A modern flue-gas cleaning system for waste incineration plants

Since 1990, waste incineration plants in Germany have had to comply with Europe's strictest emissions legislation – a clean-air decree known as the '17th BImSchV'. Building on the clean-air limits contained in the 1986 German decree 'TA-Luft', it also forms the core of the European Union's guideline for the thermal treatment of hazardous waste that took effect in 1993. Total Cleaning and Recycling (TCR) is a process, developed by ABB, which ensures compliance with the '17th BImSchV', in some cases guaranteeing results well below the limits given in it. Because TCR systems are of modular design, they can be easily retrofitted to older incineration plants. Results from a full-scale demonstration system in operation in Hobro, Denmark, confirm the good performance of the new ABB technology.

Public approval of municipal waste incineration plants is low mainly as a result of the pollutants emitted by facilities that were built back in the 1970s and early 1980s. This has led, understandably, to criticism of thermal disposal as such and fuelled an ongoing debate about the best way to change the public's 'use and throw-away' mentality. For some time now, society has perceived waste incineration as a mainstay of this attitude.

In Germany even new, stricter legislation, calling for a drastic two-stage reduction in flue-gas emissions from waste incineration plants and upgrading of older plants in the short term has not been able to change this perception.

Waste incineration plants equipped with modern flue-gas cleaning technology emit practically no dioxins into the atmosphere. On the contrary, they act as dioxin sinks, destroying the dioxins which are naturally present in the waste and actually lessening the impact this pollutant has on the environment.

More recently, a general rethinking of the situation has become apparent. The consensus is that the thermal treatment of the waste after sorting – and its avoidance, where possible, in the first place – should be tied into a total waste management programme. A new German decree regulating the disposal of domestic waste ('TA Siedlungsabfall') points the way. This makes it unlawful to dump materials with an organic content of more than 5 percent, meaning that in practice the waste remaining after sorting has to be disposed of by incineration.

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The shortage of suitable landfills makes incineration – within the framework of total waste management – the only practicable solution. Nevertheless, a common criticism of this solution is that a third of the waste still remains afterwards, mainly in the form of slag. This is only half the truth. While it is true that incineration reduces the waste to just a third of its mass, it reduces it at the same time to one tenth of its volume, and this is what matters most in the context of landfilling.

New legislation is more rigorous

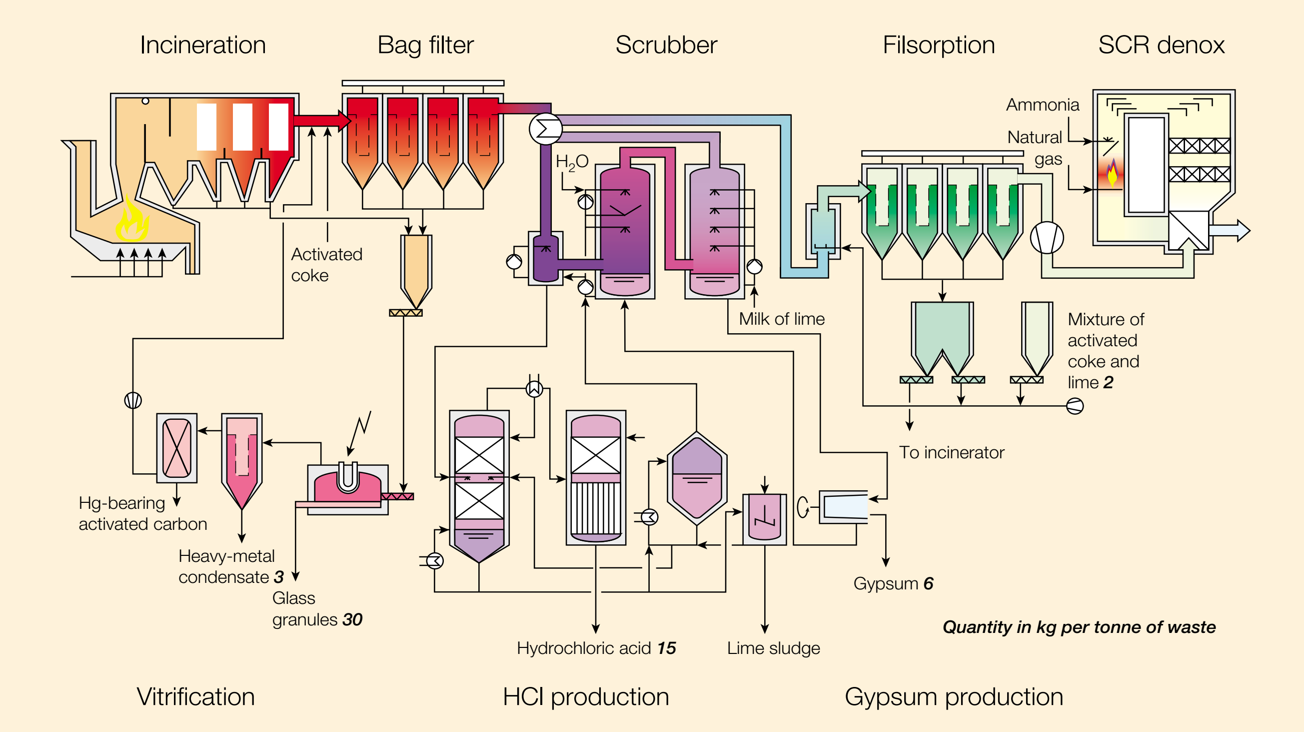
Legislation and regulations applying to waste incineration plants have become far more stringent in recent years. The German clean-air decree 'TA-Luft' was passed in 1986, and in 1990 the emission limits were reduced once more through a further decree known as the '17th BImSchV'. The European Union guideline for the thermal treatment of hazardous waste that has existed since 1993 is also largely based on the stipulations contained in the '17th BImSchV'. *Table 1* shows how the limits for emissions and pollutants have been reduced since the 1986 decree.

Besides fulfilling these requirements, plant operators are also making a strong effort to utilize the energy produced by the thermal process and to recover and recycle the residual materials. The extremely low emission levels have a political goal, namely to gain public acceptance of thermal waste disposal. Although they should not be seen as a solution to the overall emissions situation as it applies in Germany, they are inevitably providing new benchmarks for industry as a whole.

Modern flue-gas cleaning with TCR

The more stringent regulations have led the environmental control industry to step up its development programmes in a dramatic way.

ABB has developed its own advanced



TCR process, with resource recovery, for flue-gas cleaning in waste incineration plants **1**

process, which it calls Total Cleaning and Recycling, or TCR.

As the process schematic **1** of the modular TCR facility shows, the flue gas first passes from the incineration grate to the heat-recovery boiler and then to a bag filter, where the dust is removed. The high efficiency of the bag filter has a very positive effect on the performance of the scrubbing stages, and especially on the recovery of resources from the scrubbing liquids. The majority of the particulate containing heavy metals is also removed with the dust.

In the first scrubber, quenching is followed by wash-out of the hydrochloric acid (HCl) under acidic conditions. The second scrubber absorbs the sulfur dioxide. This solves the initial problem of removing the principal acidic constituents of the flue gas. In addition, the first scrubber dissolves and separates the gaseous heavy metals (eg, mercury) and the residual heavy metal particles.

The scrubbing stages are followed by a second bag filter in which a process known as *filsorption* – a name taken from filtration and adsorption – takes place. The filsorption filter uses a mixture of activated coke and lime hydrate, and is largely responsible for the exceptionally good clean-gas data. It is especially good at adsorbing dioxins and furans as well as any residual mercury left after scrubbing, while it also removes any harmful acids, dust and heavy metals still present. As a result, clean-gas values even lower than the detection limits are achieved.

Table 1:
Allowed pollutant emissions for waste incineration plants (in mg/Nm³, dry, 11 % O_2) – average daily values and mean value during sampling

Pollutants	TA Luft '86	17th BImSchV	EU Guideline
Dust	30	10	10
Carbon monoxide	100	50	50
Organic materials (C tot)	20	10	10
Sulfur oxides as SO_2	100	50	50
Gaseous anorg. comp. of chloride as HCl	50	10	10
Gaseous anorg. comp. of fluorine as HF	< 5	1	1
Nitrogen oxides as NO_2	500	200	–
Cd, Tl	φ 0.2	0.05	0.05
Hg		0.05	0.05
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	–	0.5	0.5
Dibenzodioxins/-furans in ng/Nm³, dry, 11 % O_2	–	0.1	0.1
(Toxic equivalent (TE) in accordance with NATO-CCMS)			

Filsorption is offered by ABB as its preferred alternative to coke bed filters. With reactors containing several hundred cubic meters of activated coke, the latter represent a genuine fire hazard. Both processes employ the highly efficient technology known generically as adsorption.

A direct comparison shows the filsorption process to be better not only in terms of safety but also with regard to dust, heavy metal and carbon monoxide emissions. With regard to all the other components, the two processes perform at similar levels.

The *denox stage*, which employs selective catalytic reduction (SCR), is usually positioned by ABB at the end of the flue-gas cleaning process. The filsorption filter upstream provides optimum protection for the catalyst. Since the denox process can take place at a temperature of 200 °C or lower, long residence times are possible.

Reasons can also be given, however, for installing the catalyst immediately after the scrubbers. In this case, a combined catalyst is used. It first reduces the nitrogen oxides (NO_x) and then oxidizes the organic substances, in particular the dioxins and furans. The operating temperature with this configuration is about 300 °C. Its advantage is that the dust collected in the filter is practically free of dioxins.

The residues produced by flue-gas cleaning are treated in different process stages:

- The fly ash from the incinerator and the dust collected in the first bag filter are passed through the *DEGLOR* process [1], in which an electrically heated furnace melts them into a harmless glassy slag suitable for use in, eg, sand-blasting or road construction, plus a ‘heavy metal concentrate’ which can be processed in specialized metallurgical plants.
- The draw-off from the scrubbing process can be treated in different stages (distillation, evaporation, crystallization, filtration, etc) to recover valuable resources. Some possible products are hydrochloric acid, sodium chloride for chlorine-alkali electrolysis, and gypsum (eg, for use in manufacturing wall-board).
- The sorbent material used in the filsorption process is led directly back to the furnace in order to destroy the dioxins and furans contained in it. Alternatively, the material can be vitrified together with the dust collected in the first filter.

The TCR concept is so new that all the modules making up the facility could not yet be installed and used together in the same incineration plant. However, each individual module has been tested in the field on a large scale. The flue-gas cleaning system, for example, is operating in several plants, and reliable emission data with this system is now readily available.

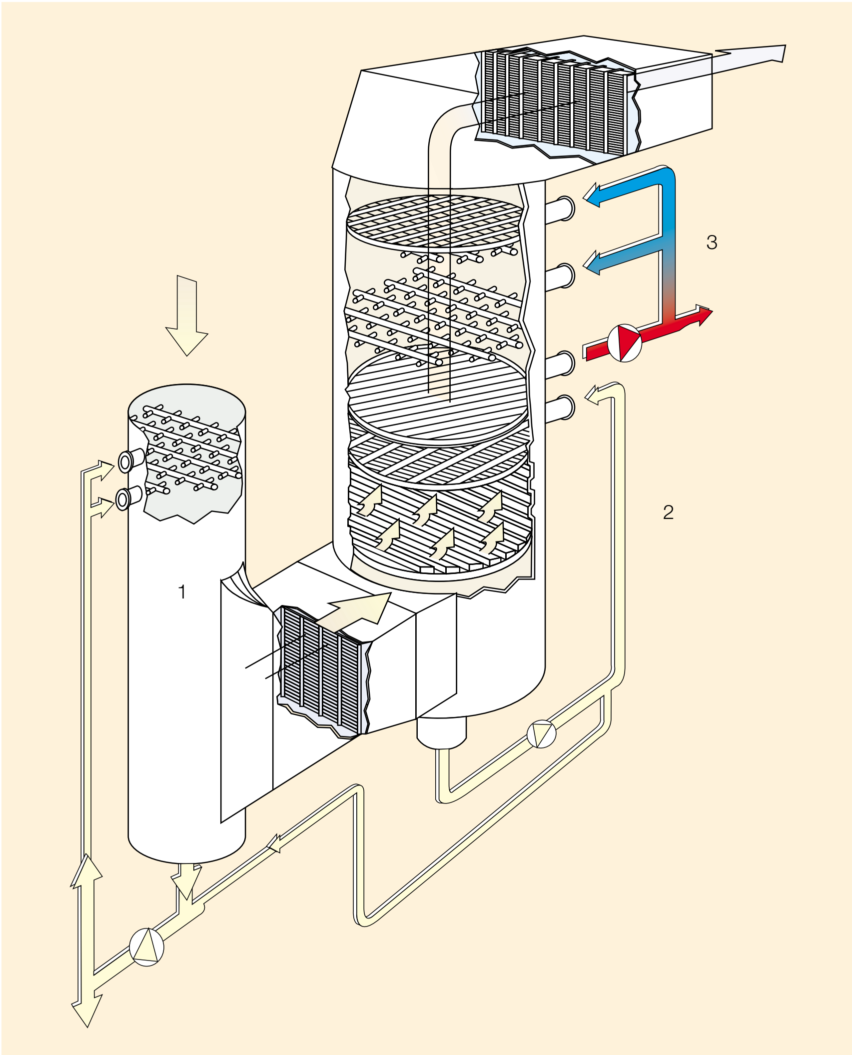
Further development of the dual-alkali process

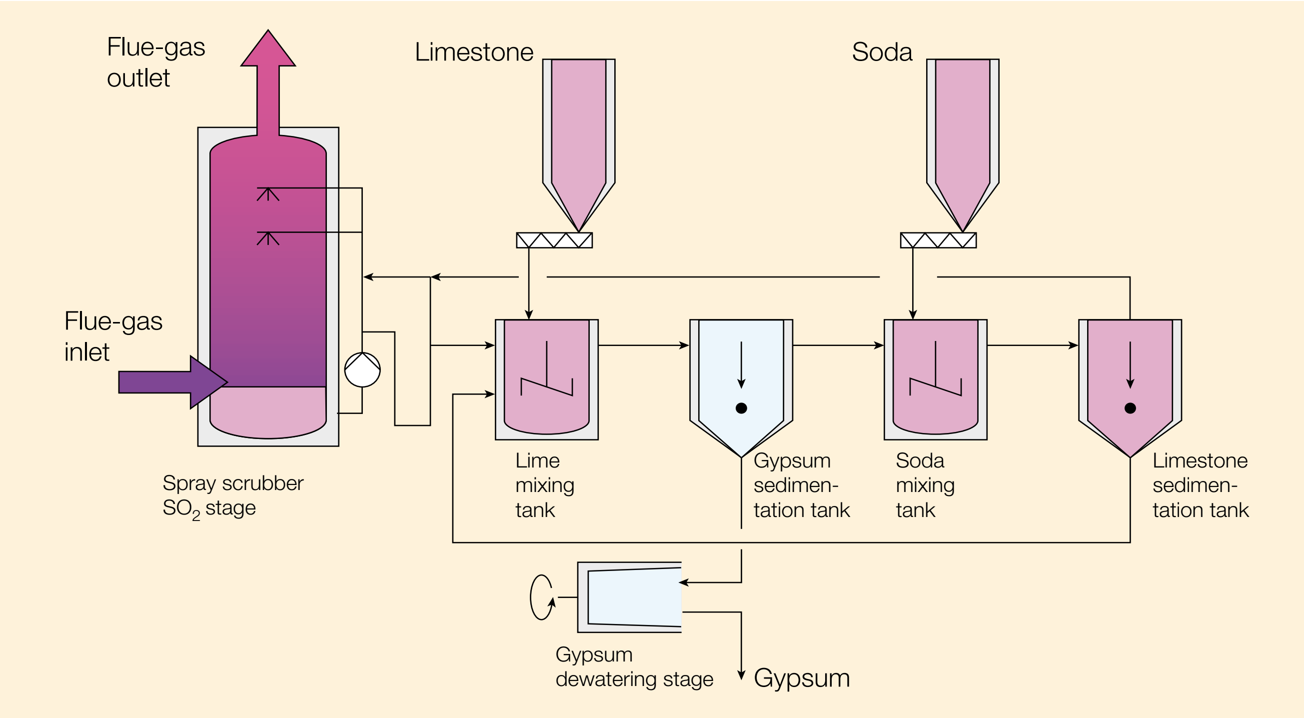
ABB has developed a particularly interesting variation of the TCR process for washing out the harmful acidic gases. It combines the ABB spray scrubber **2** with the dual-alkali process developed by ABB especially for waste incineration plants.

The state of the art is to separate the acidic gases hydrogen chloride (HCl) and sulfur dioxide (SO_2) in consecutive scrubbing stages. Prior to the absorption (ie, during quenching) the flue gas is cooled to its wet-bulb temperature by co-current spraying of a liquid into the flue-gas flow. In the

ABB spray scrubber used in combination with the dual-alkali process for washing out harmful acidic gases **2**

1 *Quenching stage* 2 *HCl stage* 3 *SO_2 stage*





Flow chart of the dual-alkali system developed by ABB. Gypsum is precipitated by this patented process. **3**

first scrubber the HCl in the flue gas is absorbed by an acidic solution comprising HCl and water. At the top of the HCl stage very fine droplets of the scrubbing agent are sprayed into the gas flow in the counter-current direction. The diluted hydrochloric acid that is produced collects at the bottom of the tank and is pumped back to the nozzle level in the circuit. The scrubbing liquid is drawn off and replaced by fresh water according to the acid concentration. The drawn-off liquid can be processed to obtain concentrated hydrochloric acid, etc.

In the second scrubbing stage the sulfur dioxide is absorbed by mixing caustic soda or lime hydrate (calcium hydroxide) with the scrubbing agent to keep it neutral. Use of crushed limestone ($CaCO_3$) as a neutralizing agent is also possible. Continuous measurement of the pH value is necessary in this stage.

The type of neutralizing agent chosen will generally depend on the overall costs. Calcium hydroxide and limestone being much cheaper than caustic soda, incineration plant operators often prefer a scrubber that uses limestone rather than a caustic soda solution. Another reason for this preference is that many operators prefer gypsum ($CaSO_4 \cdot 2\ H_2O$) to sodium sulfate as an end-product, since the former has more commercial uses.

Although the above considerations weigh heavily, scrubbers using a caustic soda solution have several clear technological advantages over those which use limestone, particularly in the areas of operation and reliability. These benefits can be summarized as follows:

- All feed material and reaction products are in the form of aqueous solutions; no solids are involved.
- No protection against erosion has to be provided.
- Since there are no sediments, the liquid does not have to be circulated to prevent sedimentation.
- Only minimal maintenance of the demister is required.
- The alkaline stage can be installed simply on top of the acid stage, saving floor space as well as costs.

Important benefits in respect of the SO_2 separation are:

- Since a clear solution is used, the resistance to mass transfer during the absorption process and oxidation to sulfate is very low.
- The ratio of the liquid to flue gas in the scrubber is small.
- There is only a small pressure drop; the residence time is short.

To be able to take advantage of the benefits of a scrubber that uses a caustic soda solution and produce gypsum at the same time, ABB has further developed the so-called dilute mode dual-alkali process, modifying it for flue-gas cleaning in waste incineration plants. In this process **3**, which has been patented, the solution drawn off from the neutral SO_2 stage of the scrubber has lime hydrate ($Ca(OH)_2$) added to it. Through this simple ion interchange, gypsum is precipitated and the caustic soda solution is regenerated:

$$Na_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4 + 2NaOH$$

Although it is usual for the lime hydrate to be added in the dry state, lime milk or even slaked quicklime can also be used.

In a second stage, a very small quantity of soda (Na_2CO_3) is added to the solution regenerated with lime hydrate in order to replace the Na+ ions lost during the process. The use of soda, which is relatively cheap, also has the effect of softening the regenerated solution according to

$$Na_2CO_3 + Ca^{2+} \longrightarrow CaCO_3 + 2Na^+$$

before it passes back to the scrubber, thus reducing the risk of sedimentation in the scrubber cycle.

The calcium carbonate which is produced is precipitated, separated from the clear regenerated solution and re-used in the effluent treatment plant.

The regeneration process for recovering the caustic soda solution takes place in a separate plant and therefore has no influence on the availability of the scrubber and the chemical reactions. Oxidation of the remaining sulfite to sulfate takes place in a separate oxidation tank located in the outlet of the scrubber's SO_2 stage. Complete oxidation is easily achieved since both the sulfite and the sulfate are present in the dissolved state.

$$2Na_2SO_3 + O_2 \longrightarrow 2Na_2SO_4$$

Control of this process is also easy. The dose rate for the regenerated NaOH solution passed back to the scrubber is controlled via the pH value in the scrubber circuit, while the amount to be drawn off is regulated according to the level of the liquid in the system. Control of the lime feed rate is also relatively simple, regulation taking place in direct proportion to the amount of SO_2 separated. This is possible due to the stoichiometric ratio being close to unity.

In terms of operating reliability, the combination of NaOH scrubber and dual-alkali system offers good flexibility due to separate stages being used for scrubbing, oxidation and NaOH recovery (with precipitation of the sulfate). One of the main goals of the development work was to ensure that the process has only a minimal effect on the availability and operation of the scrubber. This is often the key to reliable operation of the incineration plant. The separate process stages also provide numerous possibilities for optimizing plant operation, for example through the installation of intermediate storage tanks or the use of parallel or common systems for more than one incineration line. The scrubber may also be operated with just fresh caustic soda solution if required.

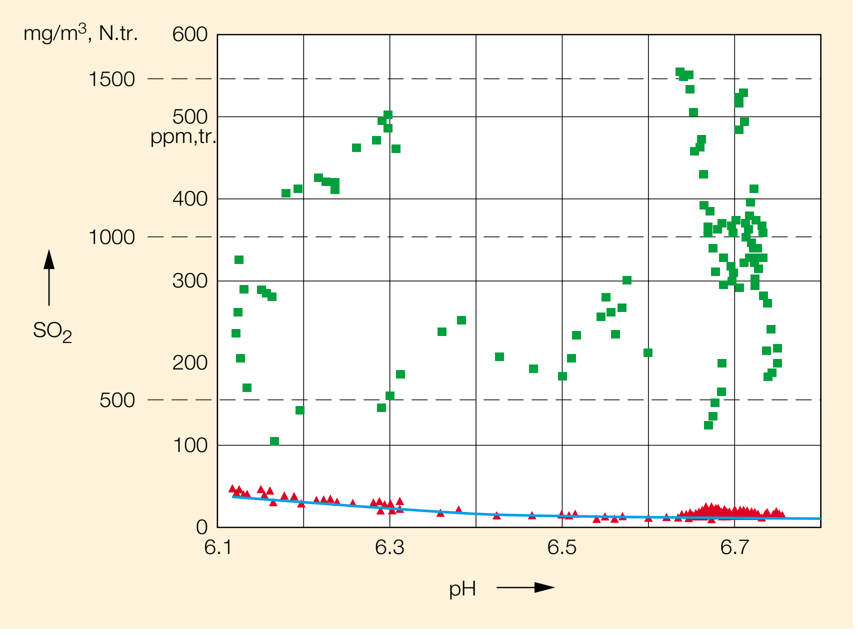
An installation of the type described has been built in the Hobro waste incineration plant in Denmark, allowing full-scale field experience to be gained for the first time with this technology.

Initially, the quality of the gypsum produced in the Hobro plant was evaluated under the assumption that it would probably be disposed of in landfills. This assumption was made on the basis of the quantity produced in a waste incineration plant usually being much smaller than the amount produced, for example, in a coal-fired power plant. In addition, the theoretical risk of the gypsum quality varying was far greater, due mainly to the operating conditions in a waste incineration plant fluctuating more strongly than in a power station, where the quality of the coal remains relatively constant. The recovery of products from waste incineration is also a political issue, since they are automatically considered to be 'dirtier' than the same material originating from other sources. The goal was to achieve a gypsum quality that would allow disposal in Class I landfills as per the German 'TA Siedlungsabfall' decree. This reduces the cost of landfilling substantially, compared with the alternative of gypsum disposal in Class II landfills, as is usually necessary when the calcium salts come from a treatment plant in which the wastewater is still contaminated with heavy metals.

The results from the Hobro demonstration plant were promising from the beginning, and gypsum suitable for Class I landfilling could be produced immediately and without problems. The requirements for

Separation of sulfur dioxide with the ABB spray scrubber **4**
(N.tr. = standard condition, dry gas)

Green *SO_2, inlet* Red *SO_2, outlet* Blue *SO_2, theoretical equilibrium*



Filsorption stage with scrubber using a sodium hydroxide solution, as retrofitted recently in the waste incineration plant at Zirndorf in Germany **5**

construction-quality gypsum could also be fulfilled from the start. At about the same time, several countries began to require waste incineration plants to produce recyclable end-products only. In view of this, special emphasis was placed on demonstrating the Hobro plant's capability for producing construction-quality gypsum (eg, for wall-board).

Tables 2 and *3* compare the achieved gypsum quality with the requirements for Class I and II landfilling as well as for wall-board manufacture. It can be seen that all the requirements are easily satisfied.

Operating experience in the Hobro waste incineration plant

Scrubber

The scrubber, which uses a caustic soda solution, is a proven ABB design with more than 65 modules; 15 of these are part of the waste incineration flue-gas cleaning process. Since the scrubber was optimized for this application from the start, emission values are very low **4** . Features that make a decisive contribution to the good results include the design of the nozzle lances and the intermediate bottoms.

Additional optimization of the scrubber was not necessary. The principal lesson Hobro has taught is therefore that scrubber operation is not affected at all by the operation of the dual-alkali system. From this it can be concluded that all sodium-based ABB scrubbers can be retrofitted with a dual-alkali system. As a rule, other, non-ABB scrubbers using a caustic soda solution can also be brought up to the standard required for retrofitting with an ABB dual-alkali system.

The demister flushing system in the Hobro plant was shut down completely for several weeks, during which time no trace of sedimentation could be detected. Likewise, there were no signs of incrustation in the scrubber. This shows how effective the soda is at softening the regenerated caustic soda solution.

Dual-alkali system

The experience gained in the Hobro incineration plant mainly concerns the dual-alkali system, in which the entire liquid flow from the scrubber is treated. The tests have shown that the scrubber and regeneration system can handle all the operating conditions that could arise in practice. Full-scale operation was especially important for the way it helped with the design and fine-tuning of the control system.

Operation on this scale is also necessary to obtain reliable mass balances for the combined scrubber and regeneration system. Tests were carried out both with dry slaked lime and lime milk.

Full-scale trials are also important as they provide experience with operation of the individual components. The only component that has had to be replaced during the programme is the gypsum dewatering system. Because the gypsum crystals obtained with the new system are considerably larger than those obtained with similar systems and with the pilot installation in the ABB research center in Växjö, Sweden, the drum filter had to be replaced by a band filter. The advantage of the larger crystals in terms of dewatering, washing properties and gypsum purity were recognized at an early stage and subsequently put to good use, as the gypsum quality data given in *Tables 2* and *3* show.

The trend to zero emissions

Operators of waste incineration plants equipped with advanced flue-gas cleaning technology target zero emissions as their operational goal. A prerequisite for this, besides high-performance wet scrubbing and catalytic reduction of the nitrogen oxides, is a filter with a 'safeguard' function. The described filsorption process performs this task in an ideal way.

Considerable experience with the new technology is available in Germany, especially with the systems installed in waste incineration plants in Ingolstadt, Zirndorf and Bonn. Other installations are currently under construction or at the planning stage. All existing German waste incineration plants have to comply with the 17th BImSchV decree by 1996.

The plant in Zirndorf **5** is unique in a number of ways. For example, it is the first one in Germany to feed the spent sorbent from the filsorption stage back to the incinerator. This procedure was approved by the authorities because the dioxins are destroyed in the furnace and the mercury is discharged from the acidic scrubber. As a result, an additional residual material has been avoided.

The Zirndorf incineration plant [2] was shut down for a short time in 1990 because the dioxin values measured at the plant were too high. Installation of an NaOH scrubber and filsorption stage took about four months, and the plant went back on stream in 1991.

September 1992 also saw a retrofitted filsorption stage begin operating in the waste incineration plant in Uppsala, Sweden. This plant is about seven times larger than the one in Zirndorf. *Table 4* compares the gas emissions of the two plants with the limits specified by the 17th BImSchV decree.

It can be seen that several of the values for clean gas (an exception is the NO_x, due

Table 2:
Eluate analysis for gypsum: requirements and results at Hobro waste incineration plant, Denmark

		Hobro results	Requirements, Class I landfill	Requirements, Class II landfill
pH		10.3	5.5 – 13	5.5 – 13
Conductivity	µS/cm	2,000	< 10,000	< 50,000
Pb	mg/l	< 0.1	< 0.2	< 1
Cd	mg/l	< 0.05	< 0.05	< 0.1
Hg	µg/l	< 0.5	< 5	< 20
Zn	mg/l	< 0.1	< 2	< 5
F	mg/l	4.8	< 5	< 25

Table 3:
Gypsum composition: requirements and results at Hobro waste incineration plant

		Hobro results	Requirements for wall-board
Gypsum content	%	96.8	> 95
pH		7.6	5 – 8
Magnesium oxide	%	0.005	< 0.1
Potassium oxide	%	0.0002	< 0.06
Chloride	ppm	70	< 100
Calcium sulfite	%	0.1	< 0.5
Aluminium oxide	%	0.023	< 0.3
Iron (III) oxide	%	0.031	< 0.15
Silicon dioxide	%	0.11	< 2.5
Ca and Mg carbonate	%	0.91	< 1.5

Table 4:
Clean-gas emissions at Zirndorf and Uppsala waste incineration plants

Pollutants		Zirndorf flue-gas rate: 30,000 Nm³/h mg/m³	Uppsala flue-gas rate: 200,000 Nm³/h mg/m³	Relevant limit in 17th BImSchV mg/m³
Total carbon	C	< 2	nm*	10
Hydrogen chloride	HCl	< 1	< 1	10
Sulfur dioxide	SO_2	< 2	10	50
Hydrogen fluoride	HF	< 0,1	< 0.1	1
Nitrogen oxides	NO_x	425*	nm*	200
Mercury	Hg	< 0.006	< 0.001	0.05
Cadmium and thallium	Cd + Tl	< 0.002	nm*	0.05
Residual heavy metals		0.011	< 0.02	0.5
Total dust		< 0.6	< 1	10
		ng/m³ TE	ng/m³ TE	ng/m³ TE
Dioxins/furans	PCDD/PCDF	< 0.006	< 0.02	0.1

* The retrofit made no provisions for reduction of this pollutant (nm = not measured)

München Süd, Germany's first district heating plant based on waste incineration to be equipped with the SCR denox system **6**

to the Zirndorf installation only starting up in February 1995) lie considerably below the given limits, also that the scale-up did not lead to any notable increase in the figures.

In the meantime, results from several years of large-scale selective catalytic reduction of NO_x in the waste incineration sector have also become available. The first plant in Germany to be equipped with this technology is the München Süd waste incineration facility **6**, in which the flue-gas exits at a rate of 2 × 240,000 Nm^3/h. In this plant the NO_x reduction takes place downstream of a dry flue-gas cleaning process with bag filter. Since being installed in 1990 the SCR system has operated trouble-free and still works with its original catalysts. A guarantee value of 70 mg/m^3 was given for the NO_x emissions in the clean gas. (This compares with a maximum value of 600 mg/m^3 in the raw gas.) In practice, NO_x values of 50 to 60 mg/m^3 are achieved for the clean gas.

Waste incineration plants as dioxin sinks

Waste incineration plants have become a permanent fixture of modern refuse disposal programmes and are unlikely to be replaced by alternative technologies.

Since the 17th BImSchV decree, all the concerns about waste incineration plants can be safely said to be no longer based on fact. Modern waste incineration plants emit practically no dioxins; in fact, they act as dioxin sinks, since they destroy those dioxins naturally present in waste. Also, by making the organic part of landfilled waste inert they prevent chemical reactions from occurring that could otherwise last decades, possibly with pollutants escaping uncontrollably into the environment.

State-of-the-art flue-gas cleaning technology for waste incineration plants is today the new benchmark by which all other industrial sectors have to measure their clean air performance.

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