

EPPSA Report

FLUE GAS CLEANING RETROFIT

GUIDELINE FOR ASSESSMENT AND DESIGN RECOMMENDATIONS



European Power Plant Suppliers Association

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The European Power Plant Suppliers Association (EPPSA) is the voice, at European level, of companies supplying power plants, components and services.

EPPSA actively promotes awareness of the importance of flexible and efficient, state-of-the-art thermal power generation and its crucial contribution to ensuring a clean, secure, and affordable energy supply.

Virtually all thermal power plants in the EU are built by members of EPPSA or equipped with their components, and provide more than 50% of Europe's electricity.

EPPSA members provide the most advanced thermal power technologies in the world.

The aim of this paper is to outline the need to have a global vision while retrofitting coal fired power plants in order to comply with regulations on nitrogen oxides, sulphur and dust emissions in the European Union. Retrofitting of coal fired Circulating Fluidised Bed boilers is not completely covered in this paper, as the combustion technology has an impact on emission levels as well as applicable control technologies.

1. Introduction

What is the BREF?

In order to safeguard human health and the environment, legislation on both the national level and the EU level exists in order to prevent or as much as possible limit emissions of harmful substances into air, water, and soil.

The emission levels that are permitted are those consistent with **Best Available Techniques**, or BATs. Best Available Techniques are those which achieve a high general level of protection of the environment and are both economically and technically feasible; overall, they must be reasonably accessible to the operator. Finally, BATs refer not only to specific types of technology or to specific components, but also to the way that an entire installation is designed, maintained and operated.

Emissions into air, water and soil may of course differ dramatically depending on the type of industrial activity. For each type of industrial activity, there exists a document that represents an overview of the Best Available Techniques – the **Best Available Techniques Reference Document**, or BREF. Currently, 32 BREFs exist, covering all kinds of industrial activities ranging from cement manufacture to large combustion plants.

For large combustion plants, the permitting authorities in each Member State [‘competent authorities’] must

ensure that permits are granted only to installations that are able to fulfil Europe’s strict emissions legislation, and this is guaranteed by requiring the application of BAT, which can be found in the BREFs.

Previously, emissions legislation consisted of several sectoral directives and the IPPC [Integrated Pollution Prevention and Control] directive [see figure 1]; these different directives have now been consolidated into the Industrial Emissions Directive [IED], which was voted in 2010. With the entry into force of the IED, the contents of the BREFs – more specifically, their BAT conclusions – became legally binding and must be taken into account by permitting authorities when considering granting or withholding a permit.

Technological progress necessitates a periodic review of the BREFs as new technologies that are able to further reduce harmful emissions are developed and refined. In order to ensure that the highest possible environmental protection is achieved throughout Europe given the currently best available techniques, the IED contains provisions for a process of information exchange under the so-called Article 13 Forum. In this forum BREFs are periodically reviewed in a transparent process involving stakeholder input from governments, industry, and civil society.

Once a BREF has been updated and its BAT conclusions adopted, permitting authorities in Member States

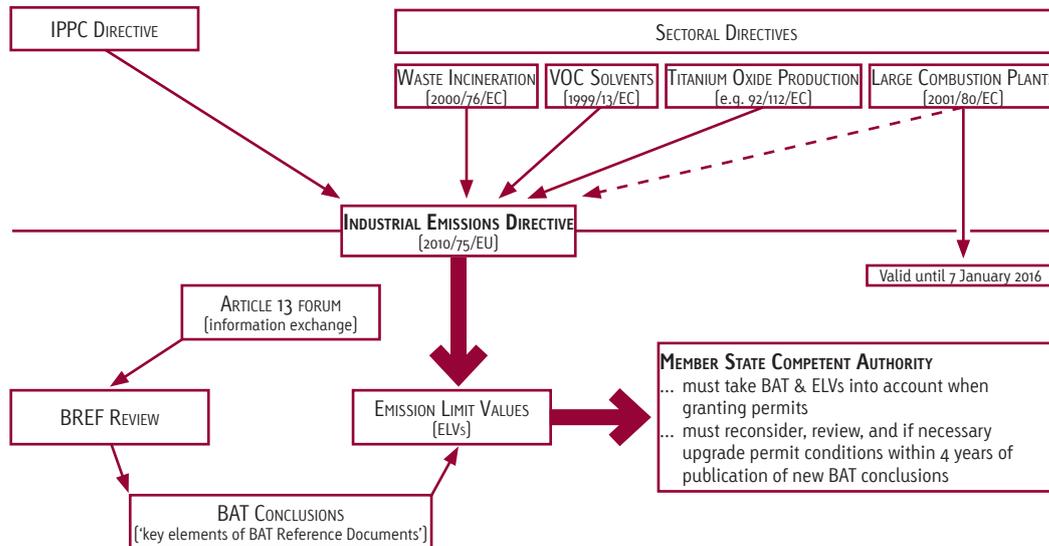


Figure 1: The IED Framework

have a period of four years in which they must review and, if necessary, update their permits to ensure that the new Emission Limit Values (ELVs), based on the new BAT conclusions, will be met (see figure 1).

Overall, it can be said that emission limits drive technological Research and Development (R&D), which result in better available technologies, which then influence future legislation; this represents a cyclical process towards increasingly better technologies for an increasingly cleaner environment and, consequently, a healthier planet and society.

Applicable legislation in Europe

For large combustion plants, currently applicable legislation in Europe consists of the IED, which replaced the Large Combustion Plants (LCP) Directive on the 7th of January 2016.

After this date, all large combustion plants operating in the EU must fulfil the requirements of the IED, although these vary depending on the age, size, fuel, and lifetime of the plant (see figure 2).

For example, older plants can be included in so-called ‘Transitional National Plans’ to allow enough time for them to be refurbished with BATs, or they may

be exempt from the IED’s requirements via the so-called ‘Limited Lifetime Derogation’, which is granted provided they operate for a limited number of hours. In addition, temporary derogations are possible in the case of supply shortages.

Despite these different exceptions, the ELVs as specified by the IED mainly consist of two groups: Annex V Part 1 ELVs and Annex V Part 2 ELVs. Annex V (1) ELVs are less strict than Annex V (2), and apply to plants which obtained their permit before 2013; Annex V (2) ELVs are stricter and apply more broadly¹. Thus, once the different temporary exemptions expire, all large combustion plants in operation in the EU will have to meet the ELVs as set out in Annex V – until, of course, the BREF review process arrives at newer, stricter values. BATAELs contained in the revised LCP BREF should be published in 2017 and will be translated into new ELVs. From the publication date, the new BATAELs must form the basis for new permit conditions for new plants, and up to 4 years after the BREF’s publication for existing plants.

¹ The ELVs differ according to pollutant, plant thermal input, and fuel type, so a full overview and comparison of Annex V (1) and Annex V (2) ELVs is impossible here; see the IED for more information. <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32010L0075>

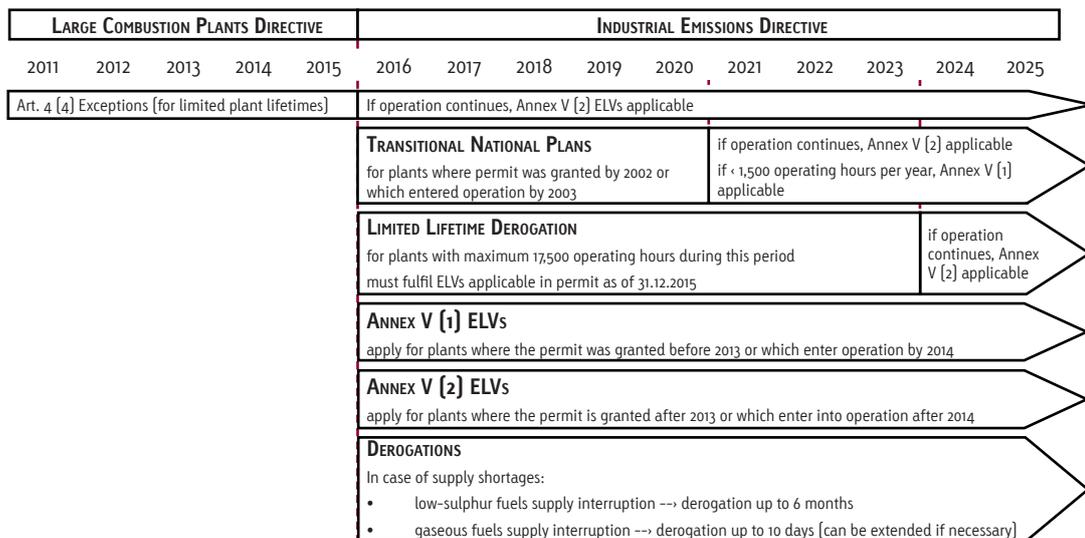


Figure 2: ELVs and Exemptions in the IED

2. Retrofit project preparation & initiation

Retrofitting an existing unit for compliance with new and stricter emission levels is not a simple and easy process. Although compliance with legislation and with the latest BATs is key, it is of the highest importance to dedicate the right amount of time to the preparation:

- A lack of preparation will lead to expensive, difficult and lengthy retrofits; while sufficient preparation will smooth and ease the projects.
- A wrong choice will impact the economics of the plant for the next decades: an incomplete analysis of the multiple factors can increase operating cost and/or investments.

This is why it is paramount to execute the project correctly, regardless of the time/cost pressure, to save costs in the long term. Choosing the right FGC technique [see Chapter 3] is critical but not sufficient to secure a smooth execution of the project.

This section intends to establish a typical list of points to take into account when retrofitting an existing unit. Although it will of course have to be adapted to suit a specific project, it should help any project team facing a retrofit project.

First step: knowing what is today's & tomorrow's situation

In many cases, tender documentation does not fully specify assumptions or the assumptions are not confirmed during operation. For example, in the case of Flue Gas Desulphurisation (FGD), coal specification is one of the critical aspects to achieve the desired removal efficiency. When the coal deposit is not consistent, it is fundamental to fully understand the coal input in the next decades to avoid over- and under-designing the FGC system.

The main plant parameters to be evaluated prior to design are:

- Fuel specification and resulting flue gas parameters (including acid gas compounds [SO₂, SO₃, HCl, HF and HBr] in flue gas);
- Fly ash composition (including calcium

compounds and alkalis);

- Sorbent parameters (type, composition and particle size);
- Existing Flue Gas Cleaning upstream the FGC (e.g. in-furnace limestone injection in fluidised bed boilers, SNCR/SCR);
- Operating mode (base load/fluctuating, load factor curve, ...);
- Remaining lifetime of the plant;
- Availability.

Interactions between FGC techniques [lit. 13]

Once the requirements are well defined and the existing Flue Gas Cleaning (FGC) line is known, it is important to evaluate the cross-impacts between the different types of equipment.

Indeed, some techniques described below for one pollutant can also reduce others.

An example of such a cross-impact is the installation of a dry technique which includes, in most cases, the installation of a new filter. This will impact the dust removal, decreasing the dust emissions at the stack. Opting for a wet sulphur removal technique will not impact dust emissions as significantly, imposing a retrofit of the existing dust control device.

This demonstrates the importance of looking at the totality of the Flue Gas Cleaning line rather than cutting it up into smaller projects, as this could potentially lead to:

- Interface issues between the projects (i.e. flue gas composition)
- Increased investments that are not necessarily technically justified
- Increased operating cost, complexity and maintenance

Preparation of retrofit projects

EPPSA members are among the best companies to gather positive and negative aspects of retrofit tenders. This section lists those aspects so that every project team can learn from past errors and follow good examples.

DOs

- Secure a reasonable timeframe to allow for [1] a feasibility study to evaluate different alternatives and to come up with a budget, [2] a preparation of the tender, [3] a preparation of the quotation and [4] the negotiation and execution of the contract;
- Secure the right financing tools, taking into account the invoicing timeframe;
- Get a full “buy-in” from the plant’s team;
- Base your specification on a “fit for purpose” philosophy;
- Consider implementation dates of regulations, taking into account that other customers are focusing on retrofits;
- Choose suppliers with a solid reference base, because of high complexity in retrofit projects;
- Define clear evaluation criteria considering OPEX and or CAPEX to get your optimised customised solution.

DON'Ts

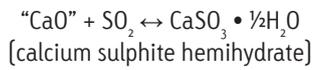
- Avoid changing the specification during advanced project execution;
- Avoid “overspecifying” the FGC when it comes to design margins and equipment requirements.

3. Technology selection

A. Sulphur removal (lit. 5 and lit. 13)

A little bit of chemistry...

The sulphur content of the flue gas is mainly composed of SO₂ with, usually, a small fraction of SO₃. These are created during the combustion process from the sulphur which is contained in the fuel used. The quantity to be removed is thus a function of the fuel burned and its specification. Removal of sulphur from the flue gas follows this standard scheme:



In wet technologies (illustrated in figure 3), calcium sulphite is oxidised into calcium sulphate di-hydrate – also known as FGD-gypsum [CaSO₄ • 2H₂O] (lit. 16). The source of Calcium in wet technologies is either calcium carbonate slurry, known as limestone (CaCO₃) or a slurry of calcium hydroxide, known as milk of lime [Ca(OH)₂]. The choice of reagent is linked to local consideration as reported in literature (lit. 15, and lit. 21). This process is highly efficient to capture SO₂ but demonstrates a reduced efficiency with regards to SO₃.

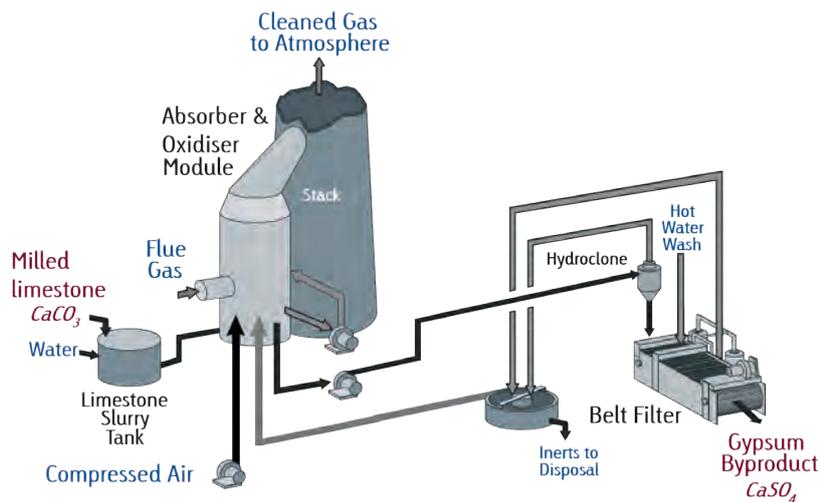


Figure 3: Flow diagram of wet technique based on limestone

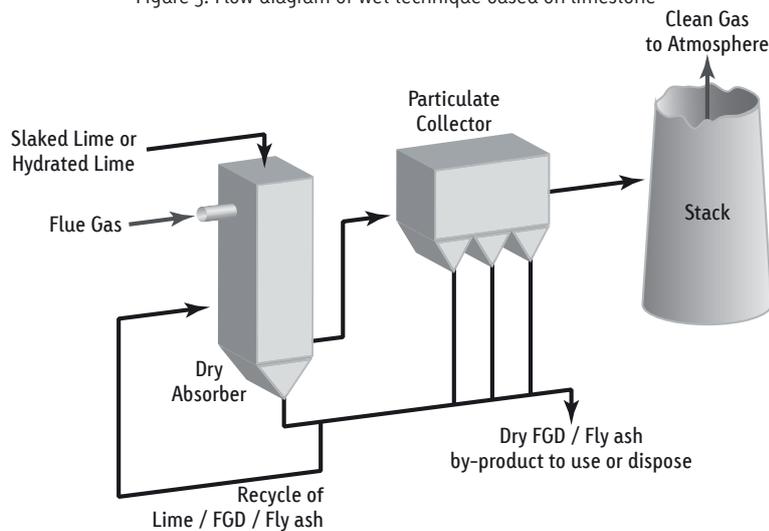


Figure 4: Flow diagram of semi-dry technique [CDS]

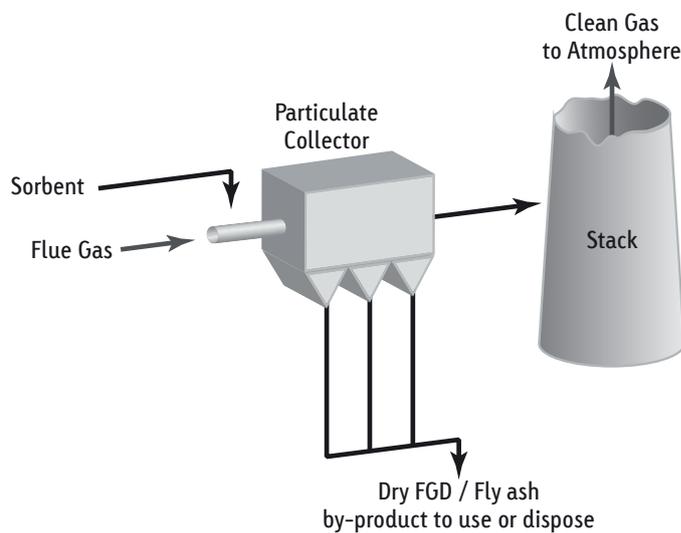


Figure 5: Flow diagram of dry technique (DSI)

In (semi-)dry techniques (illustrated in figure 4), the reagent is calcium hydroxide [Ca(OH)₂ or hydrated lime], which is in contact with the flue gas. The properties of the injected hydrated lime – such as the specific surface area, porosity and Ca(OH)₂ availability – as well as process parameters (moisture level, temperature, ...) have an influence on the dosage requirement for a given removal efficiency. This family of techniques is efficient on both SO₂ and SO₃ but also on halogen acidic components (HF, HCl) (lit. 18). Two main techniques can be identified in this family:

- Circulating Dry Scrubber (CDS) in which the injected sorbent is dry calcium hydroxide (commonly called hydrated lime) and some water is sprayed separately to control flue gas temperature and humidity. The calcium hydroxide can be delivered ready to be injected or can be produced at the FGC unit starting from calcium oxide (CaO or quicklime) when the unit includes a hydrator (lit. 1, lit. 7, lit. 10 and lit. 18).
- Spray Drier Absorber (SDA) in which the reagent is injected under the form of slurry of lime (also called milk of lime). This technique needs to include a slaking unit in order to transform calcium oxide (CaO or quicklime) into suspension.

Those 2 techniques differ from a simple Dry Sorbent Injection (DSI – illustrated on figure 5) with additional features such as:

- Flue gas conditioning (temperature control / moisture control);
- Sorbent recirculation;
- Improved contact between reagent and flue gas in an absorber/reactor.

All these features aim to both improve the efficiency and reduce the reagent specific consumption.

The reagent utilisation rate is a common Key Performance Indicator (KPI) used in FGC techniques. It represents the percentage of reagent fed into the FGC system that reacts with SO₂. Reagent utilisation in a wet Limestone system, when considered on a removed SO₂ basis, is very close to the required theoretical level, typically greater than 97%.

This high level of reagent utilisation is also required to maintain the quality of gypsum if it is to be used for wallboard manufacturing.

In the wet lime process, lime reagent utilisation is higher due to its high reactivity and the small particle size of slaked lime (3 microns average).

In dry techniques reagent utilisation is lower. Although a solid-gas reaction is not as effective as a liquid-gas reaction and needs a higher dosage, the reduced operating cost and investment can compensate for

this extra reagent cost.

In a [semi-]dry scrubber integrated with a fluidised bed boiler using in-furnace limestone injection, the unreacted calcium [CaO] in ash can be further utilised in FGD and the cost of external FGD sorbent can be reduced.

“Stoichiometry”, the second classical factor, is a measure related to the reagent utilisation. Stoichiometry is the ratio of the reagent fed into the system to the SO₂ absorbed [mole/mole] and is equal to 100 divided by reagent utilisation. For example, a reagent utilisation of 98% is equal to a stoichiometry of 1.02.

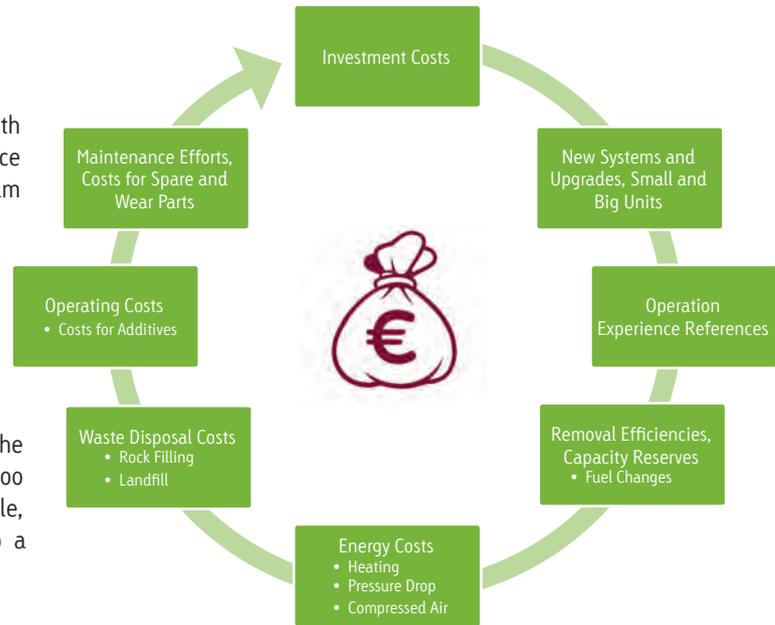


Figure 6: Key parameters to consider during technique selection

Wet or dry technique... (lit. 1)

The choice between Flue Gas Cleaning techniques is a real question. Nowadays both dry and wet technologies can manage the highest removal efficiencies required in most cases to comply with IED and associated EU legislation. The choice between systems is illustrated in figure 6, it should integrate multiple aspects, including:

- Local economics: investment cost (loan,...), utilities (water and power) costs, labour costs;
- Local legal requirements: local legislation could be more strict than EU directives;
- Local installation: space availability, infrastructure, plant layout, flue gas specifications, water availability/costs; water disposal requirements/costs;
- Local reagent source: delivered price, availability, specifications and/or logistic options of the potential calcium sorbent (lime or limestone) can drastically influence the economics of the FGC operation; and
- Local market for by-product and local landfilling possibilities/costs.

In semi-dry and dry processes, lime hydroxide

[Ca(OH)₂] will contact the pollutant through a gas-solid reaction. Solid by-products will be collected in a dedusting equipment. Fly ashes can represent a separate flow (double filtration) or be collected together. If collected together, the marketing of fly ash may be not possible and the volume to be landfilled is much higher. As bag filters offer a better contact than Electrostatic Precipitators (ESPs), they are favoured for such applications. A big advantage of a [semi-]dry system is that no waste water is produced. Efficiency is a function of many parameters, including temperature, moisture content, lime quality, recirculation rate and fresh sorbent feed rate. As this technique usually involves some work on the filter, the implementation of sulphur capture through a [semi-] dry process allows for an improved dust capture at “no” extra investment cost. The total investment cost is lower than for wet processes, especially if no double dust filtration applies.

In wet processes, lime or limestone slurry (=calcium source) contacts the flue gases and promotes a liquid-gas reaction. The reaction efficiency is mostly driven by the contact time but also by the slurry’s pH, controlled by the addition of a fresh reagent. The slurry circulates in the absorber thanks to significant pumping capacity.

The sulphur reacts with calcium and oxygen to form low-soluble gypsum which is removed from the slurry through the dewatering system (usually a vacuum belt filter). The cost of reagents in this technique is lower but the investment is higher than for dry techniques.

A case-by-case evaluation is required to choose the best technique, resulting in the economical and technical optimum. Copy-Paste solutions are usually not optimised, risking non-compliance and/or generating extra costs both at investment and during operation.

Below table underlines some factors impacting on the process selection. Every real case is of course not as simple...

Factors favouring a DRY Process	Factors favouring a WET Process
Small-Medium size plant Small-Medium flue gas flow (up to 300MW _{el}) Large size plants (up to 700 MW _{el}) with low sulphur fuel or combined in-furnace and backend FGD (CFB boiler application)	Large size plant Large flue gas flow (over 300MW _{el})
Low-Medium sulphur fuel High SO ₃ level to be removed	High sulphur fuel
Low-Medium annual operating hours	Medium-High annual operating hours
Short-Medium cost evaluation period Shorter remaining lifetime Retrofit	Medium-Long cost evaluation period Longer remaining lifetime New build

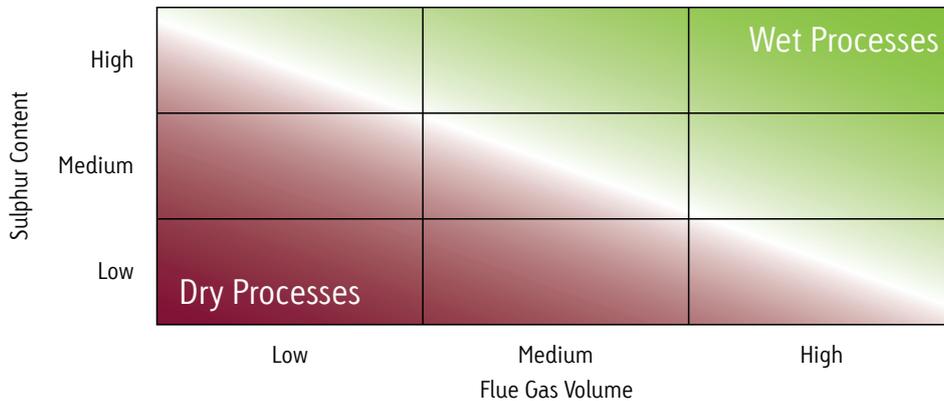
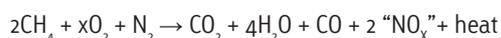


Figure 7: Typical application zone for technique

B. NO_x removal [lit. 5, lit. 13 and lit. 14]

A little bit of chemistry...

NO_x is a generic term for the nitrogen oxides NO and NO₂. They are 'naturally' produced during combustion, especially at high temperatures, by oxidation of air oxygen. Nitrogen does not take part in combustion, but under unfavourable conditions some nitrogen will be converted into NO_x. A more complete air combustion reaction is therefore:



The three primary sources of NO_x in combustion processes:

- thermal NO_x
- fuel NO_x
- prompt NO_x

Thermal NO_x formation, which is highly temperature dependent, is recognised as the most relevant source of NO_x when combusting natural gas. Fuel NO_x tends to dominate during the combustion of fuels such as coal, which have a significant nitrogen content, particularly when burned in combustors designed to minimise thermal NO_x [see primary measure below]. The contribution of prompt NO_x is normally considered negligible.

Primary measures to reduce NO_x:

Low NO_x combustion

[lit. 11, lit. 14]

The primary measures include all technologies that reduce the formation of the NO_x. Indeed, it is well established that conventional "blue flame" or bunsen gas burners produce oxides of nitrogen at levels of 30-50 nanograms per joule and are, as such, not considered to have a NO_x reduction potential. Surface combustion burners or radiant tile burners, on the other hand, have a nitrogen oxides production level that is 60-70% lower. This is why research from the '80s and '90s into low NO_x burners was focussed primarily on surface combustion techniques.

Low NO_x combustion technologies include the following technologies:

- Low NO_x burner [aerodynamically controlled top and split flame type]
- Combustion modification such as air staging and flue gas mixing
- IFNR [In-Furnace NO_x Reduction] combustion

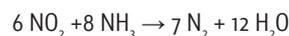
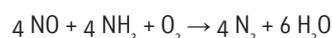
Secondary measures to reduce NO_x

When primary measures are not possible / sufficient, NO_x should be removed from the flue gas. Those processes are known as secondary measures. Two main process families are present: SCR [selective catalytic reduction] or SNCR [selective non-catalytic reduction] DeNO_x.

SELECTIVE CATALYTIC REDUCTION

The SCR process is the most efficient process for removing nitrogen oxides - NO_x - from gases. In SCR, NO_x reacts with ammonia over a catalyst to form elementary nitrogen and water vapour without creating any secondary pollutants. The main components of an SCR DeNO_x system include a reactor with catalyst and an ammonia storage and injection system. The ammonia source can be either anhydrous ammonia, ammonia water or a solution of urea.

When the reducing agent is NH₃, chemical equations are represented as follows:



Classical operating temperature is between approximately 300 [the minimum temperature strongly depends on SO₃ content in flue gas] and 420°C and the removal efficiency can reach up to 98%. Consequently the SCR unit is generally placed between the economiser and the air pre-heater, although other places may also be suitable.

SELECTIVE NON-CATALYTIC REDUCTION

SNCR is a proven method to control NO_x emissions from fluidised bed boilers, incinerators, industrial boilers, utility boilers... The method can use either urea or

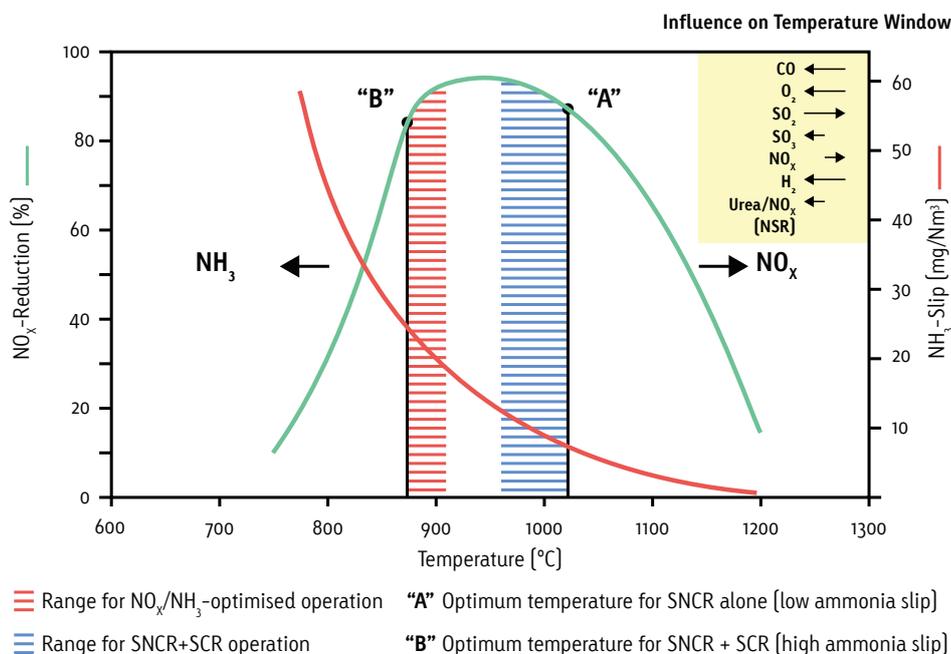


Figure 8: NO_x reduction as a function of temperature [lit. 20]

ammonia and does not require a catalyst, but the injection has to be performed in a small temperature window, between 950 °C and 1050 °C.

Comparing SCR and SNCR's advantages and drawbacks [lit. 11 and lit. 16]

The SCR process requires precise control of the ammonia injection rate and a homogeneous mixing into the flue gas to ensure efficient NO_x conversion without an undesirable release of unconverted ammonia, which is referred to as 'ammonia slip'. Catalysts are usually based on a titanium dioxide carrier which is homogeneously impregnated with active components such as vanadium pentoxide and tungsten trioxide. Those catalysts have high activity for DeNO_x reactions but also, to a smaller extent, for SO_2 oxidation: SO_2 oxidation to SO_3 could affect some downstream FGC equipment [i.e. corrosion]. Alkaline metals in dust are also known as catalyst poison. However, because of the low possibilities that they are in contact with the active site in normal operation, they are generally not so harmful for the activity.

SNCR can continuously achieve up to 50% NO_x reduction in industrial applications and is generally considered the most cost-effective technique for achieving the first increment of NO_x reduction. The process key is to introduce the reagent at the right temperature. If it is too cold, the reduction reaction is impossible while if the ammonia is too hot, it will generate extra NO_x : the optimal injection temperature is between 950°C and 1050°C. When the ammonia injection temperature is lower (e.g. during low load operation), a small slip-SCR can be installed to control the ammonia slip below the set limit. The slip-SCR will also reduce NO_x further when the ammonia slip has been consumed.

Primary measures have a 'limited' efficiency which can make these processes insufficient by themselves. Nonetheless, the implementation of such measures reduces ammonia/urea consumption which can pay back the investment.

C. Dust removal [lit. 5 and lit. 13]

How to remove dust

Dust comes mainly from fuel combustion ashes but can be mixed with Flue Gas Cleaning residues like calcium salt (used in DeSO_x processes) or activated carbon (used for the adsorption of heavy metals such as mercury). Many dust removal technologies can be applied with big differences in efficiency. Scrubber technologies and cyclones can still be found in old installations and although their low efficiencies are often not compliant with the current emission limits imposed by the EU, cyclones can, for example, still be used as a 'pre-dedusting' step in case of a dry FGD system.

Nowadays, modern boilers are all equipped with an ESP or a baghouse. An ESP is a particulate collection device that removes particles from the flue gas using the force of an induced electrostatic charge. ESPs are highly efficient filtration devices that minimally impede the flow of gases through the device, and can remove fine particulate matter such as dust from the air stream. The basic precipitator contains a row of thin vertical wires, followed by parallel large, flat, vertically oriented metal plates. The ionised particles, following the negative electric field created by the power supply, move to the grounded plates.

Some power plants install nowadays an extra ESP downstream of the wet scrubber. Those Wet ESPs are designed to achieve high removal efficiencies and can capture aerosols as well, which is the main reason to install them. Indeed, after a wet scrubber, SO_3 will appear mostly under the aerosol form $(\text{H}_2\text{SO}_4)_3$ (low efficiency for SO_3). SO_3 is a particular issue in locations like the US as they form a dark blue/brown plume (source of public acceptance issue) and can be an important source of power plant issues (corrosion...).

Baghouses or fabric filter bags use filtration media to remove particulates from raw gases. They are one of the most efficient and cost-effective types of

dedusting technologies available and can achieve a collection efficiency of more than 99%. Flue gases enter the baghouse and pass through fabric bags that act as filters. The bags can be of several materials (woven or felted cotton, synthetic, or glass-fibre material in either a tube or envelope shape) and are cleaned periodically to maintain proper operation. Dust is collected in hoppers and extracted from the equipment [lit. 1].

ESP or Baghouse ...

In general, baghouses involve a higher pressure drop than ESPs and require a compressed air consumption (cleaning) while ESPs consume electricity (electric field). In terms of investment, the baghouse's size is determined by the flue gas flow (Air-to-Cloth [A/C] ratio) while the size of the ESP is determined by the efficiency, dust composition... The most economical situation is thus a case-by-case calculation.

Fuel flexibility (between different coal sources and with co-firing options) and the increasing legislative concerns about small particulate matter (i.e. PM 2.5) are two major reasons why power plants might favour a baghouse, although ESPs with an increased number of fields are still the most common device in power plants.

Both techniques allow for clean gas with a dust content below 10 mg/m^3 [i.e. up to 99.9% removal efficiency].

4. Technology choice's impacts on the plant operation

Link between Reagent and Flue Gas Desulphurisation technology (lit. 3, lit. 5 and lit. 6)

Performance of such FGD systems depends mainly on:

- The quality of the reagent used:
 - Chemical properties (purity and impurities level)
 - Physical properties (particle size, specific surface [BET], reactivity, hardness...)
- The design and the quality of the equipment
- The perfect alignment between the quality of the equipment & that of the reagent

Because FGD systems represent added costs without compensating revenue streams, determining the right reagent is critical to effective cost-control initiatives.

For wet systems, for instance, the purity of the limestone is based on the calcium carbonate content. But the relative performance of the limestone cannot be predicted solely based on this factor. Crystal shape is, for example, also a dominant factor. Impurities also have a significant effect on removal efficiency and/or gypsum quality:

- SiO_2 will increase wear and thus maintenance cost



Figure 9: Wear caused by high silica content (wear on rubber lining from centrifugal pump in wet limestone system)

- Al_2O_3 can combine with Fluor to form an aluminium-fluoride complex that can hinder the limestone dissolution process (lit. 12, lit. 17 and lit. 19).
- Fe_2O_3 promotes the oxidation of gypsum but also has an impact on the gypsum colour and particle size distribution at higher values (figure 10)

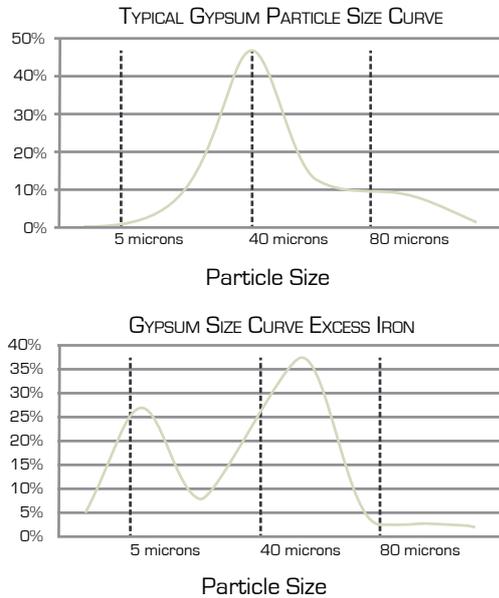


Figure 10: Influence of iron oxide on gypsum particle size

- Mn_2O_3 also promotes the oxidation of gypsum but can initiate, at higher Mn values, corrosion of some alloys (especially alloy 2205, which is used mainly in the USA)
- MgO/MgCO_3 , soluble, will boost alkalinity and thus the reaction's kinetics. Such soluble salts are, however, limited in Euro-gypsum specification.

Reactivity of the limestone, unlike the other parameters, does not have a standardised method of measurement. We nevertheless recommend using a method which is simple, replicable and for which **every** parameter is specified. Most common European techniques measure the dissolution rate of limestone in water by addition of an acid. This addition is classically controlled to keep a constant pH in the tested sample. The techniques used by EPPSA members usually differ with regards to parameters such as agitation, temperature, type & concentration of acid used, pH set point, etc. but applying the chosen one consistently settles the issue.

For lime-based systems, the reactivity of lime is critical for the design of the FGD system/reagent island. The stability of the lime's reactivity and purity are preferred for smooth operations. The standard methods for assessing the quality of lime-based sorbents are the

Available Lime Index (ASTM-C25) or VGB-M703 method for available $\text{CaO}/\text{Ca}(\text{OH})_2$. The reactivity of quicklime is also defined by using the procedure described in EN 459-2. The specific surface (BET) of hydrated lime is also a key parameter describing the sorbent's quality. Typically, a BET higher than 18-20 m^2/g is an indication of good quality sorbent. The BET or porous volume of some special but more expensive hydrated limes may be much higher [e.g. 40 m^2/g / 0.2 cm^3/g]. Those special limes, despite their higher cost per tonne, might be the most economical option in terms of total cost of ownership as the quantities required are lower.

In case of a non-optimised reagent, classical consequences are non-compliance with the emission levels at the stack, increased reagent consumption and/or operational issues.

Reagent Preparation & Handling

Most plants are required to operate continuously with a functioning Flue Gas Cleaning (FGC) system, which places a premium on reagent availability.

Preparation of the reagent is often composed of several steps outside of the power plants' core business. For example, in wet limestone systems, slurry preparation involves the grinding of a high-calcium crushed limestone to a fine particle size (95% smaller than 45, 63 or 90 microns, function of the design) in a mill. The finest size allows for a more complete use of the limestone and a decreased slurry volume. Maximising reagent utilisation also minimises the amount of unreacted reagent in the gypsum by-product. Figure 11 illustrates the impact of limestone particle size on efficiency: a finer top size sample is more reactive than coarser limestone from the same deposit.

In (semi-)dry FGD systems, reagent can be purchased as specified or prepared on site from quicklime in a slaker/hydrator. Quicklime can be sourced either pulverised or as pebble lime. When pebble lime is used, an on-site crushing step before the hydration process is required while pulverised quicklime is ready-to-use and widely available in Europe. Hydrators are available based on either mechanical mixer or fluidised bed processes.

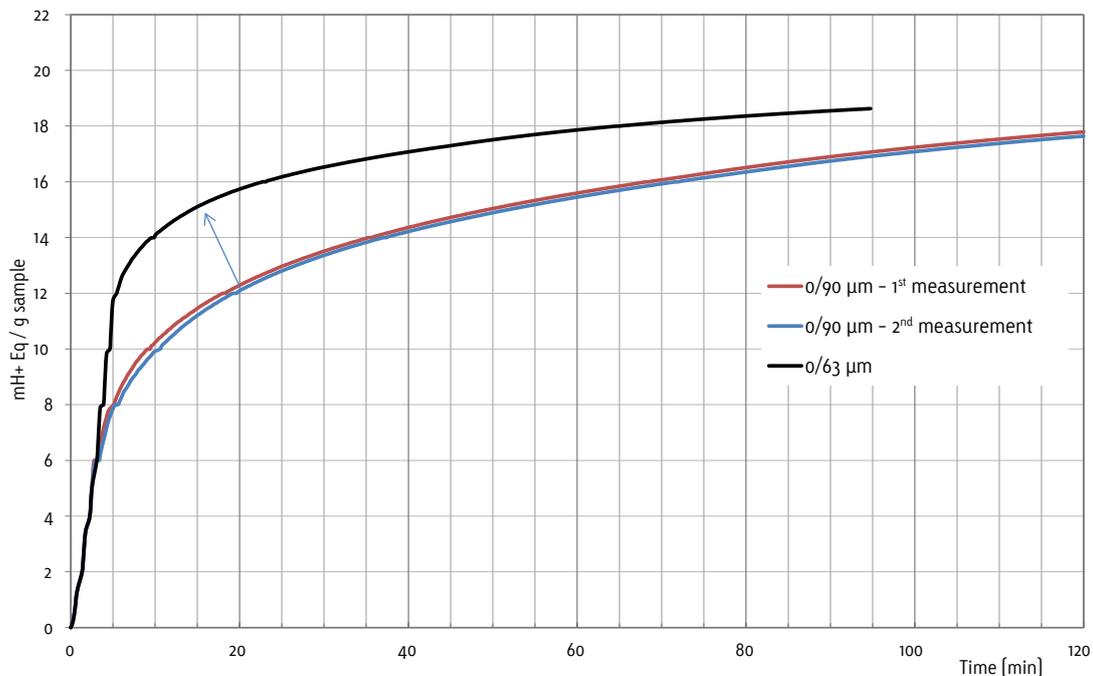


Figure 11: Influence of particle size on the limestone reactivity: Reactivity curve according to the Carmeuse method of the same stone at 2 different particle size distribution

Next to the preparation itself, adequate storage and handling systems need to be installed. The size and the specification of the equipment need to be designed accordingly to the FGD technique, the reagent specification, and the reagent logistics, which should also be optimised both for the power plant and the reagent supplier. Not taking these aspects into account will result in extra costs during operation and/or on the reagent.

This means that a detailed reagent study needs to be performed prior to the FGD tender preparation to cross-check this alignment, taking into account the reagent quality, all logistic aspects and the long-term vision.

Long-term vision

The correct and consistent use of FGC reagents is the key to ensuring a smooth operation and compliance with today's strict emission requirements. As Flue Gas Cleaning represents a significant investment, it is key to align the source of the reagents with the lifetime of the equipment. The long-term capabilities of potential reagent suppliers are also critical to optimise the total cost of the reagent ownership and study.

During quarry operation, unexpected events can happen... Back-up solutions and/or sufficient storage are needed to mitigate those risks.

After commissioning, effective and reliable FGD operation is required to ensure a consistent by-product that meets designed specifications. Regular analysis of the process allows for a continual fine-tuning of the system to optimise the operation and minimise treatment costs.

Some reagent suppliers are more knowledgeable regarding the effect that their product has on the overall efficiency of an installation, and are able to provide product improvements and optimisation advices based on previous experience in working with such installations.

By-Product Utilisation

(lit. 6 and lit. 9)

The by-product of wet systems, FGD-gypsum, can be sold on the market after dewatering it to 90% solids (10% moisture). FGD-gypsum can also be disposed of in a landfill, either in a slurry or dewatered, and either alone or blended with fly ash. Gypsum can be used in the production of wallboards. As wallboard manufacturers have stringent limits on the various impurities that are allowed to be present in the by-product, the installation and the reagent have to be optimised to produce high quality gypsum (more info in the EUROGYPSUM norm²). Gypsum can also be used as an additive for concrete, or as an agricultural soil conditioner.

With the increasing prevalence of wet lime and limestone scrubbers for FGC, the power industry is faced with the challenge of finding a home for all of the by-products generated, even for high quality gypsum.

Dry Scrubber by-products have a narrower market utilisation. Indeed, further utilisations are a function of the composition, the content of fly ashes (whether the collection was common or separated), the local legislation, and the presence of the right partner... Nevertheless, Dry Scrubber by-products can be marketed in niche applications (fertiliser, civil engineering, construction...) or they can also easily be landfilled.

Because of this challenge of finding economical solutions for FGC by-products, it is very important to have a partner who can supply a high quality reagent and with the knowledge to produce a high quality by-product instead of a waste.

² Info on EUROGYPSUM norm can be found on the association's website: http://www.eurogypsum.org/_Uploads/dbsAttachedFiles/eurogypsumbd2.pdf



Figure 12: Example of by-product reuse

5. Conclusions

Whatever the retrofit project that utilities need to undertake to comply with new and stricter legislation, planning and preparation is key. The parameters of the plant, like the evolution of coal properties as well as the evolution of European, national, regional and municipal legislation need to be evaluated. Those parameters are not directly linked to power generation's core business. Most utilities are looking forward to the support of dedicated engineering teams, either internal or external; to widen the scope of the project and include all required aspects.

Once the requirements are known, an evaluation of available techniques and, in particular, the interactions between FGC techniques, is a strategic decision. Although "slicing" the retrofit project into smaller projects around each key equipment will simplify the selection of the technique, it will greatly increase the complexity of the interfaces specifications

and it will prevent maximising the cross-effects between techniques which could have led to savings (investment and operating cost). Looking at the totality of the project might sound more complicated and more time-consuming during the preparation but will allow for a reduced cost and a simplified execution.

Finally, it is important to underline that correctly estimating and tackling the financing needs prior to starting the project will smooth its execution. The partner selection obviously needs to include financial aspects, but it should include more than that. The technical evaluation of the proposed solution needs to be done thoroughly and must include an evaluation of the references. Previous achievements are a significant source of information: past customers are the best placed to inform project managers about the strengths and weaknesses of potential suppliers.

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Abbreviations

A/C ratio	Air-to-Cloth Ratio [m/s]	FGT	Flue Gas Treatment
BAT	Best Available Technique	IED	Industrial Emissions Directive
BATAEL	Best Available Technique Associated Emission Level	IFNR	In-Furnace NO _x Reduction
BET	Brunauer, Emmet and Teller (surface area adsorption calculation method)	IPPC	Integrated Pollution Prevention and Control Directive
BREF	Best Available Technique Reference Document	KPI	Key Performance Indicator
CDS	Circulating Dry Scrubber	LCP	Large Combustion Plant
CFB	Circulating Fluidised Bed	LSFO	Limestone Forced Oxidation
DeSO _x	Desulphurisation	MW _{el}	Megawatt (Electricity)
DSI	Dry Sorbent Injection	PM	Particulate Matter
ELV	Emission Limit Value	PM 2.5	Particulate Matter with a diameter of 2.5µm or smaller
ESP	ElectroStatic Precipitator	ppm	parts per million
EU	European Union	SCR	Selective catalytic reduction
FF	Fabric Filter	SDA	Spray Drier Absorber
FGC	Flue Gas Cleaning	SNCR	Selective non-catalytic reduction
FGD	Flue Gas Desulphurisation	R&D	Research and Development
		VOC	Volatile Organic Compound

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