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The dry and/or conditioned dry gas cleaning with the Conditioning Rotor – Recycle Process offers proven advantages, including:

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In the course of the last years, semi-dry and conditioned dry sorption procedures with the use of Ca-based additive powder qualities as well as the dry sorption with the use of NaHCO₃ gained special importance in the field of incineration plants. Starting from the prohibition of disposal in the year 2005 until today, the vast majority of new plants for waste and RDF combustion in Germany has been provided with one of these process technologies. This trend continues with regard to the new planning of WtE-plants in Europe and other parts of the world.

As a result of continuous further developments, these procedures gave proof of their reliability, performance and not least their economic efficiency in comparison to the technologies available on the market. The following lecture deals with the presentation of some established procedures and their assessment on the basis of practical examples. It may be remarked in addition that the main focus of this lecture is on the sorption
of the acid crude gas components HCl and SO$_x$. The suitability of the corresponding procedures for the simultaneous separation of other pollutants existing in the gas, such as e.g. dioxins/furans as well as mercury and other heavy metal compounds will not be discussed in this lecture.

1. Ca-based procedures

1.1. Spray sorption

Already since many years this technology has been used for the gas cleaning downstream waste incinerators. The waste incinerators in Kassel (1986) and in Bremen (1989) serve as example of this. The basic procedure including some possible measures for optimisation is shown in Figure 1.

During the spray sorption, the separation of the acid crude gas components HF, HCl and SO$_x$ takes place by means of chemisorption with lime slurry – suspension of Ca(OH)$_2$ in water. Normally the Ca(OH)$_2$ is produced on site by means of a slaking process of CaO and water. Within the spray absorber finest droplets of lime slurry are brought into contact with the gas. The acid crude gases are reacting with the additive powder and in the downstream installed fabric filter they are isolated from the gas flow as dry salts. The injection of additive powders in the wet phase increases the separation efficiency. Further details of this process are described in [2].
The simple plant design and the use of CaO as additive powder are the advantages of this process. The cost advantage of CaO in comparison to Ca(OH)$_2$ totals to about 25 percent of purchase price.

However, these advantages are faced with serious disadvantages.

- Crude gas peaks are difficult to control
- The additive powder has to be injected with a stoichiometric factor of about 2.2 up to 2.5 related to the separated pollutants in order to achieve the emission limit values requested for waste incinerators [1].

The additional measures illustrated in picture 1 have been taken as optimisation steps at a large number of plants.

- Graded additive powder injection
In many cases, a high-reactive Ca(OH)$_2$ is additionally injected into the gas downstream spray absorber. After adjustment of injection quantity to the crude gas input values, even crude gas peaks can be controlled as far as possible [8].

- Multiple re-circulation of additive powders and reaction products separated in the filter into a reactor upstream of filter
Particularly during realisation of high particle recycle rates, the particle re-circulation demonstrably leads to a clear improvement of degree of separation of acid crude gas components and/or to a reduction in additive powder consumption rate [5].

- The residence time of additive powder particles within the system is increased.
- Near reactor upstream filter there is a higher additive particle density – resulting reaction time in reactor more than two seconds.
- Achievement of a frequent spatial new orientation of the re-circulated additive powder particles with attachment to the filter fabric.

In spite of these optimisation steps, the comparatively high additive powder consumption rate remains an important disadvantage in comparison to other sorption procedures. This fact has been examined in more detail at the gas cleaning system of WIP Ludwigshafen. The results are summarised in [1].

### 1.2. Dry sorption with particle and gas conditioning

The conditioned dry sorption was developed for consequent avoidance of the disadvantages of spray sorption technology. Figure 2 shows a possible design. In this case an evaporative cooler is used instead of a spray absorber for the adjustment of optimum reaction temperature. The separation of acid crude gas components takes place in reactor-filter combination by means of injection of Ca(OH)$_2$ and multiple particle re-circulation including conditioning of recycled particulate. Further possible design types are described in [2].
Figure 2: Conditioned dry sorption

The good separation efficiency of this process is achieved by means of:

- Creation of good reaction conditions due to a particle re-circulation up to n x 100 g/Nm³.

- Improvement particularly with regard to the SO₂ separation, due to the wetting of the re-circulated particulate.

- Further, even though minor reduction of gas temperature.

After optimised operating mode, this process allows particularly with regard to dry-bulb temperature and gas humidity the achievement of stoichiometric factors definitely < two-fold [3, 7,9]. Figure 3 shows the records of crude gas and clean gas values for HCl and SO₂ in the RDF fired power plant Stavenhagen as example for the performance efficiency of the conditioned dry sorption process.

In case of increased requirements on the separation efficiency for the acid crude gas components HCl and/or SO₂ – mainly due to high input values or in case of need also for the observance of very low emission limit values – it might be reasonable to use the evaporative cooler as upstream installed reaction chamber. Besides the additional reaction time of more than two seconds, it offers excellent reaction conditions for the separation of acid crude gas components by means of the cloud of water droplets generated for the gas cooling. [5]
CaO can also be used for the conditioned dry sorption to benefit from the cost advantage of about 25 percent with regard to the procurement of additive powder compared to Ca(OH)$_2$. In this case a dry hydrator is then used on site for the conditioned dry sorption. [3]

1.3. Comparative assessment of conditioned dry sorption with other procedures

1.3.1. Comparison of conditioned dry sorption with spray sorption

Not long ago, the existing spray sorption with graded additive powder injection of two of four incineration lines of WIP Rothensee have been converted to the conditioned dry sorption. The reasons for the modification are the following:

- Reliable observance of emission limit value for SO$_2$ and HCl even in case of arising crude gas peaks.
- Clear reduction in additive powder consumption rate for the optimisation of operating costs.

Figure 4 shows the gas cleaning system after modification. The spray absorber was kept as unit but now mainly serves as evaporative cooler for the adjustment of the optimum reaction temperature. A small quantity of additive powder is still injected as suspension for the reduction of acid dew point and a graded sorption. Depending on the crude gas input values, the main quantity of additive powder is injected into the reactor upstream filter in the form of Ca(OH)$_2$. Ca(OH)$_2$ is produced on site from CaO by means of a dry hydrator.
Figure 4: Gas cleaning system of WIP Rothensee

Figure 5: Trend curves WIP Rothensee
Figure 5 shows the separation efficiency of process by means of continuously measured crude gas and clean gas concentrations for HCl and SO₂ over a period of time of 24 hours. It is clearly visible that not least as a result of the multiple particle re-circulation and the wetting of the re-circulated particulate the limit values can reliably be kept in automatic operation even in case of HCl and SO₂ peaks.

Due to the fact that in the beginning only two of four lines have been modified, it is possible to evaluate the additive powder consumption rates for the two competitively working sorption procedures. Figure 6 displays over a period of about one month the potentials for savings regarding additive powder procurement and remainder recycling for the conditioned dry sorption in comparison to the spray sorption. The savings with an under-consumption of about thirty percent are considerable. This result confirms the ranges of stoichiometry mentioned in chapters 2.1 and 2.2. It may be remarked in addition that besides the weight-related under-consumption for the conditioned dry sorption the complete additive powder quantity will be provided in the form of CaO. The injection of an expensive, high-reactive Ca(OH)₂ is completely cancelled.

![Graph showing lime consumption and remainder quantity after modification of FGT compared to original]

**Figure 6:** Additive powder savings for conditioned dry sorption versus spray sorption

1.3.2. Comparison: conditioned dry sorption – wet flue gas cleaning

In 2004 the complex wet process consisting of spray dryer, electrostatic precipitator, multi-stage scrubber and aerosol separator has been replaced by a conditioned dry cleaning system (Figure 7).
Up to the year 2008, another wet flue gas treatment system had been operated in parallel at the WIP Ludwigshafen until its conversion, thus allowing a direct comparison of both installed variants. Figure 8 shows the average values of emissions of chosen gas ingredients for the year 2005 [5].

Figure 7: Modification of gas cleaning system at WIP Ludwigshafen from wet to conditioned dry

Figure 8: Comparison of gas cleaning system wet and conditioned dry (2005)
The comparison shows that the conditioned dry sorption process is equal to the more complex wet system. The only difference is the reference variable for the separation of the acid crude gas components, i.e. SO₂ for the scrubber and HCl for the conditioned dry sorption. It has to be noted in addition that regarding this application the nearly complete SO₂ and SO₃ separation allowed a reduction of gas temperature upstream SCR plant from previously 300 °C to 230 °C.

2. Combination SNCR-conditioned dry sorption – wet scrubber (TwinSorp)

At this point it may be remarked that in case of increased requirements on the requested emission limit values – not least also with regard to NOₓ – a combination of SNCR and conditioned dry sorption with downstream installed scrubber may offer advantages. The wet stage then serves as a fine cleaning stage for HCl and SO₂ as well as possibly for the separation of NH₃ in the acid stage of scrubber. Subject to correct design, this process is working free from waste water. [6]

The basic scheme of TwinSorp process is shown in Figure 9. The conditioned dry sorption of this process variant is operated in that way that the crude gas downstream this stage will as far as possible comply with the requirements of e.g. EU Directive 2000/76/EC. Depending on the application in question, the downstream installed fine cleaning stage serves for the

- separation of NH₃
- progressing reduction in emission values e.g. for the acid crude gas components
- heat recovery.

Further details concerning this process as well as a comparative assessment with process technologies using the SCR-process can be taken from [6].
Figure 10 shows a plant in Finland which is operated in accordance with the TwinSorp process. The clean gas values for HCl, SOx and NH3 are far below the requirements of EU Directive 2000/76/EG. At this plant the wet scrubber has been realised as condenser in order to use the condensation heat for a district heating system.

3. Dry sorption and use of NaHCO₃

3.1. General design, advantages and disadvantages

The dry sorption with NaHCO₃ competes with process technologies using Ca-containing additive powder qualities. The simple process technology of the basic variant is shown in Figure 11. The additive powder is pulverised and injected into the gas flow upstream filter. In case of crude gas temperatures larger than 140 °C, a thermal activation of sodium hydrogen carbonate will take place which becomes quicker with rising temperatures. This results in the formation of a high-reactive sodium carbonate. The reaction time from the injection point of additive powder until the arrival at the filter fabric should last at least two seconds.

Normally the required emission limit values are reliably achieved in continuous operation with the correct plant design and an above-stoichiometric factor of 1.2 up to max. 1.5. Particularly in case of lower temperatures the multiple re-circulation of the particles separated in the filter into the flue gas flow upstream filter can be advantageous.

Further details concerning this process as well as the advantages and disadvantages can be taken from [4].
3.2. Application example domestic waste incineration in France

Figure 12 shows an application example for a gas cleaning plant downstream domestic waste incinerator in France. Compared to the basic variant shown in Figure 11, this plant is additionally provided with an evaporative cooler for the adjustment of the gas temperature as well as with a particle re-circulation.
In 2009 extensive examinations have been realised at this plant in order to determine the influence of operating temperature and particle re-circulation on the additive powder consumption [4]. Whereas temperatures in a range between 150 °C and 180 °C do only have a very low, hardly recognisable influence, the operation with and without particle re-circulation shows a considerable difference.

Figure 13 clearly shows the influence of the particle re-circulation. In case of an adequately dimensioned plant and integration of a particle re-circulation system, stoichiometric factors of smaller than 1.2 can reliably be kept in continuous operation.

![Figure 13: Influence of particle re-circulation on the additive powder consumption](image)

Source: Margraf, R.: Dry sorption with sodium bicarbonate – Really a very simple process? Examinations at a waste incinerator in France; 5th symposium; Dry crude gas cleaning for solid fuel firings and thermal process technology; Haus der Technik Essen, 2009

### 3.3. Comparison of operating costs with conditioned sorption

The selection of a most suited process in competition between the dry sorption with sodium bicarbonate and the conditioned dry sorption for a given application is mainly influenced by the overall costs to be expected.

In general, two essential influence factors regarding the selection of process on the basis of NaHCO₃ or Ca(OH)₂/CaO can be named.
Assessment of Dry and Semi-Dry Sorption Procedures

- Plant size:
  Increasing plant sizes entail advantages for process technologies using Ca-containing additive powders.

- Specific costs for remainders:
  Higher specific costs for the disposal entail advantages for the utilisation of NaHCO₃.

It may be remarked in this connection that the major part of new plants realised in Germany since 2005, a Ca-based process of dry sorption with NaHCO₃ has been preferred. Most of the plants have been designed for a combustion capacity of about 100,000 t per year or larger. Furthermore, as a result of the possibility of mine filling, Germany offers the advantage of a cost-effective recycling of remainder products.

4. Summary

The present lecture deals with the comparison of different sorption procedures on a dry and conditioned/semi-dry basis. Based on operating experience at hand, the conditioned dry sorption proved to be the best solution in most of the cases. Economic advantages compared to the alternative solutions spray sorption and dry sorption with sodium bicarbonate could be proven in many applications.

To be able to use all process-related advantages of this technology, the basic variant of the conditioned dry sorption has possibly to be adjusted to the requirements of each application by means of modifications, such as graded additive powder injection or also downstream installation of a fine cleaning stage.

At this point it may be remarked that beside the discussed systems a lot of further process variants and types of construction are offered on the market. Many of them are described in [2]. For each new application and subject to the local conditions as well as the particular boundary conditions it has to be checked which process technology or also which process variant will offer the most-suited solution.

Not only the here discussed separation of acid crude gas components but also the efficiency of corresponding process regarding the separation of other gas ingredients such as NOₓ, NH₃, dioxins/furans, mercury and other heavy metals has to be evaluated in addition.

5. References


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Emissions-related energy indicators
for flue gas treatment systems in waste incineration

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The aim of this study is to demonstrate such discrepancies or dependencies between attainable emission reductions and the emissions-generating energy input necessarily incurred by flue gas treatment technologies in attaining those reductions.

The study initially focuses on current investigations and assessments related to this issue, as well as on the legal emission requirements. Due to the wide range of components involved in flue gas treatment systems and their consequent numerous combination possibilities, six different system Variants are presented and compared. It is notable in the context of the present study that both single and two-stage or multi-stage systems are considered in the set of Variants, which differ not only in their structure and additive use but also in their separation capacity. These six basic Variants reflect the systems frequently employed in practice and represent non-congruent procedural steps with their respective target emission levels. Based on the fact that each of these Variants is already in operation in thermal waste incineration plants, the assessment draws on many years of existing operative experience.

The individual energy demands for the Variants described are determined on the basis of mass, material and energy balances.

Evaluation criteria for energy demand at the different emission reduction ratios are deduced from the formulation of emissions-related energy indicators. This establishes a set of tools with which to assess emissions-generating energy demand in the context of emission reduction ratios.

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