to achieve suitable SCR temperature conditions.

Snetterton was however, as explained previously, established with a full stream SCR facility and a re-arranged FGD filter step operating at 190 ˚C with high activity lime to prepare for expected future more stringent NO_x limitation without the need for major rebuilding.

Due to a review clause in the typical local environmental permit these plants, among other the Snetterton sister plants Sleaford and Brigg, these now (from August 2021) face stricter NO_x limits in view of the recently adopted BREF practise (for existing plants).

Currently they are required to comply with an annual NO_x limit of 180 mg/Nm^3 which is barely achievable by SNCR alone (and an increased ammonia consumption) and/or having to rely more on the part stream SCR facility they have with limited overall NO_x reduction capability. Other plants are less fortunate relying on SNCR alone.

For these plants it is now possible to propose the CataFlex concept as an attractive solution to augment the NO_x reduction capability without involving a major rebuild of the flue gas treatment train, not least with a much shorter outage period involving significant production losses.

A similar situation is bound to exist in other EU countries, although this has not been investigated in detail yet.

Advanced catalytic bags for combined abatement of NOx and particulate matter in biomass boilers

Cogeneration plants, waste incineration plants and similar plants meet in-creasingly stringent requirements for emissions.

Many plants today can only reduce NOx emissions to the required levels by adding ammonia (NH3) directly into the boiler for so-called SNCR (selective non-catalytic reduction) - this allows for around 40-65% NOx removal.

Stricter NOx emission requirements mean that SNCR either require excessive ammonia dosing or is not sufficient, and therefore SCR (selective catalytic reduction) becomes necessary. Dedicated SCR reactors for NOx reduction is a well-known technology but require substantial investments to be implement-ed in an existing flue gas treatment facility.

Haldor Topsøe has in collaboration with FLSmidth developed a filter bag which functionally is a combined filter bag and SCR catalyst. This CataFlex™ filter bag works as a drop-in solution for systems with fabric filters for dust removal. Installation of CataFlex catalytic filter bags enables the reduction of NOx levels directly across the filter bag, whereby a separate investment-heavy SCR reactor and associated piping system can be avoided. The catalyst is the same as used in conventional SCR, and NH3 injection is required.

Especially on plants where removal rates that can be obtained using SNCR becomes insufficient due to tightening of NOx requirements, CataFlex™ will be able to ensure that the plant can be in compliance with new and stricter requirements for NOx emissions without entailing significant rebuilds like the traditional SCR solution requires

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