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Technologies for emissions reduction in the metallurgical and chemical process industries

D. SCHREUDER
Envirotherm GmbH, Benoni, South Africa
envirothermsa@vodamail.co.za

Conditions in the South African market relating to atmospheric emission control has changed dramatically over the last 10 years. Companies have become more responsible, environmentally aware, and have to comply to more stringent environmental limits set by legislation. This paper describes briefly the current best available atmospheric pollution abatement technologies relating to particulates, acid gases, NO_x, acid mists, aerosols, mercury, dioxins and furans. Mention is also made as to the best practices for product work-up and waste product disposal.

Introduction

The past few years have seen a complete change in the attitudes, education, responsibility and legislation in the South African atmospheric emission sector in so far as that operating companies are changing to pro-active engagement in 'cleaning up their acts'. Companies now want to be seen, by the public, to be responsible and to produce 'clean' products. That this is partly market driven, as markets more and more demand 'clean' products is clear. Many companies cannot sell their products in first world markets, unless they comply with stringent environmental practices. South Africans are becoming more educated, both in their responsibility towards the environment, as well as in the benefits of having a clean environment. Public participation between communities and operating companies today is very comprehensive compared to say 10 years ago. In this regard, legislation is now also more in line with that of Europe and America, behind whom we lag by many years. Atmospheric emissions control, however, costs money, with seldom any financial payback to the operating company. As we enter into stringent emission control legislation, the question is often asked as to what best suitable technologies are available, what the rest of the world has done about this and how this can be applied to the South African market, making use of extensive experience gained in the rest of the world. This paper will outline, briefly, the best suitable technologies for atmospheric emission control.

Major groupings of conventional atmospheric pollution

There are at least five major groupings of atmospheric sources of pollution generally attributed to the metallurgical and chemical industries, each with specific best practice technologies for abatement. This is not a comprehensive list, as the petro-chemical industry as an example, would demand solutions of a total different nature compared to the metallurgical industry. Also, where strong acid gas concentrations are encountered, alternative flue gas cleaning technologies are implemented such as sulphuric acid plants. In this presentation we will look briefly at the following:

- Dust and dust related abatement technologies
- Acid gases such as SO_2/HCl and HF
- NO_x abatement technologies
- Acid mist and other aerosols
- Mercury, dioxins/furans and volatile organic compounds.

For the acid gas fixation technologies, product disposal as always remains a challenge. In the vast majority of applications, waste products are simply land-filled with the necessary operating costs that come with it.

However, here and there such technologies are implemented with a payback, such as gypsum sales to the cement or board industry, saleable weak sulphuric acid, and the like.

Best practice abatement technologies

For dust and dust related applications

The three major technologies employed for removal of particulates are electrostatic precipitators, bag or fabric filter plants and wet scrubbing methods.

Electrostatic precipitators have been around for a long time. The first unit was built by Lurgi in 1913. Up till 2006, more than 20 000 such units have been built in the general process industries. A typical breakdown by a major supplier of such units can be seen in Figure 1. (13 000 references).

Electrostatic precipitators can be classified in the following major categories:

- Dry-type designs for more than 5 000 000 m^3/h
- Wet-type designs for maximum particulate removal
- Horizontal and vertical type precipitators
- Precipitators for tar and other difficult materials
- Hot gas designs for operation at temperatures above 500°C
- Precipitators for corrosive gas and dust applications.

The principal of operation for an electrostatic precipitator is the ionization of the particulate within an electric field. The particle is then collected on an electrode and discharged mechanically to a collection hopper. (see Figure 2).

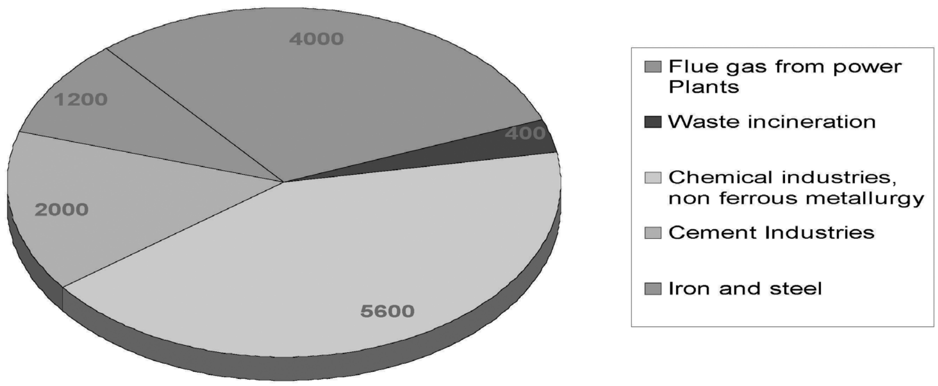

Figure 1. Envirotherm ESP's in operation worldwide by industry

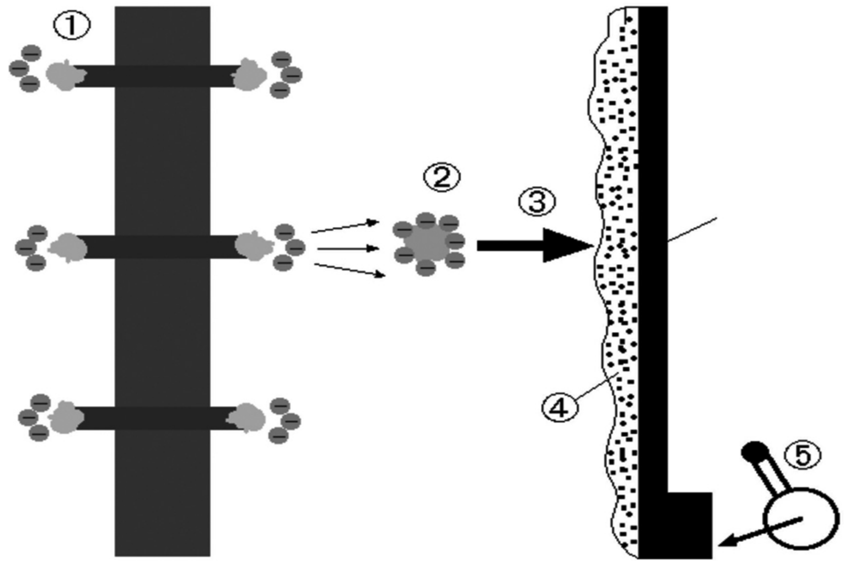

Figure 2. Process principle for ESP operation

Process steps

1. Electron emission
   - Corona discharge
2. Charging of dust particle
   - Diffusion charging for particles < 0.5 μm
   - Field charging for particles > 0.5 μm
3. Transport of charged particles
   - Coulomb force
   - Stokes's law
4. Dust agglomeration on collecting electrode
   - Cohesion/Adhesion forces
   - Voltage
5. Dust removal from collecting electrode
   - Mechanical rapping
   - Shearing forces.

The vast majority of electrostatic precipitators are involved with capturing dust from high temperature applications, i.e. boilers, rotary kilns, furnaces, ovens, smelters and incinerators.

Electrostatic precipitators are generally good for dust removal of up to 30mg/Nm^3 and temperatures of up to 450°C.

Similarly, fabric filter plants have been in operation for many decades, in as diverse applications as electrostatic precipitators. The principle behind a fabric filter plant is one of a porous barrier, whereby the particulates are drawn onto the outer surface of the fabric material and the clean gas passes through. The particulates are then discharged via an air pulse and collected in the hopper for further disposal. (see Figure 4.)

There are two major types of fabric filter plant.

- Low pressure with pulsing of between 25 to 85 kPa and
- High pressure with pulsing between 2 to 8 bar.

Fabric filters are generally good for particulate removal of up to 10 mg/Nm^3 and temperatures of up to 200°C.

Low pressure pulse jet fabric filter plants are particularly suited for retrofitting existing electrostatic precipitators. Electrostatic precipitators have a very low pressure loss and retrofitting in this way alleviates the need for higher duty ID fans, which can be a large cost component. Due to the ever increasing demand for higher particulate removal efficiencies, many electrostatic precipitators today are being converted to fabric filter technologies. (see Figure 6.)

Fabric filter plants are found on all major technological applications and in all industries but are not as popular for high temperature applications as are electrostatic precipitators.

Tables I and II list some pros and cons between these two major particulate removal technologies.

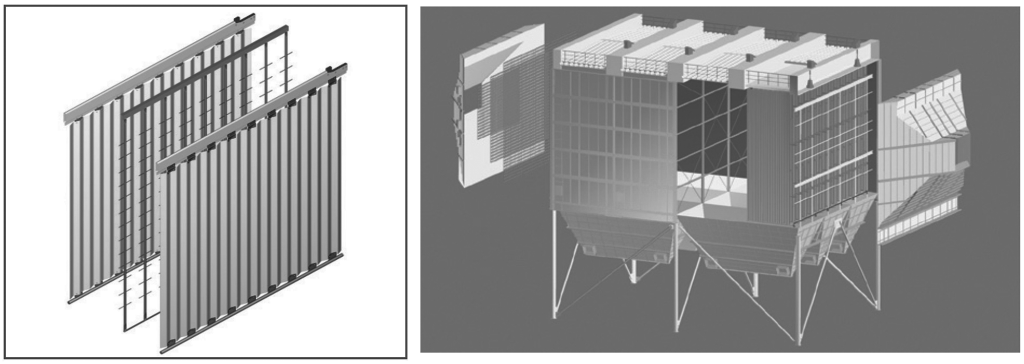

Figure 3. Diagrammatic illustration of an electrostatic precipitator

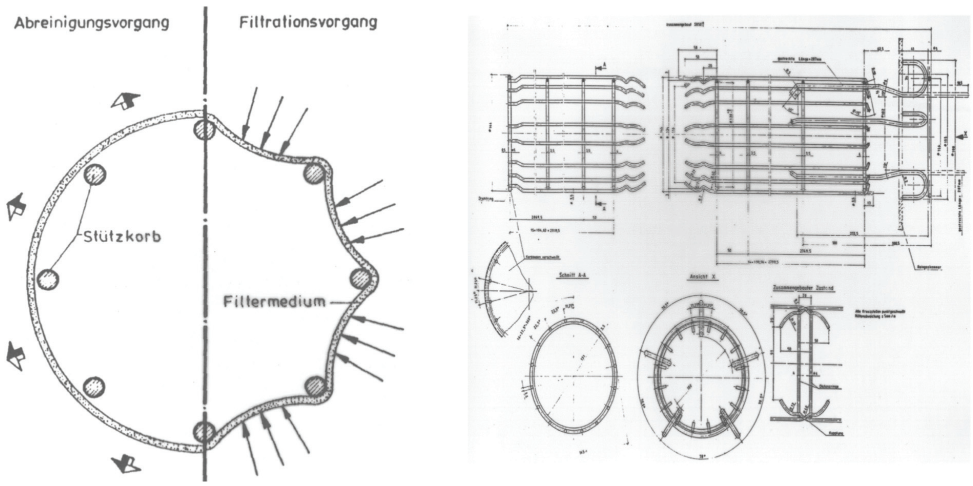

Figure 4. Operating principle of the fabric filter plant

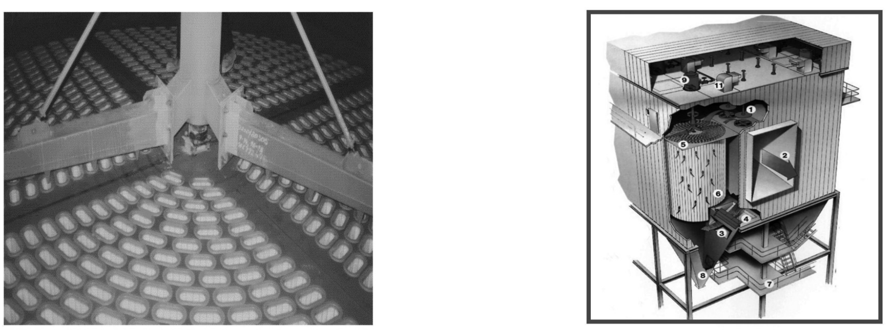

Figure 5. Low pressure pulse jet fabric filter plant

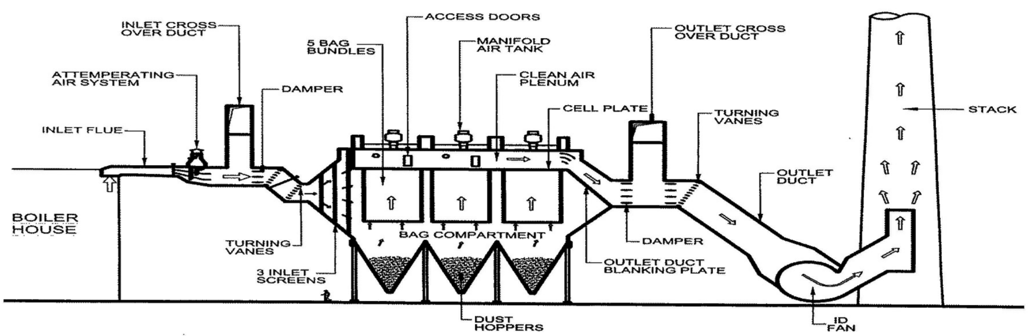

Figure 6. Diagram showing a typical fabric filter retrofit to an existing ESP

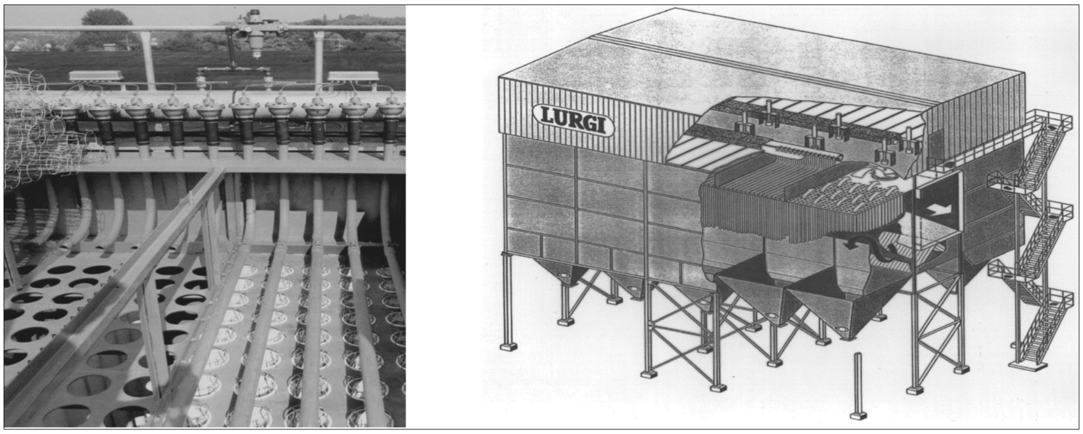

Figure 7. High pressure fabric filter plant

Table I
Electrostatic precipitators

Pro	Contra
• Low pressure drop (< 2.5 mbar) • Low maintenance effort • High lifetime expectancy (>15–20 years) without any major overhaul • Insensitive against boiler tube leakage • Low total energy consumption and operation cost • Low maintenance time required • High reliability	• Dependence of collection efficiency and ESP-size on changing fly ash properties • Relatively big installation volume • Relatively high investment cost • Low $DeSO_x$ effect behind FGD or spray dryer installations

Table II
Fabric filter plants

Pro	Contra
• Clean gas dust content independent from boiler load and ash type (less than 30 mg/Nm^3) • Clean gas dust content less than 10 mg/m^3 without problems • Safe and simple sizing procedure • $DeSO_x$ effect in ash layer on filter bag behind FGD or spray dryer installations • Relatively low investment cost	• High pressure drop from boiler load and ash type(15–30 mbar) • Limited lifetime of filter bags dependent on bag material • Low emergency operation temperature • Sensitive to flue gas temperature lower than dew point • Sensitive to boiler tube leakage • Maintenance time needed for changing of filter bags (approx. 1000 h per FF every 5 years) • Pre-coating needed for commissioning

Apart from electrostatic precipitators and fabric filter plants there are many other technologies for removal of particulates, but these are seldom efficiently applied for dust burdens below 100 mg/Nm^3.

Table III lists some of these alternative technologies as well as the efficiencies that can be expected.

For acid gases

The main acid gases we find in conventional flue-gas streams are sulphur dioxide (SO_2), sulphur trioxide(SO_3), hydrochloric acid (HCl) and hydrofluoric acid (HF).

Abatement of these pollutants can be broadly classified into four classes:

- Dry scrubbing
- Semi-dry scrubbing,
- Wet scrubbing and
- Adsorption technologies

For most of these applications, a reagent is required to affect the required abatement. Typically these are lime,

Table III
Comparison of filtration efficiencies of different particulate removal systems for a range of particulate sizes

Type of collector	Approximate filtration efficiency on a standard dust			
	60% 60μm 30% 10μm 10% 2μm	10μm	5μm	1μm
High efficiency cyclone	84.2	85	67	10
Small multi-unit cyclones	93.8	96	89	20
Low pressure drop cellular collector	74.2	62	42	10
Spray tower	96.3	96	94	35
Self-induced spray collector	90.4	97	93	32
Wet impingement scrubber	97	99	97	88
Venturi high pressure scrubber	99.7	99.8	99.6	94
Dry electrostatic precipitator	94.1	98	92	82
Wet electrostatic precipitator	99	99	98	92
Fabric filter	99.8	99.9	99.9	99
Refractory filter	>99.97	>99.99	>99.94	>99.9

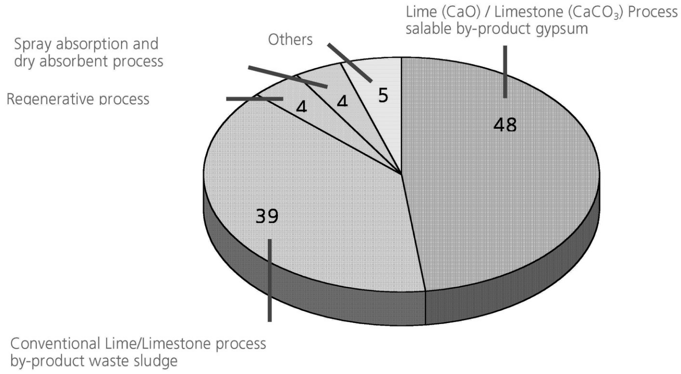

Figure 8. Worldwide applications of flue gas desulphurization technologies by volumes treated

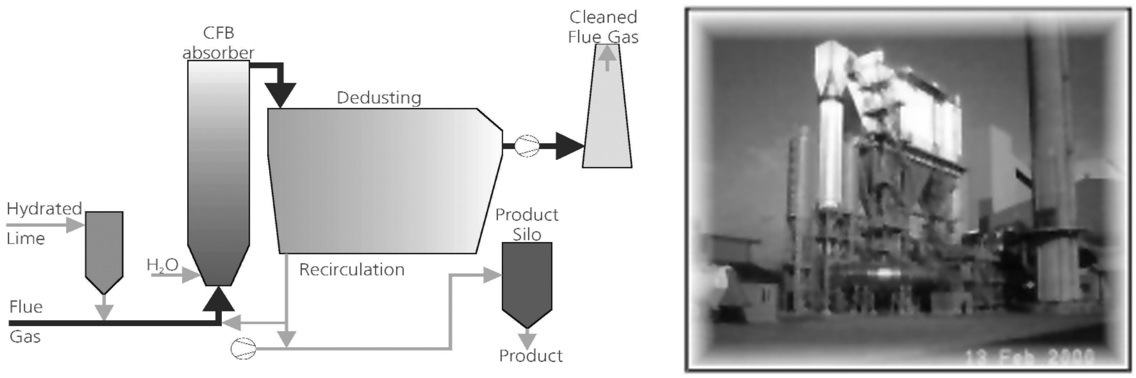

Figure 9. Dry circulating fluidized bed technology

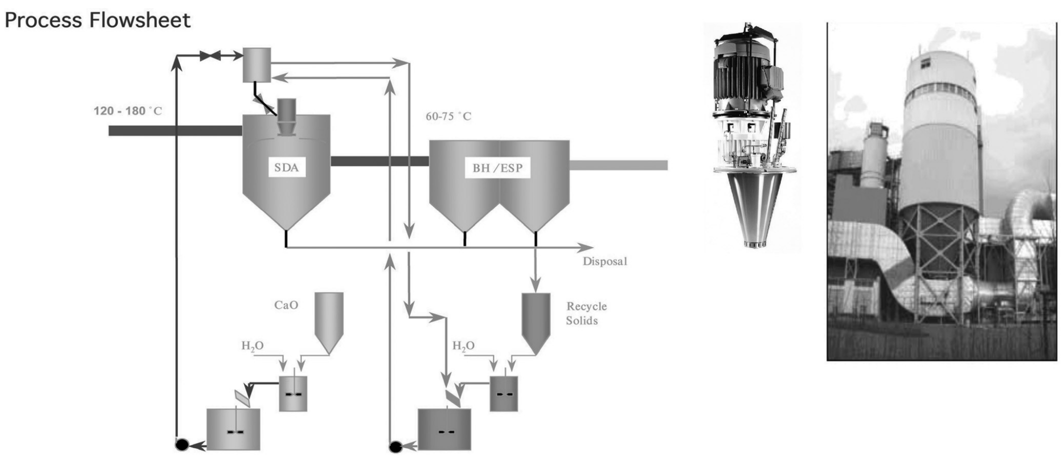

Figure 10. Process flow for the semi-dry spray drying technology, atomizer and actual plant

hydrated lime and limestone. For smaller scrubbers caustic and other reagents may be used. For adsorption technologies a variety of activated carbons and catalysts may be used.

Dry scrubbing technologies have the clear advantage that no water is required in the process and that the end product is of a dry nature. When one deals with solids and particulates dry, flowable materials greatly simplify plant design.

The basic principle of the dry process is illustrated in Figure 9. This technology employs the so-called circulating fluidised bed technology, which has been successfully applied to many applications throughout the world in all possible process applications. This technology can reduce acid gases to below 20 mg/Nm^3 and combined with a bag filter will reduce particulates to below 10 mg/nm^3.

Semi-dry scrubbing technologies employ a certain amount of water that is evaporated in the gas stream to bring the gas temperature to an optimal point for efficient scrubbing. Semi-dry processes include the circulating fluidized bed as well as spray drying technologies, where the reagent is contacted with the gas after an atomiser has dispersed the fluid to a very fine mist as the following process diagram explains. This technology can reduce acid gases to below 20 mg/Nm^3 and combined with a bag filter, particulates can be reduced to below 10mg/Nm^3. The most common reagent used is burned lime slaked on site to hydrated lime. This type of technology is extensively used world wide and is very well referenced. (see Figure 10.)

Wet scrubbers have been employed very successfully for acid gas scrubbing. This is a very well-established technology, which has been around for a very long time. The process principle is very simple where the acid gas is contacted counter current with a solution containing an alkali as reagent. On very large scale scrubbers such as mega power plants, this is the technology of choice as limestone, which is the most cost-effective reagent available, can be employed. Negatives are higher capital cost due to more exotic materials of construction and power requirements. Also a wet product is generally more difficult to dispose of than a dry product. (see Figure 11.)

A wet technology which is not often seen is flue gas scrubbing with sea water. (see Figures 13 and 14.)

A further novel process for acid gas scrubbing is an adsorption process over activated carbon which produces a weak solution of sulphuric acid for re-use by the client. Two such plants are in operation in South Africa. (sse Figure 15.)

For process plants that produce ammonia as a by-product, ammonia water scrubbing is an additional process that may be employed for acid gas removal.

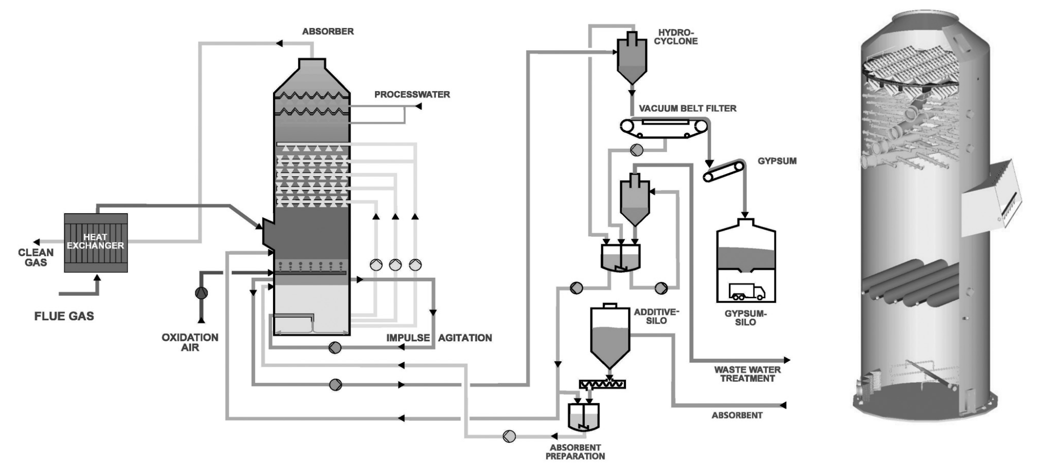

Figure 11. Typical process flow for a wet scrubber with gypsum plant and absorber

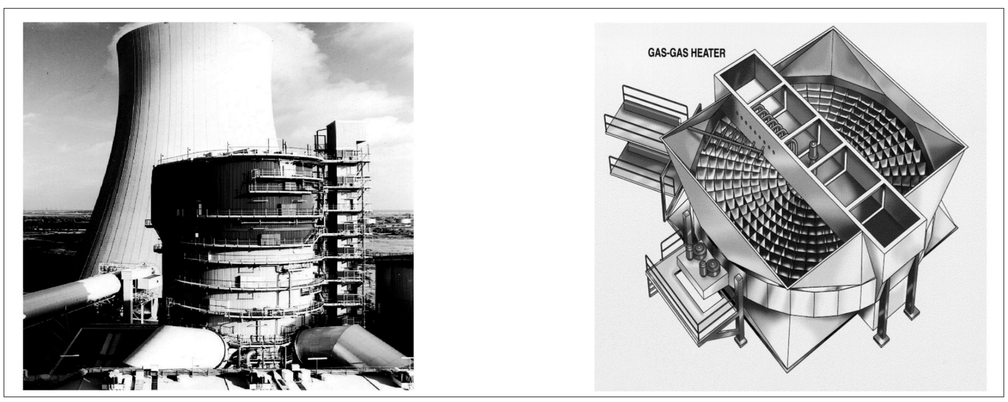

Figure 12. Actual power plant wet scrubber and gas heater for plume abatement

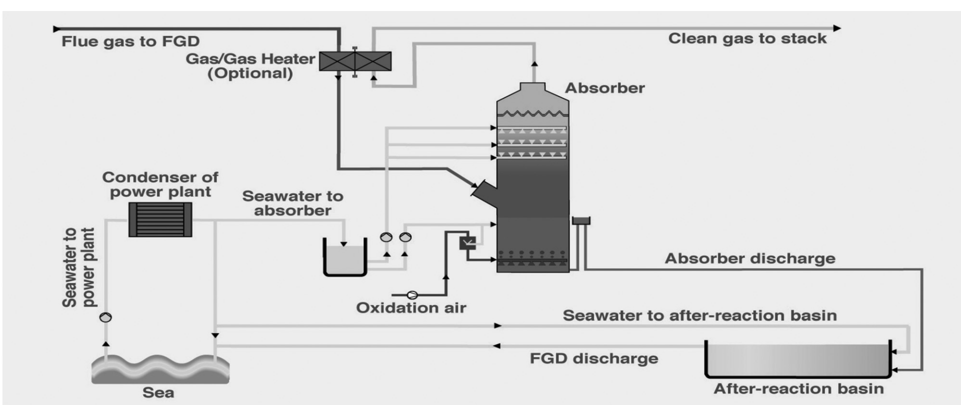

Figure 13. Process flow, sea water scrubbing

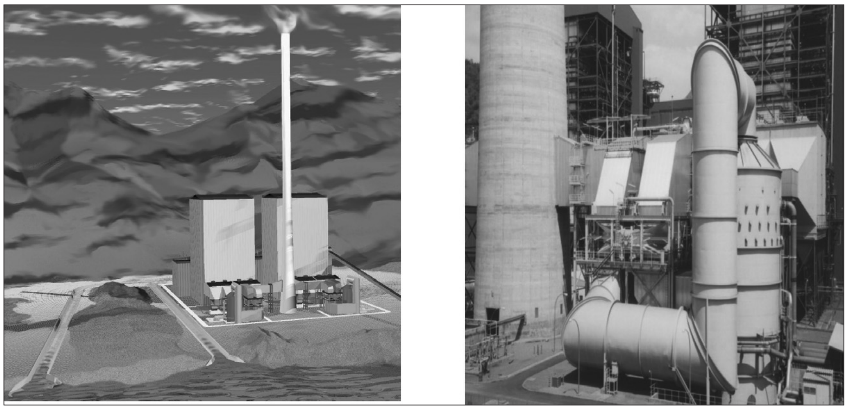

Figure 14. 3D Model and actual plant with sea water scrubbing technology

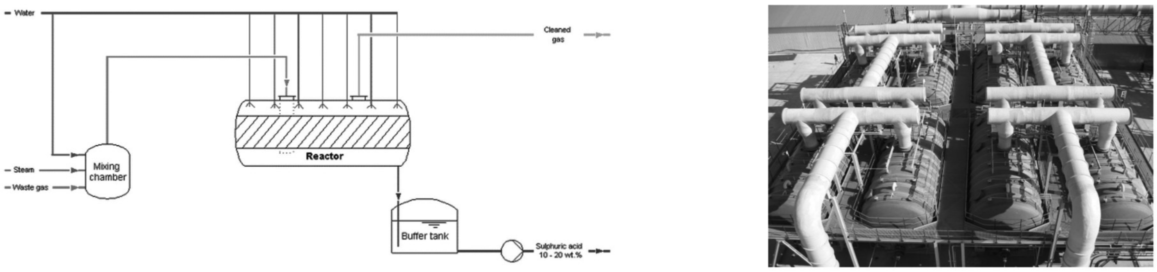

Figure 15. SulfAcid™ process

Table IV
Cost comparison for acid gas scrubbing technologies

Description	Unit	CFB FGD	Seawater-FGD	Wet Limestone FGD	Wet Ammonia Scrubbing
Investment Cost	%	50	65	100	120
Power Consumption	% of PP capacity	1 - 1.5	1 - 2	1 - 2	1.5 - 2
Absorbent	-	lime / hydrated lime	seawater	limestone / lime	NH_3 - water
Stoichiometric value	-	1.35	5	1.03	1.02
SO_2-emission	mg/Nm3	< 40	< 200	< 200	< 200
SO_2-removal efficiency	%	> 98	> 98	> 98	> 98
By - product	-	dry calcium sulfite / calcium sulfate mixture	sulfate ions (dissolved in seawater)	gypsum	ammonium sulfate
Space Requirement	m^2	600 - 1,500	1,000 - 3,000	1,000 - 2,000	2,000 - 4,500

NO_x control

NO_x abatement technologies include Selective Catalytic Reduction (SCR) whereby NO_x is destroyed over a catalyst with a small amount of ammonia. This can be done at moderate temperatures. (see Figure 16.)

Selective Non Catalytic Reduction (SNCR) destroys NO_x by injection of ammonia into the high temperature regions of the boiler or furnace.

Acid mist and aerosols

Acid mists and aerosols are typically removed with wet electrostatic precipitators.

Wet ESP's are highly efficient, have low power consumption, but due to the wet atmosphere, materials of construction are more expensive than for dry systems. (see Figure 17.)

Wet electrostatic precipitators (sse Figure 18) are extensively used in the following industries and have a very wide field of application.

- *Non-ferrous metal industry*—among other things to clean zinc-, lead- and cadmium oxide-laden exhaust air
- *Building material industry*—among other things to clean lime furnace waste gases
- *Chemical industry*—for the removal of dust and aerosols e.g. from sulphur-, phosphorous-, titanium oxide; bichromate of sodium; hydrochloric acid; super-fine salt-containing waste gases; production- and combustion waste gases
- *Automotive industry*—for the cleaning of exhaust air from paint booths
- *Power engineering*—for the removal of aerosols and dust from power stations; residential waste-, industrial waste- and hazardous waste incineration plants; generator-, protection- and inert gas plants; mixed gases such as top gas and coke oven gas, for coal and lignite gasification process
- Coke oven plants, among other things—for tar collection in the normal- and hot gas zone; de-oiling of coke oven gas; cleaning of coke-laden exhaust air

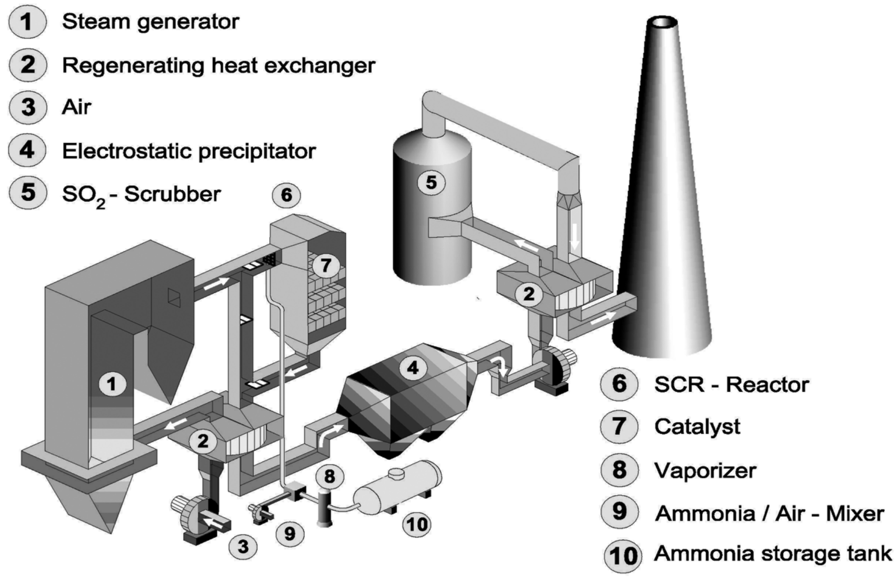

Figure 16. SCR NO_x plant

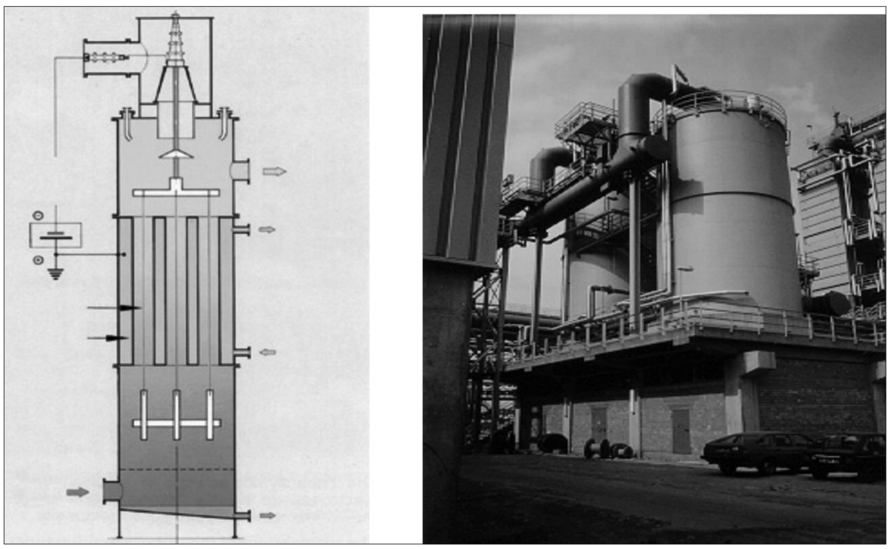

Figure 17. Process principle and actual operating plant

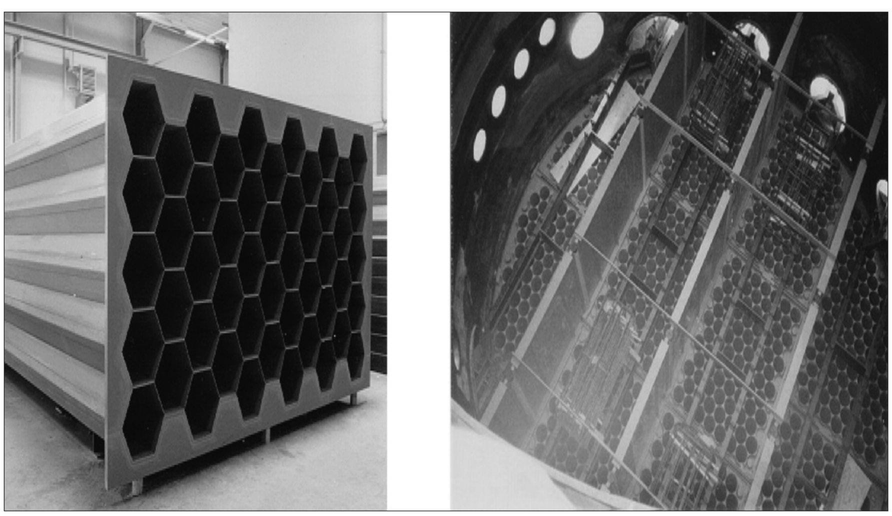

Figure 18. Wet ESP inner column construction

Figure 19. Activated carbon plants for VOC removal

- Iron- and steel industry—among other things to clean exhaust air coming from convertors, blast furnaces, cast houses, scarfing machines and blow-torch cutting-off machines, casting pits, desulphurization stands, tube lines, cupola melting furnaces.

Mercury, dioxins, furans and volatile organic compounds (VOC's)

Mercury, dioxins, furans and VOC's are compounds that are increasingly being targeted by the South African industry for removal due to government legislation and public pressure. Very efficient technologies are available for removal and destruction of these compounds and are all based on adsorption technologies with the use of activated carbon beds. In the case of VOC's these may be recovered in usable form and re-used. Others like mercury are slowly adsorbed and the carbon bed then has to be disposed of.

Activated carbon scrubbers are especially popular for cleaning up mercury, dioxins and furans from incineration applications. In South Africa, many such applications are currently being looked at.

Another popular use of activated carbon is its addition tinto the reagent streams of the above technologies for mercury removal combined with acid gas removal.

Other activated carbon plants in use today capture a wide range of organics such as MEK, benzene, toluene, xylene, H_2S, DMT, etc.

Conclusions

Atmospheric pollutant control has reached an advanced stage of abatement in Europe and America. The technologies that are presented in this paper have been tested and proven over many decades and are all very well referenced world wide. Industry in South Africa now has to comply with stringent environmental legislation. They have the advantage of implementing these technologies without the learning curve that other countries have had to follow over the last few decades.

The main challenge for industry, over and above the financing aspects, is the disposal of generated waste streams. Industry experience shows that companies are wary when they treat one pollution source only to generate another.