

Supporting Information Cover Sheet

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Title:

Simultaneous removal of mercury, PCDD/F, and fine particles from flue gas

Description:

There are 9 pages in the supporting information section which describe details on the pilot waste incinerator that delivered the raw gas for the MFS pilot plant, the MercOx, ADIOX[®] and CAROLA processes, and an economic evaluation of the MFS.

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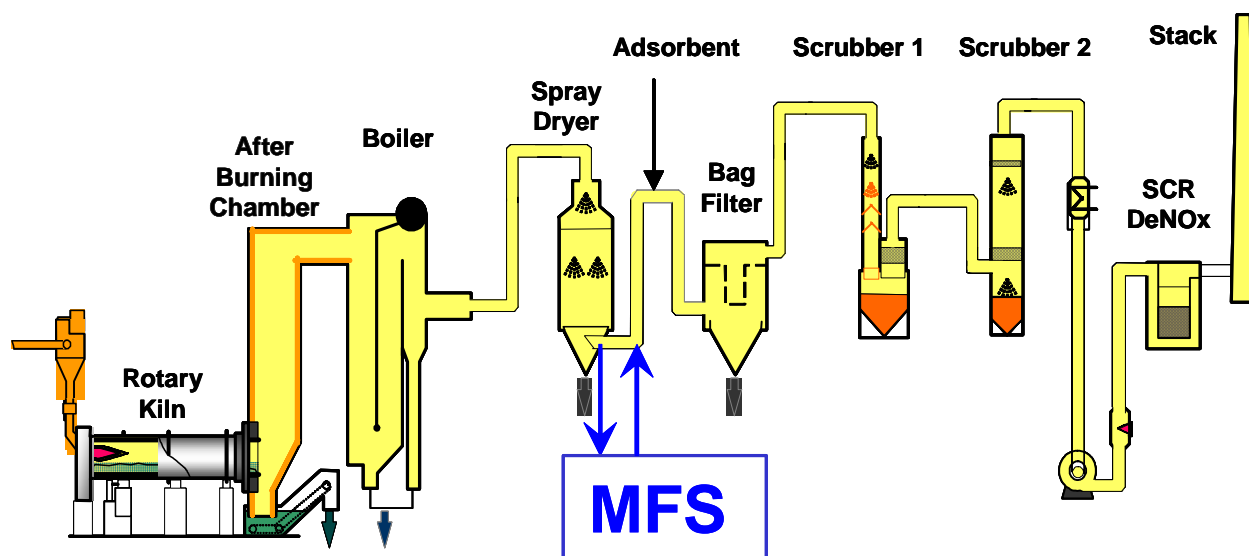


FIGURE S1. Flow chart of the incineration pilot plant for special wastes at Forschungszentrum Karlsruhe consisting of rotary kiln furnace, after burning chamber, boiler and flue gas cleaning. A slipstream of 250 m³/h was extracted downstream of the spray dryer at a temperature of 180 °C.

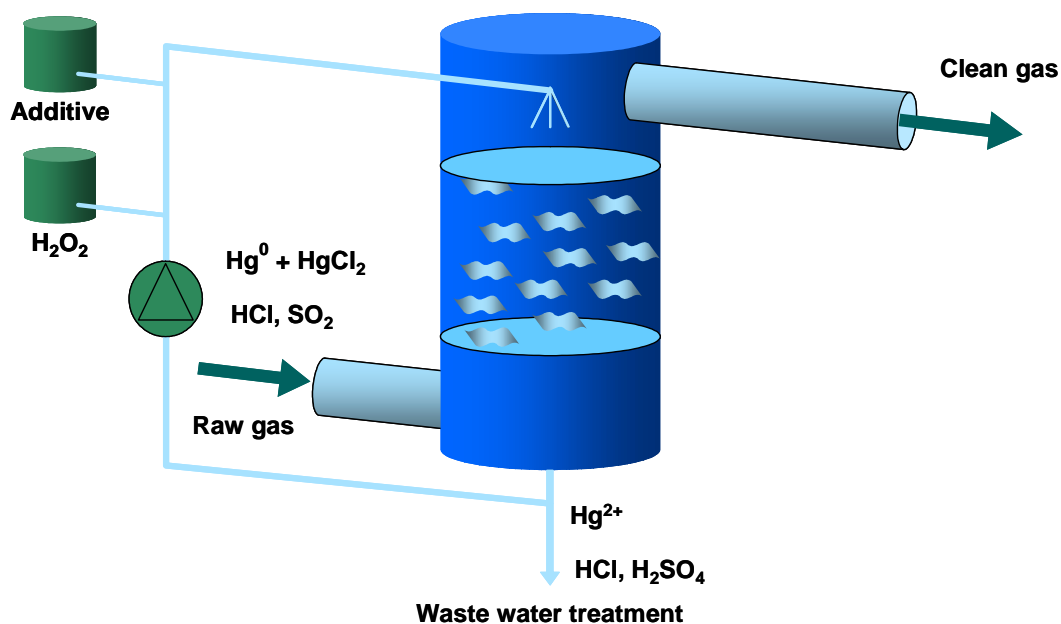
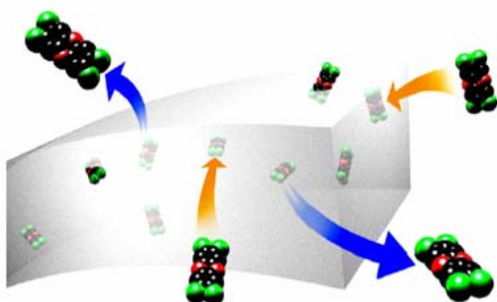


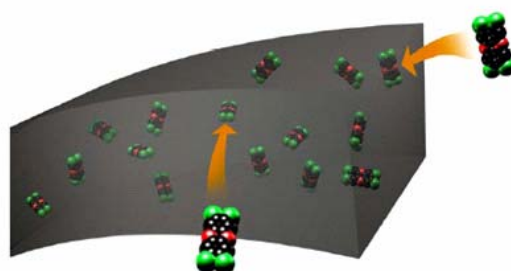
FIGURE S2. MercOx wet scrubbing process for removal of Hg, SO₂ and HCl. H₂O₂ is used to oxidize elemental mercury and SO₂. The additive prevents the oxidized mercury from being reemitted from the scrubbing liquid.

Dioxins in pure plastic



Absorption-desorption equilibrium:
Memory Effect

Dioxins in Adiox



Absorption in plastic and
adsorption at carbon particles

FIGURE S3. ADIOX[®] process for removal of PCDD/F. PCDD/F are absorbed in the plastic and then adsorbed irreversibly at carbon particles in the material.

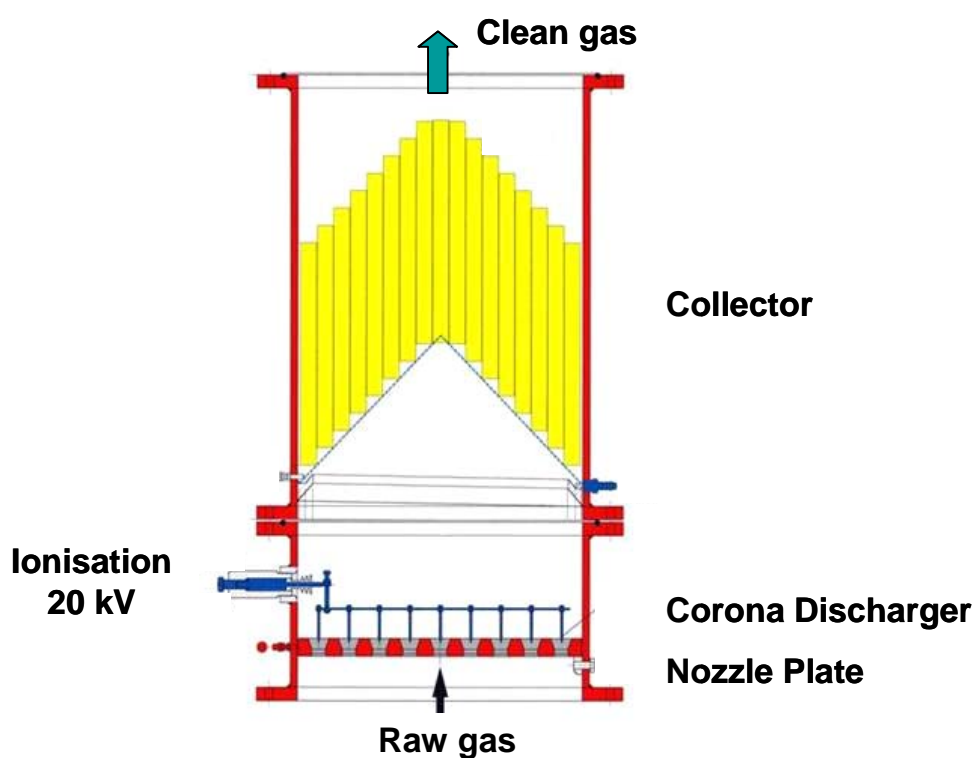


FIGURE S4. CAROLA process for removal of fine particles. Particles in the flue gas are charged during passing a nozzle plate with corona discharge. The charged particles are precipitated at a grounded collector.



FIGURE S5. Industrial scrubber at a Swedish waste incineration plant treating a flow rate of $120,000 \text{ m}^3/\text{h}$.

Economic evaluation of the MFS

The total costs of a flue gas cleaning plant are comprised of different cost types. The total capital investment is the sum of “depreciable” and “nondepreciable” investments. Depreciable are those costs that can be depreciated during all or part of the time the plant is in operation. They can be written off on income tax returns. Costs as land and work capital are nondepreciable because they are recoverable when the plant ceases operation. The total annual costs are comprised of direct annual costs, indirect annual costs and recovery credits. Direct annual costs are proportional or partially proportional to the throughput of the plant while indirect annual costs are independent of the throughput. Examples for direct annual costs are costs for operation of the plant (chemicals, electric power, steam), for the disposal of residues and for maintenance. Indirect annual costs are for example property taxes and insurance. Recovery credits are due to energy and materials recovered by the plant (S1).

The costs of a conventional flue gas cleaning train consisting of a baghouse filter with activated carbon injection plus acid and neutral wet scrubbers and of a configuration consisting of an electrostatic precipitator plus MercOx scrubber have been compared previously in a detailed design study for a new flue gas cleaning plant of a sewage sludge incinerator (S2). The latter configuration turned out to have lower capital costs and lower operating costs than the conventional flue gas cleaning system. In this case the complete HCl, SO₂ and Hg removal took place in the MercOx scrubber. The favorable costs for this process are mainly due to the low SO₂ concentrations in the sewage sludge incinerator flue gas.

In an independent study (S3) two variants were compared for the flue gas cleaning of a thermal soil treatment plant. In the first variant SO₂ was absorbed in a scrubber with NaOH and mercury was removed in a fixed bed carbon filter. In the second variant SO₂ and mercury were captured in a MercOx scrubber followed by a fixed bed carbon police filter. The second variant proved to be more cost effective but the savings depending strongly on the SO₂ concentration and the adsorption capacity and price of the activated carbon. Two types of activated carbon with adsorption capacities of 15 and 30 g Hg per kg carbon have been considered. At an SO₂ concentration of 800 mg/m³ the savings are roughly 10,000 EUR/a using the carbon with a Hg capacity of 15 g/kg and 3,000 EUR/a using the carbon with a Hg capacity of 30 g/kg (S3).

The multifunctional scrubber should be advantageous regarding investment costs because several functions are accomplished in one unit. Data on investment costs of flue gas plant technology have been calculated and compared by Achternbosch and Richers (S4). The costs are related to two incineration lines (incineration capacity 200,000 t/a) omitting costs for construction services, instrumentation and control systems. Information supplied by plant constructors and plant operators were used along with literature data.

To estimate investment costs for the multifunctional scrubber two MFS flue gas cleaning configurations were compared with two state-of-the-art configurations. Based on the data calculated by Achternbosch and Richers (S4) relative investment costs of the MFS and state-of-the-art configurations have been calculated. The different flue gas configurations are shown in Figure S6.

In configuration A particles are removed in the electrostatic precipitator and in the multifunctional scrubber. This configuration is suited for flue gases with a low SO_2 raw gas concentration (below 100 mg/m^3). The SO_2 , HCl, Hg and PCDD/F removal takes place in the multifunctional scrubber only.

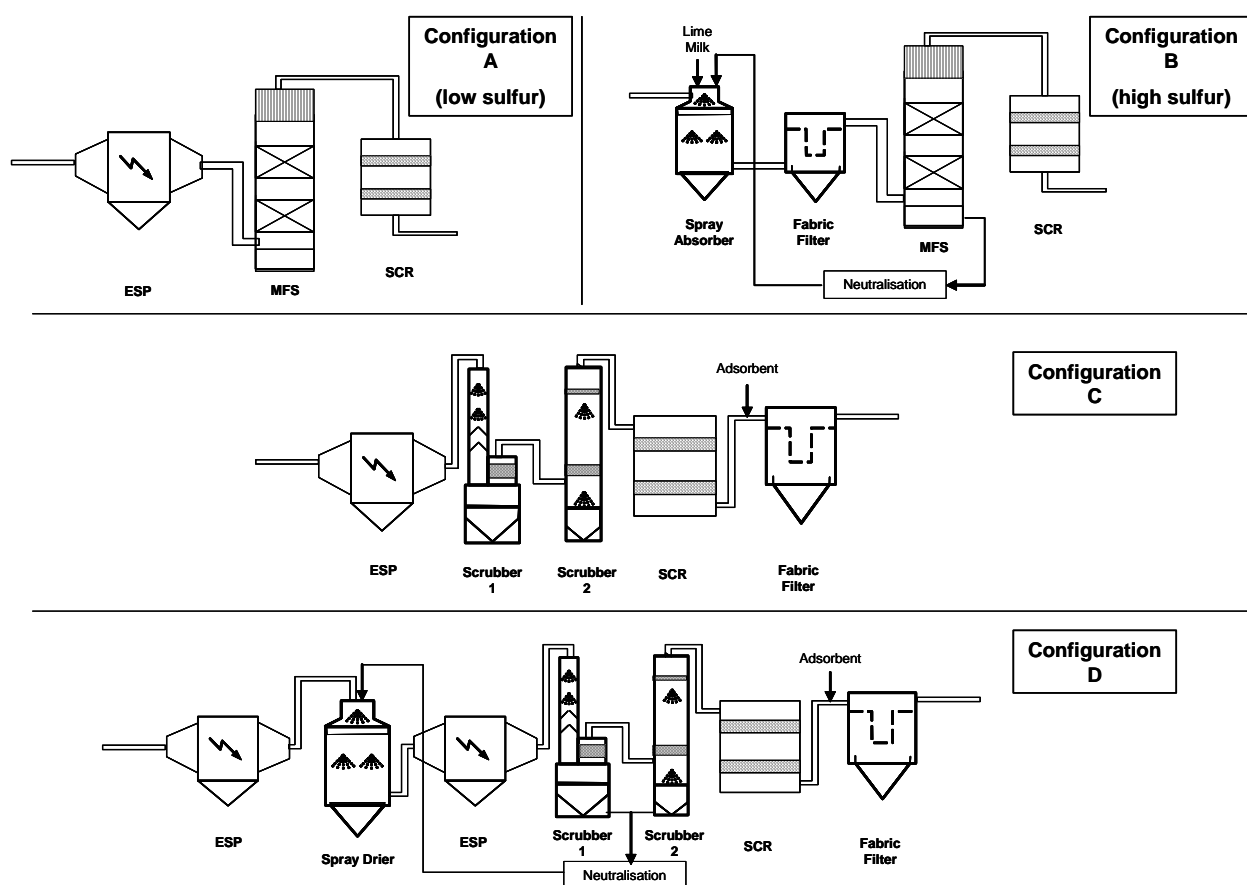


FIGURE S6. Flue gas cleaning configurations used to compare investment costs.

In configuration B for flue gases with higher SO₂ raw gas concentrations the main SO₂ load is removed by the spray absorber by the injection of lime milk. The remaining SO₂, HCl, Hg and PCDD/F are absorbed in the multifunctional scrubber. Particles are removed in the fabric filter and in the MFS.

In configuration C particles are removed in the electrostatic precipitator and in the fabric filter. The SO₂ removal takes place in the neutral scrubber (Scrubber 2). HCl is removed in the acid scrubber (Scrubber 1). Mercury and PCDD/F are removed in the entrained flow reactor (adsorbent dosage) with fabric filter. Oxidized mercury is also removed in the wet scrubbers.

The particle removal in configuration D is achieved by the application of two electrostatic precipitators and the fabric filter. The SO₂ removal takes place in the neutral scrubber (Scrubber 2). HCl is removed in the acid scrubber (Scrubber 1). Mercury and PCDD/F are removed in the entrained flow reactor (adsorbent dosage) with fabric filter. Oxidized mercury is also removed in the wet scrubbers.

The configurations B and D are waste water free while an additional waste water treatment is needed for configurations A and C.

Achternbosch and Richers (S4) assumed the following clean gas data for the configurations C and D (standard dry state, 11 vol.% O₂): SO₂ 4 mg/m³, HCl 2 mg/m³, Hg 4 µg/m³.

According to our experimental results these clean gas data can also be assumed for the multifunctional scrubber configurations A and B. The relative investment costs of the different flue gas cleaning configurations are shown in Figure S7.

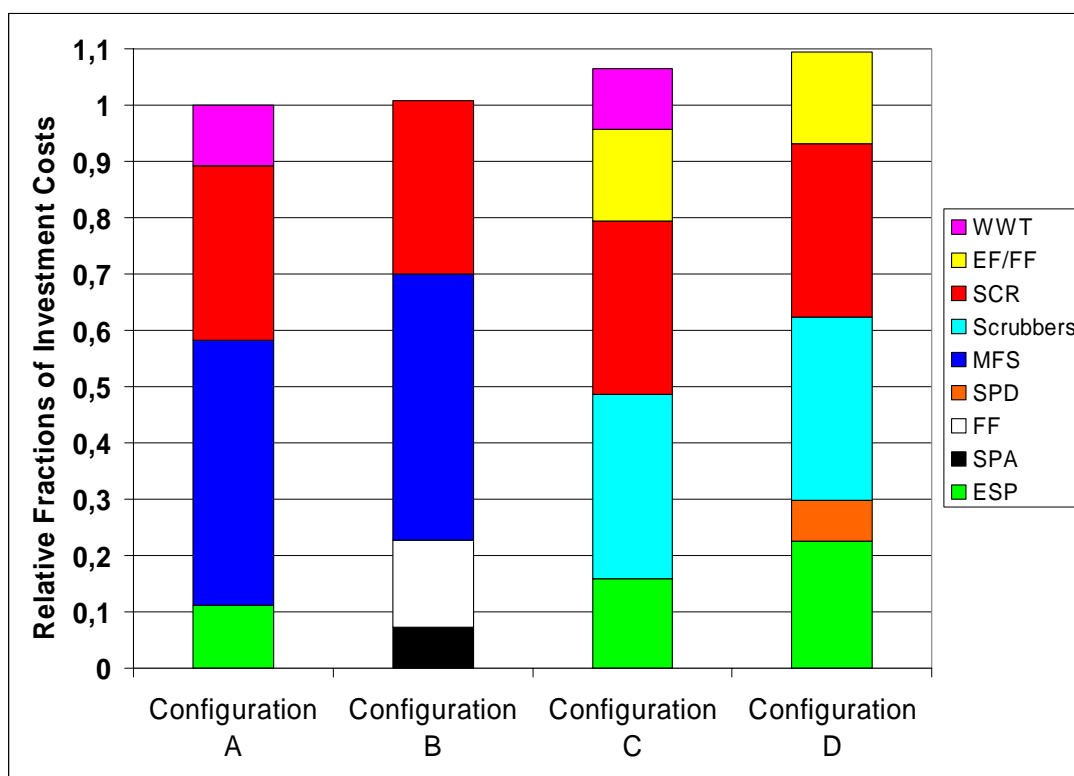


FIGURE S7. Relative investment costs of different flue gas cleaning configurations calculated according the procedure of Achternbosch and Richers (S4). Abbreviations of flue gas cleaning components: Spray Absorber (SPA), Spray Dryer (SPD), Electrostatic Precipitator (ESP), Fabric Filter (FF), Entrained Flow Reactor with Fabric Filter (EF/FF), acid + neutral wet scrubbers (Scrubbers), Multifunctional Scrubber (MFS), Selective Catalytic Reduction of NO_x (SCR), External Waste Water Treatment (WWT).

If mercury and PCDD/F are removed from flue gases by means of lime / activated carbon mixtures large volumes of contaminated adsorbent are produced which causes high disposal costs for the safe final storage of these materials. The spent adsorbents cannot be incinerated because of the resulting desorption of mercury. Dry or semi dry flue gas cleaning processes frequently show lower removal efficiencies than wet systems.

The SO_2 concentration upstream of a multifunctional scrubber (MFS) plays a key role regarding the consumption of the oxidizing agent hydrogen peroxide. For this reason in flue

gases with a high SO₂ concentration a pre removal of SO₂ is important to limit the H₂O₂ consumption. Such a pre removal can be achieved by the application of a spray absorber with lime milk injection like in the example mentioned above. The main difference between the MFS configurations A and B and configurations C and D (Figure S6) is the location of the mercury and PCDD/F removal step. In the MFS mercury is absorbed in the scrubbing liquid and PCDD/F are absorbed by the tower packing material. In configurations C and D mercury and PCDD/F are adsorbed on activated carbon. By this way huge volumes of contaminated activated carbon are produced. The residue which is produced during operation of the multifunctional scrubber consists mainly of precipitated salts from the waste water treatment. Since the quantity of those residues is relatively low the costs for their disposal can also be considered as low. The ADIOX[®] tower packing material can be incinerated as hazardous waste after use (normally several years). With these facts the multifunctional scrubber should have also operation cost advantages compared with other flue gas cleaning systems.

Literature Cited

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- (S3) Mercury reduction by the MercOx process. EU Life99 ENV/S/000626, Final Report
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