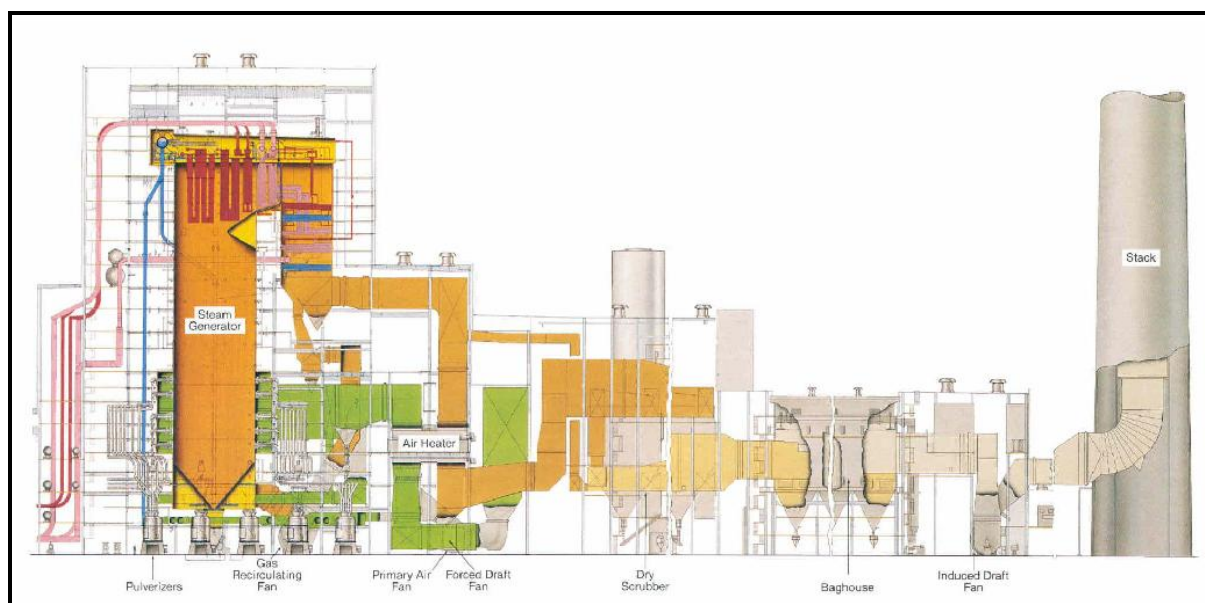


# **Chapter 10 Cross effects and total gas clean-up system lay-out**

## **10.1 Introduction**

Often more than one pollutant has to be removed from a flue gas or fuel gas. For power plants the emission regulations are usually less strict than for waste incinerators, for example, and less species have to be controlled at a typical power plant (typically only SO<sub>2</sub>, NO<sub>x</sub> and particulates) than for flue gases from waste incineration. Also for a certain species such as SO<sub>2</sub> or NO<sub>x</sub> the emissions regulations depend on process type and plant size. Some compounds such as alkali or chlorine may not be of any concern from an emissions point of view but are controlled to prevent corrosion, damages to process equipment or operational problems in general. In other cases the gas is a product that has to fulfill certain specifications, such as a maximum concentration of 2.5%-vol CO<sub>2</sub> in natural gases. For the process economy priorities can be ranked as 1) emission regulations or fuel gas quality requirements, 2) process operation and plant life and 3) thermal power efficiency.



**Figure 10.1** Typical pulverised coal combustion and gas clean-up system: dry scrubber + baghouse filter for SO<sub>2</sub> and particulate control (picture from Stultz and Kitto, 1992)

Whatever the situation, when more than one piece of equipment must be installed the question arises of how to arrange the equipment. Although the answer partly follows from the temperature profile of the process, the interactions between the emissions control steps play an important role as well. These issues are discussed briefly in this last chapter, excluding the greenhouse gas CO<sub>2</sub> (7 chapter 9).

## 10.2 Gas clean-up for power plants

For a conventional pulverised coal-fired power plant a set-up is shown in Figure 10.1, with a gas clean-up system composed of a dry sorbent injection + baghouse filter arrangement for SO<sub>2</sub> and particulate control. For solid fuel -, oil - or gas - fired power plants typical positioning of gas clean-up devices is given in Table 10.1. What equipment is needed depends on fuel quality, local regulations and process type.

**Table 10.1 Typical positioning of flue gas or fuel gas clean-up equipment for power plants**

	Furnace	> 400EC	200 - 400EC	< 200EC
Gas fired furnace or engine or NGCC*	Flue gas recirculation, water injection, reburning fuel	SNCR	SCR	
Oil fired furnace or engine	Flue gas recirculation, water injection, reburning fuel	SNCR	SCR, (semi-) dry FGD	wet FGD
Pulverised fuel furnace	Reburning fuel, furnace sorbent injection FGD	SNCR	SCR, hot ESP, duct sorbent injection FGD	cold-side ESP, baghouse filter, wet FGD,
AFBC / PFBC-CC**	Ca-based sorbent, reburning fuel	cyclone, SNCR	SCR, hot ESP	cold-side ESP, baghouse filter
IGCC for solid fuels	Ca-based sorbent	tar cracking, hot gas filter, alkali, halogen removal, H <sub>2</sub> S/COS removal, NH <sub>3</sub> removal ***	SCR	

\* Natural gas-fired combined cycle

\*\* For PFBC-CC : expansion turbine after cyclone or cyclone + SNCR

\*\*\* All upstream of the gas turbine combustion chamber

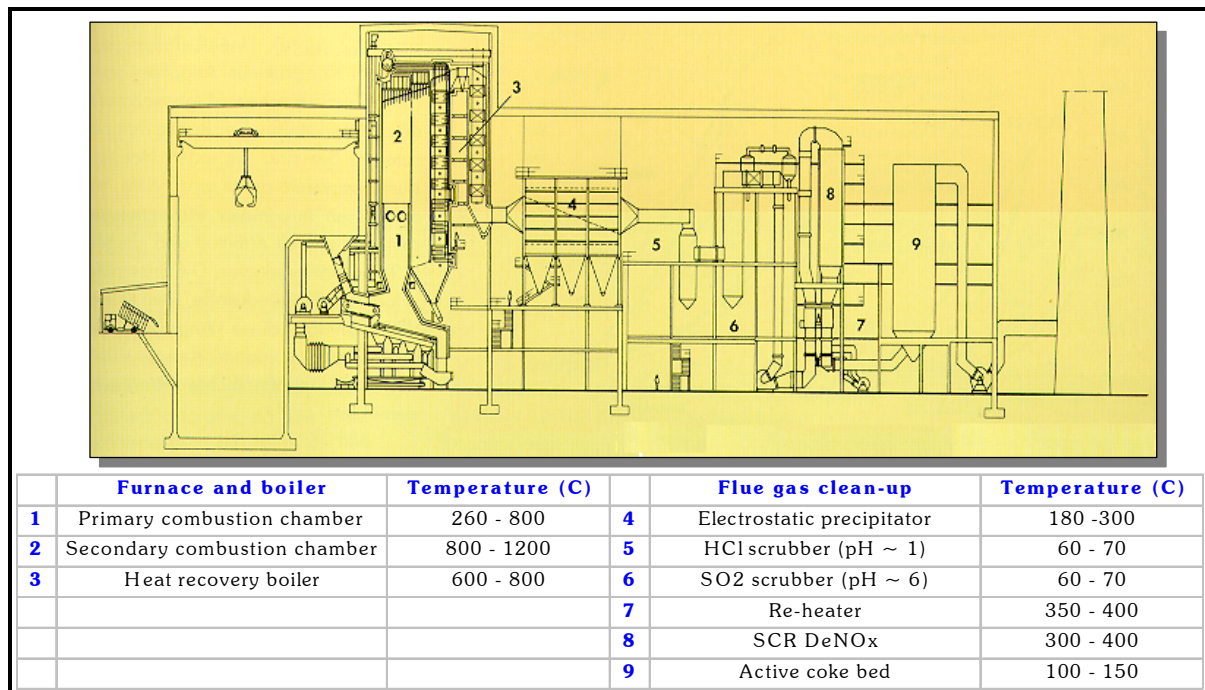


Figure 10.2 Lay-out of a modern solid waste incinerator facility with gas clean-up (picture from Krupp VDM, 1999)

For natural gas firing the only species of concern is NO<sub>x</sub>, for oil firing SO<sub>2</sub> may need attention as well. For solid fuels dust, SO<sub>2</sub> (except for biomass fuels) and NO<sub>x</sub> emissions must be controlled. Solid fuel-fired IGCC processes involve hot gas clean-up to upgrade the fuel gas to gas turbine inlet specifications. It is expected that around 2005 mercury (Hg) emissions will be regulated as well for power plants.

### 10.3 Gas clean-up for flue gases from waste incineration and cement plants

For waste incineration a rather wide range of pollutants must be controlled. The composition of most wastes is characterised by high concentrations of halogen (mainly chlorine in the form of PVC) and trace elements. Furthermore, the burning process typically results in significant VOC and PAH emissions due to the relatively large “fuel” size and mixing limitations. Particulates are the first to be removed from the flue gas, as to remove the most concentrated pollutant first and to protect gas clean-up equipment downstream. As the lay-out for a modern waste incinerator in Figure 10.2 shows, reheat is needed for the DeNO<sub>x</sub> SCR device operated at 350-400EC. This is then followed by activated carbon (as a bed or injected as powder), after part of some species such as PAHs, PCDD/Fs may have been destroyed already by oxidation in the SCR. Table 10.2 lists the positioning of control devices in a waste incinerator flue gas clean-up train.

**Table 10.2 Typical positioning of flue gas or fuel gas clean-up equipment for solid waste incinerators and cement plants**

	Furnace	> 400EC	200 - 400EC	< 200EC
Waste incinerator			SCR (after re-heat)	ESP, acid scrubber for HCl, scrubber for SO <sub>2</sub> , (SCR at 350-400EC), activated carbon filter for trace elements, PAHs, PCDD/Fs
Cement plant				cold-side ESP or baghouse filter

Also mentioned in Table 10.2 are cement plants. Here, SO<sub>2</sub> and trace elements are primarily retained in the clinker product, whilst NO<sub>x</sub> emissions standards are less strict than for other processes. Reducing NO<sub>x</sub> emissions from cement plants currently receives much research attention (*e.g.* Tokheim, 1999). In most cases a cold-side ESP or baghouse filter is still sufficient nowadays.

#### 10.4 Clean-up of fuel gases

Two major types of gases can be considered here: natural gases and gasification product gases. Natural gas processing involves mainly the removal of H<sub>2</sub>S and CO<sub>2</sub> as discussed in chapters 3 and 9, respectively, as listed in Table 10.3. For gasification product gas the purity is dictated by the downstream gas turbine (hot gasification product gas clean-up is included in Table 10.1), the fuel cell or the chemical process wherein the gas will be applied.

**Table 10.3 Typical positioning of clean-up equipment for natural gas and for low temperature gasification product gas clean-up.**

	> 250EC	< 250EC
Natural gases	Claus process for H <sub>2</sub> S	Chemical or physical sorption of H <sub>2</sub> S, CO <sub>2</sub>
Gasifier product gas		Dust filtration (including alkali), chemical or physical sorption of HCl, H <sub>2</sub> S, CO <sub>2</sub> , NH <sub>3</sub>

#### 10.5 Cross-effects between gas clean-up processes

Combining clean-up devices for flue gas or fuel gas in a certain arrangement inevitably results in cross-effects between the removal processes. For example, high-dust SCR will suffer from faster catalyst deactivation than low-dust SCR, and chlorine

removal prevents the formation of dioxins and furans downstream. As the different arrangements of the devices and the temperatures at which these operate can vary widely the number of possible interactions between the chemical species, distributed over gas phase and condensed phases, is enormous. An attempt to list the most important of these is given in Tables 10.4 through 10.9. It summarises what was already mentioned in the earlier chapters.

**Table 10.4 Effect of sulphur species emissions control on other pollutants' emissions**

Nitrogen	- <i>In situ</i> calcium based sorbents in FBC reduce NO emissions but may increase N <sub>2</sub> O emissions - High SO <sub>2</sub> concentrations may result in NH <sub>4</sub> HSO <sub>4</sub> and (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> deposits in SCR for DeNOx
Particulates	- Low-sulphur fly ashes are problematic for ESP
VOCs / PAHs	
Halogens, PCDD/Fs	- Wet FGD and dry scrubbing (duct injection or furnace injection of sorbent) also removes HCl, HF, HBr - The presence of SO <sub>2</sub> in flue gases reduces PCDD/F formation
Trace elements, alkali	- Wet FGD and dry scrubbing (duct injection or furnace injection of sorbent) also removes trace elements
Other	- SO <sub>2</sub> forms aerosol particles in the atmosphere that lower the enhanced greenhouse effect

**Table 10.5 Effect of nitrogen species emissions control on other pollutants' emissions**

Sulphur	- The SCR catalyst catalyses SO <sub>2</sub> to SO <sub>3</sub> - High SO <sub>2</sub> concentrations may result in NH <sub>4</sub> HSO <sub>4</sub> and (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> deposits in SCR for DeNOx
Nitrogen	- SCR for DeNOx may give NH <sub>3</sub> emissions ("slip") - SNCR, especially when using urea, may give N <sub>2</sub> O emissions
Particulates	- Low NOx methods may increase carbon-in-ash
VOCs / PAHs	- Low NOx methods may increase CO emissions - NO is used to oxidise diesel engine exhaust soot in the CRT
Halogens, PCDD/Fs	- Dioxins/furans emissions are reduced by SCR
Trace elements, alkali	- The SCR catalyst catalyses Hg <sup>0</sup> to Hg <sup>2+</sup>
Other	- N <sub>2</sub> O is a greenhouse gas - NO affects the ozone layer

**Table 10.6 Effect of particulate emissions control on other pollutants' emissions**

Sulphur	- Ash particles possibly catalyse SO <sub>2</sub> to SO <sub>3</sub> - Fly ash in a wet FGD scrubbers: deposits, low quality gypsum
Nitrogen	- Hot-side ESPs before SCR for DeNOx protects the catalyst
VOCs / PAHs	
Halogens, PCDD/Fs	- Removing particles removes also possible catalysts for the Deacon reaction and possible dioxin/furan formation
Trace elements, alkali	- ESPs remove most Class I + II trace elements, some Class III
Other	- Cyclones before an ESP or filter may save costs

**Table 10.7 Effect of VOC/PAH species emissions control on other pollutants' emissions**

Sulphur	
Nitrogen	- PAHs may foul, poison, <i>i.e.</i> deactivate SCR catalysts
Particulates	
Halogens, PCDD/Fs	- VOCs and PAHs participate in dioxin/furan formation
Trace elements, alkali	- VOCs and PAHs may be also adsorbed on activated carbon
Other	- VOC control reduces ground-level ozone - PAHs may foul, poison, <i>i.e.</i> deactivate VOC oxidation catalysts

**Table 10.8 Effect of halogen species and PCDD/F emissions control on other pollutants' emissions**

Sulphur	- HF may give ALF <sub>x</sub> deposit formation in wet FGD - HCl, HBr and HF will lower the pH in FGD which negatively affects sulphur capture performance
Nitrogen	
Particulates	- HF attacks silicates, for example in filter bags
VOCs / PAHs	
Trace elements, alkali	- HCl and Cl <sub>2</sub> removal gives less volatile trace element chlorides
Other	- HCl and Cl <sub>2</sub> removal blocks dioxin/furan formation - Chlorine and other halogens hinder CO burnout

**Table 10.9** *Effect of trace elements and alkali emissions control on other pollutants' emissions*

<b>Sulphur</b>	- Removal of vanadium, for example, blocks SO <sub>2</sub> & SO <sub>3</sub> - Na <sub>2</sub> S <sub>4</sub> for Hg trapping in HCl scrubber may give some H <sub>2</sub> S
<b>Nitrogen</b>	- Vanadium oxide may act as an SCR catalyst
<b>Particulates</b>	
<b>VOCs / PAHs</b>	- Nickel is an active tar cracking catalyst - Some trace elements limit soot formation
<b>Halogens, PCDD/Fs</b>	
<b>Other</b>	- Activated carbon may adsorb other species - Trace metals like Mn and Cr may bind mercury

## 10.6 References

- Krupp VDM (1999?) "Thermische Abfallverwertung - Verfahren - Werkstoffe - Case Histories"  
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