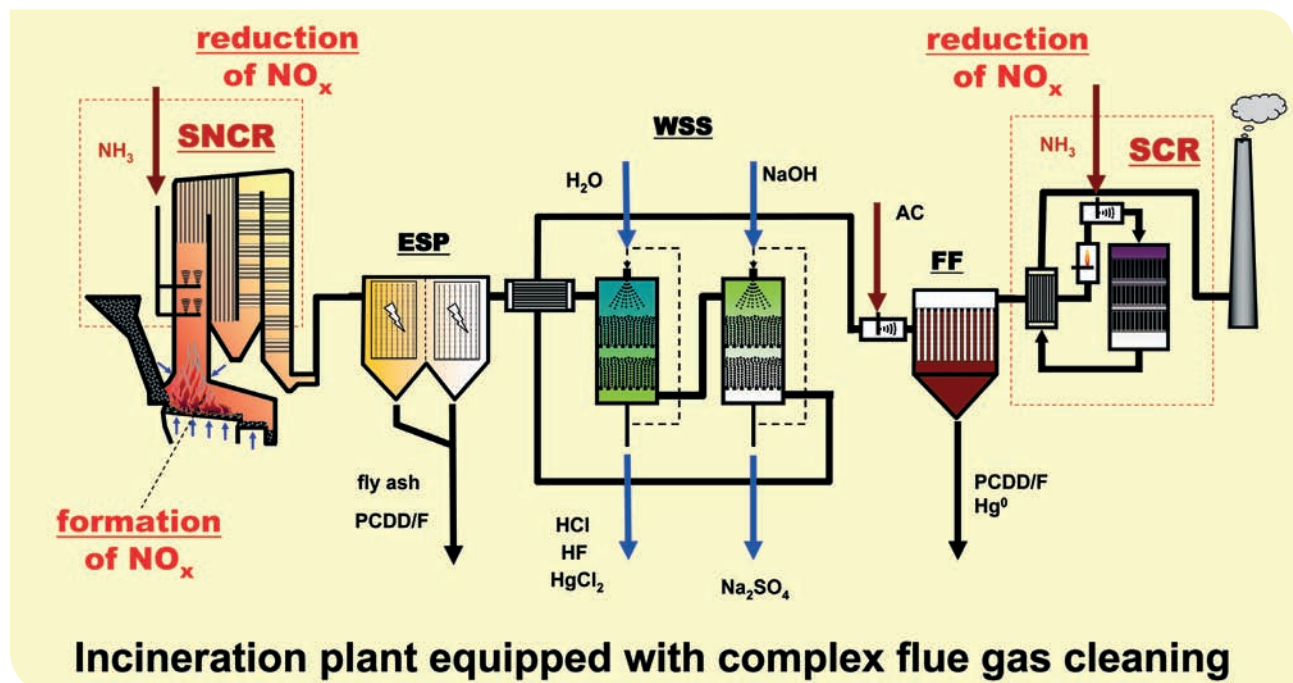


## Primary-side $\text{NO}_x$ Reduction and Bottom Ash Quality Improvement in Grate Furnaces



Nitrogen oxides ( $\text{NO}_x$ ) are produced in many combustion processes. They contribute to the so-called "acid rain" and induce ozone formation in the summer (summer smog).  $\text{NO}_x$  emissions are subject to strict legal limits. For existing waste incineration plants the  $\text{NO}_x$  emissions are restricted to  $<200 \text{ mg/std. m}^3$  (daily average, calculated as  $\text{NO}_2$ ) by the 17<sup>th</sup> German Environmental Impact Protection Ordinance (17<sup>th</sup> BImSchV.). From 1.1.2013 new plants with a thermal power  $>50 \text{ MW}$  have to fulfil a tightened  $\text{NO}_x$  limit of  $<100 \text{ mg/std. m}^3$  (annual average). For these limits to be complied with in incineration plants, efficient flue gas cleaning by special  $\text{NO}_x$  removal procedures, such as SCR or SNCR, has been necessary so far in order to reduce the nitrogen oxides produced in the raw gas.

Both  $\text{NO}_x$  removal processes require the addition of a reducing agent, such as ammonia or urea. These flue gas cleaning techniques entail considerable investments and high operating costs. One efficient way of reducing the production of pollutants by modification of the combustion process offers major cost advantages because it can do without expensive secondary processes for flue gas cleaning.

Municipal solid waste and biomass are mostly incinerated in grate furnace systems. Because of the relatively low temperatures in these combustion processes, thermal  $\text{NO}_x$  generation from airborne nitrogen plays only a negligible role. Nitrogen oxides are mainly produced from the nitrogen contained in the fuel. The characteristics of fixed-bed burnout and burnout of the primary flue gases have a considerable impact on the formation of  $\text{NO}_x$ .

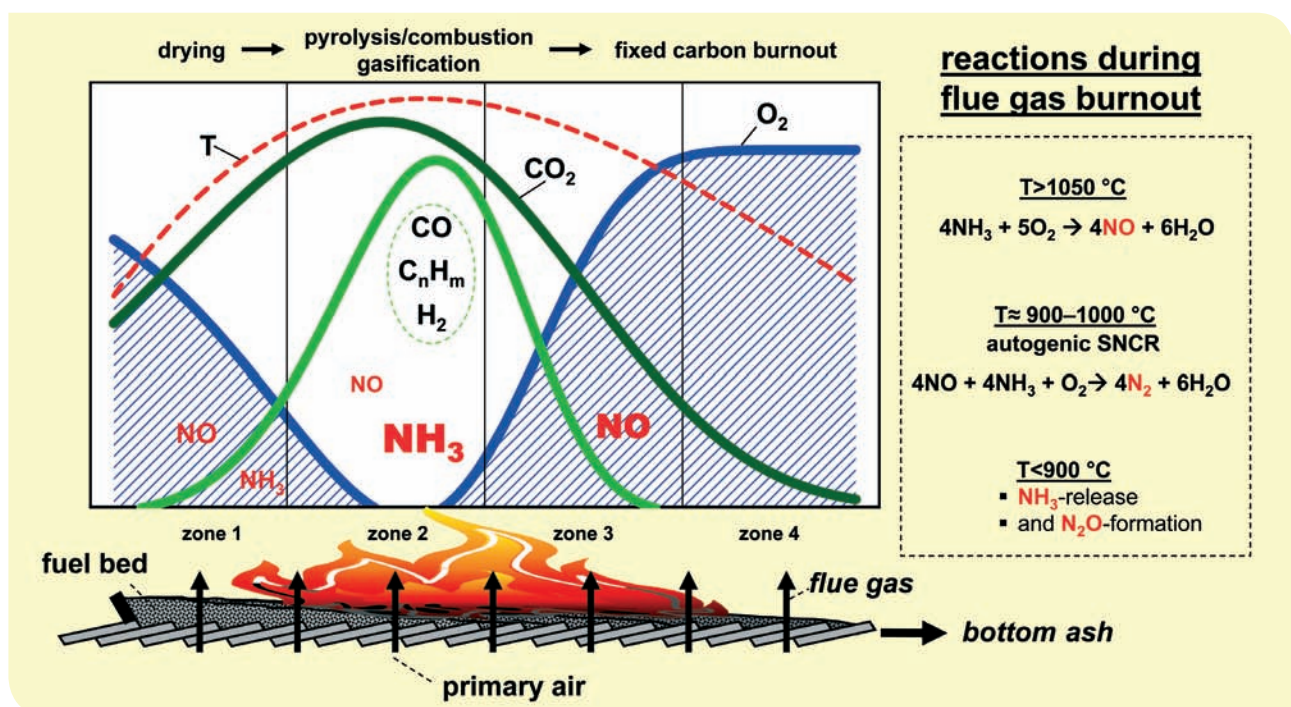
In grate furnaces, the solid fuel is transported on a furnace grate subdivided into several zones, and is burnt out under a controlled individual supply of primary air. The burnt-out bottom ash arising at the end of the grate can be used as a low-cost aggregate for building material, e.g., in road construction. However, some of the preconditions to be met for this purpose are a low residual carbon content (LAGA limit: TOC < 1 %) and a low pollutant load.

In an idealized scheme, combustion of solid fuels may be subdivided into these successive subprocesses: drying, pyrolysis, and burnout of the fixed carbon. Because of mostly insufficient mixing of the fuel bed transported on incineration grates, these subprocesses may be superimposed on each other. The front area of the grate is mainly used for drying. The oxygen supplied to this area by the primary air is not consumed. In the following pyrolysis stage, large volumes of volatile hydrocarbons are released from the fuel bed. This is the area of the grate with the highest level of carbon conversion. As a function of local temperatures and O<sub>2</sub> concentration in the fuel bed, the hydrocarbons released are burnt either completely or partly. When the oxygen supplied to the main combustion zone has been consumed completely, considerable volumes of hydrocarbons remain in the flue gas and are converted partly into CO, H<sub>2</sub>, and soot in gasification reactions. These flue gases have a high calorific value. In the rear

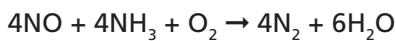
part of the grate, the fixed carbon remaining after degasification is burnt in a locally hyperstoichiometric supply of primary air. This lowers the temperature of the fuel bed, which causes the kinetics of residual carbon conversion to be relatively slow. Rising temperatures in the ash bed at the end of the grate accelerate carbon burnout, provided there is a sufficient supply of oxygen, thus ensuring low residual carbon contents (TOC) in the bottom ash removed.

Parallel to the pyrolysis process, the nitrogen contained in the fuel is converted mainly into NH<sub>3</sub> (ammonia) and, to a lesser extent, HCN (hydrocyanic acid) and nitrogen-bearing hydrocarbons. These primary N-species are partly oxidized to NO as a function of local O<sub>2</sub> concentrations and temperatures in the fuel bed.

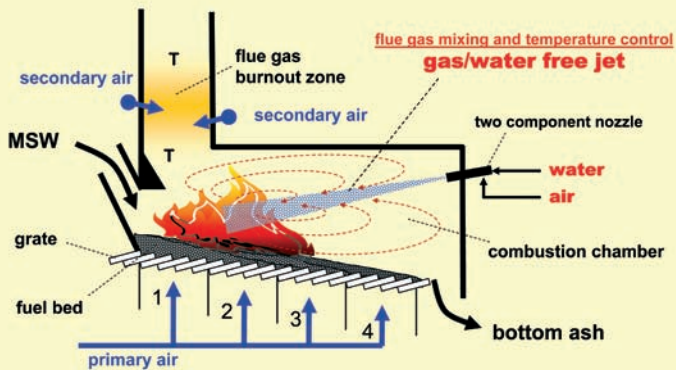
If there is a lack of oxygen (in the main combustion zone), considerable amounts of NH<sub>3</sub> remain in the highly calorific flue gas emanating from the fuel bed. The nitrogen content of the residual carbon produced is relatively low. Burnout with an excess of O<sub>2</sub> mainly produces NO (nitrogen monoxide). The volume and distribution of primary air, and the kinematics of the grate, have a significant influence on the development of burnout of the fuel bed, thus also influencing temperatures, O<sub>2</sub> concentrations, calorific values, and the NH<sub>3</sub>/NO ratio in the flue gas streams released from the individual fuel bed zones.



The high-calorific flue gases, containing NO and NH<sub>3</sub>, emanating from the main combustion zone must be burnt out as completely as possible in a second combustion step by adding and mixing secondary air. In the area of this flue gas burnout zone, complex reactions ultimately give rise to NO, N<sub>2</sub>O, and/or N<sub>2</sub>. The calorific value and the NH<sub>3</sub>/NO ratio of the flue gases before entering the flue gas burnout zone, and the temperatures and oxygen concentrations during flue gas burnout, exert a decisive influence on the resultant distribution of N-species in the flue gas downstream of the flue gas burnout zone. Under ideal conditions, NH<sub>3</sub> and NO react to produce N<sub>2</sub> during flue gas burnout as a result of an autogenous SNCR process.



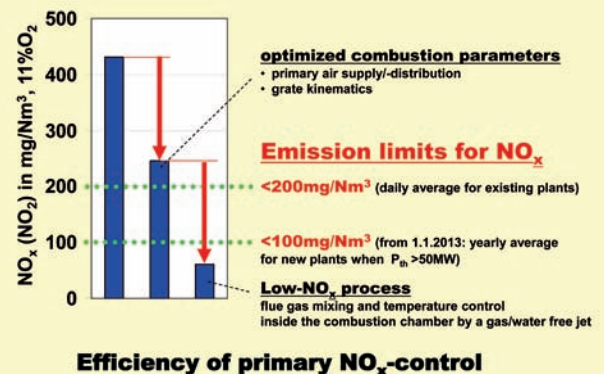
In the TAMARA experimental facility (Qth ≈ 0.5 MW) of the Institute for Technical Chemistry, the combustion process was modified by simple measures so that the main final product is N<sub>2</sub>, and the formation of NO<sub>x</sub> and N<sub>2</sub>O, respectively, is minimized or avoided. Only optimized setting of the primary air volume and distribution and of the grate kinematics reduced the formation of nitrogen oxides (calculated as NO<sub>2</sub>) from 430 to approx. 245 mg/std. m<sup>3</sup>.



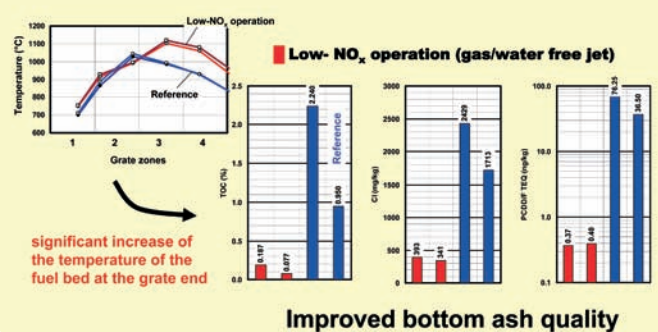
Thorough axial mixing of all flue gas streams emanating from the fuel bed zones prior to entry into the flue gas burnout zone, and simultaneous control of the temperature distribution in the combustion chamber and in the flue gas burnout zone by means of a controlled gas/water free jet, allowed the NO concentration to be reduced further to approx. 60 mg/std.m<sup>3</sup> (calculated as NO<sub>2</sub>), and thus far below the NO<sub>x</sub> emission limits for waste incineration plants. Flue gas cleaning for nitrogen oxides and the associated addition of reducing agents are no longer

necessary. The gas/water free jet can be realized, for instance, by a two-fluid nozzle. The controlled addition of water is a function of the concentrations of NO<sub>x</sub> and N<sub>2</sub>O measured in the raw gas (or alternatively the combustion temperature) by means of a corresponding process control system. No negative impacts on the quality of flue gas burnout, the formation of CO, N<sub>2</sub>O or dioxins were found.

A positive side effect of the simple method of NO<sub>x</sub> reduction is the simultaneous considerable improvement of the bottom ash quality. Axial mixing of the flue gases above the fuel bed zones clearly raises the temperature at the end of the incineration grate. As a consequence, especially the concentrations of residual carbon, chlorides, and dioxins in the bottom ash are greatly reduced, which improves the chances of recycling.



Assessment of the economic viability of the new primary-side NO<sub>x</sub> reduction technique for a waste incineration plant (100,000 t/a capacity) indicates a benefit of 3–5 % in overall investment, and approx. 2–3 Euro/t for the running operating costs. The clearly improved bottom ash burnout achieved at the same time allows plant-specific fuel throughput to be increased and thus the operating costs to be reduced further on the order of several Euro/t.



## Advantages of the new low-NO<sub>x</sub> process

- Simple, effective, economical.
- Low NO<sub>x</sub> concentration in the raw gas downstream of the boiler (< 100 mg/std. m<sup>3</sup>).
- No flue gas cleaning for NO<sub>x</sub> necessary.
- No addition of reducing agents (e.g. NH<sub>3</sub>) required.
- No negative impact on the formation of other pollutants (e.g. PCDD/F, CO ...)
- No formation of N<sub>2</sub>O and no NH<sub>3</sub> slippage.
- Clear improvement in bottom ash quality (TOC, Cl, PCDD/F).
- Potential increase in plant-specific fuel throughput.

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