7. Appendices

Contents - ◄Previous - Next►

(WHG), section 7a*

A-1 Flow diagram of energetically and environmentally relevant materials in a thermal power plant
A-2 Schematic diagram of a thermal power plant equipped with various flue-gas cleaning systems
A-3 Details of various desulfurization processes
A-4 Immission limits standards as per the German *TA-Luft*
A-5 German laws and regulations governing the limitation of emissions from thermal power plants
A-6 Emission limits for air pollutants from large firing installations (50 MW) in Germany; emission limits for new, large-scale, coal-fired power plants in various countries, plus pertinent EC and World Bank standards; conversion chart for SO_2 and NO_x emissions
A-7 Minimum requirements as per German Federal Water Act (WHG) section 7a Appendix 47: Scrubbing of flue gases from combustion plant, Sept. 8, 1989

Appendix A-1 - Flow diagram of energetically and environmentally relevant

materials in a thermal power plant

Flow diagram of energetically and environmentally relevant materials in a thermal power plant

Appendix A-2 - Schematic diagram of a thermal power plant equipped with various flue-gas cleaning systems

Schematic diagram of a thermal power plant equipped with various flue-gas cleaning systems

Appendix A-3 - Details of various desulfurization processes

In-boiler desulfurization techniques are employed for **solid fuels**, e.g., in fluidized-bed combustion systems. The SO_2 forming in the flue gas combines with lime or limestone injected into the combustion system. Desulfurization therefore takes place simultaneously with fuel combustion at roughly 850C. That relatively low combustion temperature helps limit NOx emissions to 200 - 400 mg/mSTP. The **degree of desulfurization** ranges between 80 % and 90 %. Fluidized-bed combustion systems, which only can be used in new power plants, operate according to either the stationary or the circulating principle, with the latter achieving the lower emission levels under otherwise identical boundary conditions.

Dry additive processes can be applied to **coal-fueled**, grate- and dust-fired boilers. At a temperature below 1000C, a pulverized lime product, e.g., slaked lime, is injected into the flue gas at a point above the combustion chamber, where it reacts with the SO_2 and precipitates. The requisite equipment is retrofittable and can **remove 60 - 80 % of the sulfur** from the flue gas.

The **residual product from fluidized-bed combustion and dry additive processes** - a mixture of coal ash, CaO or other unreacted additive, and various calcium salts ($CdSO_4$, $CaCl_2$, CaF_2) - is separated out in a downstream dust precipitator. In each case, it should be ascertained whether or not the residue can be put to some practical use, perhaps in the building materials industry (usually somewhat problematic due to the mixed salts), or will instead require safe disposal.

There are three basic types of **flue-gas desulfurization** processes:

- wet processes
- spray-dryer processes
- dry processes.

The **wet process** using limestone, lime or slaked lime as the additive and producing gypsum as a reaction product is the most widely employed **commercial-scale alternative**. It has yielded the largest worldwide empirical potential and is used in the majority of facilities. Appropriately processed via drying and pelletizing, for example, the gypsum can be used by the building materials industry, mixed with fly ash and landfilled, or used for land reclamation purposes in coastal areas (cf. section 2.5).

In the **spray-dryer process**, the sorbent (lime or slaked lime) is sprayed as an aqueous solution into an absorber at 60 - 70C. As the water introduced with the suspension evaporates, the additive reacts with any SO_2 present to produce a fine-grained reaction mixture that precipitates out in downstream particulate removal equipment. Consisting of various calcium salts ($CaSO_4$, $CaSO_3$, $CaCl_2$, CaF), excess sorbent and residual fly ash, the reaction product can either be landfilled or used for land reclamation purposes. Potential preteatment requirements for the residue and additional measures for preventing groundwater or coastal-water contamination due to leaching are dealt with in section 2.5.

Other flue-gas desulfurization techniques, most notably **dry processes** using activated charcoal and **regenerative processes** involving sodium sulfite as the sorbent and sulfur dioxide as an intermediate product capable of further processing into sulfuric acid or sulfur, have become widely accepted in some areas and can be used for various other specific situations. As a rule, however, such processes are more elaborate and expensive than the limestone/gypsum techniques, and they impose particularly stringent standards on the quality of the end products, for which a corresponding market, e.g., the chemical industry, is needed.

Assuming otherwise identical constraints, the **quantities of residue** produced derive in descending order from the dry sorbent, spray drying, scrubbing with gypsum, and scrubbing with sulfuric acid or sulfur (cf. section 2.3).

Appendix A-4 - Immission limits as per the German TA-Luft

Pollutant			**IW 1**	**IW 2**
-	Suspended particles	mg/m	0.15	0.30
-	Lead and inorganic lead compounds as components of the suspended particles indicated as Pb	g/m	2.0	-
-	Cadmium and inorganic cadmium compounds and components of the suspended particles indicated as Cd	g/m	0.04	-
-	Hydrochloric acid indicated as Cl	mg/m	0.10	0.20
-	Carbon monoxide	mg/m	10.0	30.0
-	Sulfur dioxide	mg/m	0.14	0.40
-	Nitrogen	mg/m	0.08	0.20

The above table lists the immission limits for the prevention of health hazards as

prescribed by the German TA-Luft, (Technical Instructions on Air Quality Control). The values IW1 and IW2 are the short-term and long-term limits, respectively. In assessing the environmental compatibility of a thermal power plant, its IW2-value (continuous operation), for which *TA-Luft* specifies a monitoring period of one year, is significant.

As protection against substantial detriment and nuisance attributable to particulate precipitation, *TA-Luft* prescribes the following limits referred to as deposition values.

Pollutant		**IW 1**	**IW 2**
Particulate deposition	g/(md)	0.35	0.65
Lead	mg/(md)	0.25	-
Cadmium	g/(md)	5.0	-
Thallium	g/(md)	10.0	-
Fluorine	g/(md)	1.0	3.0

The inorganic compounds in the above table are regarded as particulate constituents, with fluorine HF and the inorganic gaseous fluorine compounds counting as F.

Relatively little information is available on the combined, so-called synergistic, effects of pollution and on the interaction of atmospheric pollutants.

The toxicological effects of the various pollutants are listed in the Compendium of Environmental Standards.

The main effects of the most important pollutants are essentially as follows:

- **Lead inhibits various globular metabolic enzymes in humans and other mammals, causing disruption of the oxygen balance and tidal volume. Sustained intake of less than 1 mg Pb/d has injurious effects. For plants, which take in lead primarily from the soil as opposed to the air, lead is only mildly toxic, the tendency being to lower the quality, but not the quantity, of the produce.**
- **Cadmium, a freely soluble metallic element, is resorbed into the digestive tract and stored in the liver and kidneys of humans and other mammals.**

Like its various compounds, cadmium has carcinogenic properties. In Asia, the so-called Itai-Itai and Aua-Aua syndromes were found to have been caused by Cd-polluted rice. Even low concentrations of cadmium in the soil can cause extensive damage to plants. Plants assimilate cadmium through their roots as well as their leaves and branches. Apart from reducing yields, cadmium contamination is hazardous to human health in that it enters the food chain as a cumulative toxin.

- Carbon monoxide, with its affinity for hemoglobin, the protein pigment responsible for the transport of oxygen, is toxic to humans and other vertebrates. Ingested exclusively by inhalation, carbon monoxide is odorless, colorless, tasteless and otherwise imperceptible to the senses. CO is nontoxic to plants, because it rapidly oxidizes to form CO_2, which plants need for photosynthesis.

- Sulfur dioxide causes corneal clouding, respiratory distress, inflammation of the respiratory tract, irritation of the eyes, disorientation, pulmonary edema, bronchitis and cardiovascular insufficiency in humans and other mammals.

Sulfur dioxide exposure causes both direct damage to the aboveground parts of

plants and indirect damage primarily by way of soil acidification.

- <u>Nitrogen oxides</u> resulting from combustion processes occur in the atmosphere mainly as nitrogen monoxide NO and nitrogen dioxide NO_2. The preferred generic term is nitrous gases (NO_X)

Inhaled by a human or animal, an NO_X gas enters the lungs and irritates the mucous membranes. While NO_2 leads to pulmonary edema, NO affects the central nervous system.

In a photochemical smog situation, nitrogen oxides and hydrocarbons combine to form nitrate compounds that cause irritation of the eyes and mucous membranes.

All nitrous gases are toxic to plants, as evidenced by brown to brownish-black leaf margins and spots. The poisoning process culminates in dry withering of the damaged cells.

Compared to nitrogen monoxide NO, nitrogen dioxide NO_2 is substantially more toxic. For plants and animals, NO_2 is less hazardous than for human beings.

Atmospheric NO oxidizes to NO_2; consequently, NO is prevalent in the near vicinity of combustion plants and is gradually supplanted by NO_2 with increasing distance from the source.

Appendix A-5 - German laws and regulations governing the limitation of emissions from thermal power plants

- Federal Immission Control Act (*Bundes-Immissionsschutzgesetz*) (BImSchG)

Ordinance on Large Firing Installations (*Grofeuerungsanlagenverordnung*) (GFAVO)
Technical Instructions on Air Quality Control (*Technische Anleitung zur Reinhaltung der Luft*) (TA-Luft)
Technical Instructions on Noise Abatement (*Technische Anleitung zum Schutz gegen Lrm*) (TA-Lrm)
Hazardous Incident Ordinance (*Strfallverordnung*)

- Resolution of the Conference of Ministers for the Environment concerning mandatory dynamization of the Ordinance on Large Firing Installations with regard to nitrogen oxide emissions *(Beschlu der Umweltministerkonferenz)* (UMK)

- Federal Water Act (*Wasserhaushaltsgesetz*) (WHG)

General Administrative Framework Regulations on ...
Wastewater (*Rahmen-Abwasser-Verwaltungsvorschrift*),
Annexes 31, 47 to section 7a (AbWVwV)
Provisions governing the handling of substances constituting a hazard to water (section 199) (AbWVwV)

- Ordinance on the industrial sources of wastewater (*Abwasserherkunftsverordnung)* (AbWHerkV)

- Waste Avoidance and Waste Management Act (*Abfallgesetz)* (AbfG)

Technical Instructions on the storage, chemical, physical and biological treatment, incineration and storage of waste requiring particular supervision (TA-Abfall)

Appendix A-6 - Emission limits for air pollutants from large firing

Installations (50 MW) in Germany

		Data stated in mg/mSTP, dry base					
Type of fuel	MW*	Dust	Nox (as NO_2)	SO_x (as SO_2)	CO	HCl	HF
Solid	300 >300	50 50	400 200	2000 (400)1) 400	250 250	200 100	30 15
Liquid	300 >300	50 50	300 150	1700 400	175 175	30 30	5 5
Gas	300 >300	5 5	200 100	35 (100)2)	100 100		

35 (5)3)

*** MW = megawatt thermal output**

1) for fluidized-bed combustion

2) coke oven gas

3) liquid petroleum gas

Appendix A-6 - SO_2 and NOx Emissions

Conversion Chart

To convert	To: (Multiply by) (ρ)							
From	mg/	ppm	ppm	g/GJ			lb/106 Btu	
	m	NO_x	SO_2	CoalA	ilOilB	GasC	CoalA	OilB
mg/m	1	0.487	0.350	0.350	0.280	0.270	8.14 x 10-4	6.51 x 10-

ppm NO_x		2.05	1		0.718	0.575	0.554	1.67 x 10-3	1.34 x 10-
ppm SO_2		2.86		1	1.00	0.801	0.771	2.33 x 10-3	1.86 x 10-
	CoalA	2.86	1.39	1.00	1			2.33 x 10-3	
g/GJ	OilB	3.57	1.74	1.25		1			2.33 x 10-
	GasC	3.70	1.80	1.30			1		
	CoalA	1230	598	430	430			1	
lb/106 Btu	OilB	1540	748	538		430			1
	GasC	1590	775	557			430		

A:- Coal:- Flue Gas dry 6 % excess O_2: Assumes 350 Nm/GJ - ref IEA Paper 1986.

B:- Oil :- Flue Gas dry 3 % excess O_2: Assumes 280 Nm/GJ - ref IEA Paper 1986.

C:- Gas :- Flue Gas dry 3 % excess O_2: Assumes 270 Nm/GJ - ref IEA Paper 1986.

Appendix A-6 - Emission limits for new, large-scale, coal-fired power plants in various countries, plus pertinent EC and World Bank standards

Appendix A-6 **Emission limits for new, large-scale, coal-fired power plants in various countries, plus pertinent EC and World Bank Standards**

Country	SO_2 emissions [mg/m]	Size of plant	NO_x emissions [mg/m]	Size of plant	CO emissions [mg/m]	Size of plant	D e [r
EC	400	> 500 MWt	650	> 50 MWt			5
World Bank	500 t/d or 50 g/m additional immission over slight prior SO_2 burden (50 g/m) 100 t/d or 10 g/m additional immission over high prior SO_2		858 (780 for lignite)				1 (1 w g p

	burden (> 100 g/m)						
Australia	200		800	> 30 MWt	1000		8
Austria	80 % (sep. efficiency)	> 200 MWt	800	> 50 MWt	250	> 2 MWt	5
Belgium	400	> 300 MWt	200	> 100 MWt			5
Canada	740		740				1
Denmark	860	> 50 MWt	1150	> 50 MWt			5
Finland	140	> 150 MWt	200	> 300 MWt			5
France	1700 - 3400	(regional)					1
Germany	400	> 300 MWt	200	> 300 MWt	250	> 50 MWt	5
Great Britain	90 % (sep. efficiency)	> 700 MWt	760	> 700 MWt			9

India	height of stack > 500 MWt : 275 m > 200 < 500 MWt : 200 m < 200 MWt : (equation)		no limits				1 (M a
Italy	400	> 100 MWt	650	> 100 MWt			5
Japan	plant-specific		411	> 70000 m/h			5
New Zealand							1
Netherlands	400	> 300 MWt	400	> 300 MWt			5
Spain	2400						2
Sweden	290		430				3
USA	740	> 29 MWt	740	> 29 MWt			3
/.../ The minimum size of plant to which the relevant limit applies is stated in MWt;							

the volumetric flue-gas flow is stated in mSTP/h

Appendix A-7 - Minimum requirements as per German Federal water act (WHG*), section 7a

Appendix 47: Scrubbing of flue gases from combustion plant, Sept. 8, 1989

	COD	Filterable substances 4)	Fluoride	Sulfate	Sulfite	Lead	Cadmium	Chromium
Accepted engineering practice					State of the art			
General	80 5)	30	30	20000	20	0.1	0.05	0.5
	150 6)							
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Hard-coal								
power						3.8	1.8	18

plants (pollutant concentr., mg/kg chloride)	see above					mg/kg	mg/kg	mg/kg
Lignite power plants with chloride contents up to 0.05 weight % (pollutant concentr., g/h)7)	see above					0.2 g/h	0.1 g/h	1 g/h

*** WHG = *Wasserhaushaltsgesetz***

4) via quicklime
5) via limestone
6) pollutant concentration in g/h per 300 MW installed electrical output
7) after subtraction of the prior COD pollutant concentration introduced with the service water

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

42. Power transmission and distribution

Contents - Previous - Next

Contents

1. Scope

Adequate power supply systems constitute an essential part of any country's technical infrastructure. Such systems comprise facilities for the generation,

transmission and distribution of electricity.

This brief deals with the planning, construction and operation of all technical facilities required for transmitting and distributing electric power.

Transmission is understood as the conveyance of electrical energy from its place of generation to its place of use. Power transmission is characterized by the conveyance of electric power over comparatively long distances with the aid of high-voltage and medium-voltage systems. Depending on the relative locations of the power generating facilities and the power consumers, many different forms of landscape and vegetation can be affected.

Distribution is understood as the delivery of electric power from the bulk power source to the consumer. As a rule, this involves relatively short distances within populated areas by way of medium-voltage and low-voltage systems.

The technical facilities required for transmitting and distributing electric power comprise mainly:

- **overhead power lines**

- **cables**
- **transformer and switching stations.**

2. Environmental impacts and protective measures

Direct effects on the environment result from the erection and operation of such facilities, with the extent and intensity of the impacts depending substantially on the physical circumstances and the project planning.

This section describes and illuminates the direct and indirect effects of power transmitting equipment on the natural environment, i.e.:

- **resources (water, soil, air) and**
- **ecological systems (flora and fauna, interlinked biotopes)**

as well as on humans, i.e.:

- **their health and safety, occupational and otherwise,**

- **their socioeconomic and sociocultural circumstances, as well as**
- **their visual perceptions.**

2.1 Consequences for the natural environment

Soil, water and air

In wooded areas, the erection and safe operation of overhead power lines necessitate the maintenance of unobstructed lanes, the widths of which vary between 25 and 100 meters, depending on the size of the transmission line. Paved or unpaved access roads may be needed for installing and inspecting the lines and towers. That, in turn, entails the permanent destruction of forest; due to the loss of its original vegetation, the disturbed soil is at least temporarily unprotected and exposed to the climatic effects of heat, frost and rain, all of which promote erosion. Soil compaction resulting from project-site motor vehicle traffic intensifies the soil's susceptibility to erosion. Afterward, the affected area is only conditionally suitable for other forms of utilization. Any strip of land that cannot be used for forestry purposes due to its being located along a right of way (danger of grounding) should be greenbelted in order to combat erosion. The use of space-saving components helps reduce the space requirement quite substantially.

The erection of towers and tower footings on steep slopes demands detailed knowledge of the subsoil situation. Any mistake made in planning and executing the work can seriously impair the stability of the slope and lead to slip erosion.

The construction of switching and transforming stations permanently occupies certain areas and jeopardizes the soil and groundwater through the potential leakage of coolants and insulants (mineral oil or other liquids possibly containing toxic polychlorinated biphenyls - PCB) in large quantities from such components as transformers, capacitors, ground-fault neutralizers and underground cables.

Suitable collecting troughs/separators must be provided to prevent contamination of the groundwater and soil.

Flora and fauna

Due to the machines involved, the erection phase of power transmission lines and switch plant imposes stress on - and causes potentially permanent damage to - the surrounding flora and fauna.

The clearing of lanes in wooded areas modifies the microclimate by admitting more

insolation and wind, thus altering the temperature distribution. Such changes can disrupt the local ecosystem.

Depending on the attitude of the transmission route, such lanes can seriously enhance the windslash incidence in the adjacent woods.

Frequently, fire and herbicides are used to create lanes and keep them clear of vegetation. Since such practices are very damaging to both flora and fauna, they should be dispensed with to the greatest possible extent.

Due consideration should also be given to the danger of dissecting biotopes into small "islands" that are not likely to survive beyond the medium term.

Overhead power lines are a fourfold hazard for birds:

- **they debase breeding grounds;**
- **birds (particularly night-flying species) can fly into the wires;**
- **birds can be killed by simultaneously contacting two wires or a wire and the tower (medium-voltage lines);**
- **the "magnetic compass" effect can interfere with their navigating system.**

In Germany, the populations of several species of large birds have been substantially decimated; some 70 % of all white storks are lost to electrocution.

In extremely rare cases, a short circuit or other defect in a transformer or switchgear has been known to cause a fire with resultant destruction of the surrounding flora and fauna.

The roads and lanes established to enable the erection and maintenance of overhead power lines can have the same environmental consequences as other traffic routes, in particular opening-up effects (cf. environmental briefs Transport and Traffic Planning, Road Building).

Minimization and avoidance measures

The aforementioned impacts can be minimized or avoided by heeding the following points in connection with the planning and erection of overhead power lines:

- **consider possible alternatives to new construction, e.g., conversion or more efficient/multiple utilization of existing lines;**
- **adjoin overhead lines to existing traffic routes and pipelines;**

– adapt the right of way to existing landscape structures, i.e., avoid such exposed locations as hilltops and domes, ridges, razorbacks, etc.;

– significantly reduce the consumption of landscape and forest by installing high towers to permit greater spans between towers, thus traversing larger areas;

– avoid nature preserves and other protected areas, biologically and/or ecologically significant regions and recreation areas;

– use insulation sleeving, shrouding covers, perching and nesting platforms on towers for MV and LV lines as protection for birds;

– allow for the future installation of additional lines, i.e., for multiple use of the transmission route (multiple-circuit lines);

– significantly reduce space requirements by choosing suitable tower types (latticed steel, steel-pipe/concrete/wood) and configurations (size and arrangement of line-supporting cross-arms) and by using trefoil insulated LV and MV conductors;

– reduce the ground-area-requirement by using cables instead of overhead lines, even though the cable route also has to be kept free of tree growth (The use of cables can be problematic, however, for economic and technical reasons attributable to the high cost of investment and the need for highly qualified maintenance personnel.);

– minimize the danger of soil and groundwater pollution by performing routine safety inspections of pole impregnating facilities and by either replacing tar-base impregnants with more environmentally appropriate (salt-base) agents or opting for vacuum- or high-pressure impregnated wood;

– prevent soil erosion by mulching and greenbelting to cover all exposed ground. In climate zones with rainy seasons, this should be done at the beginning of the rainy season in order to prevent sheet erosion;

– modify and strengthen existing lines to save energy and additional cables;

– restock working areas under forest-traversing spans.

2.2 Human health, occupational safety and accident prevention

Accidents

The primary cause of accidents imperiling human life and limb (electrocution, serious burns) is inadvertent contact with live components, possibly in inadequately protected facilities, and the secondary cause is fire resulting from short circuits.

The danger of accidents is most acute when:

- **technical specifications relevant to safety measures are disregarded in the planning and erection of plant and equipment (use of low-quality components, inadequate sizing, negligent execution, nonobservance of safety clearances), so that the finished facilities are inherently unsafe;**
- **the operating personnel has not received sufficient training in connection with safety measures and their observance;**
- **the local populace has not been properly educated with regard to electrical hazards, which can lead to such misbehavior as climbing up on towers, trespassing on switching stations, lack of lightning conductors, illegal tapping of electricity, etc.**

In the past, and to a certain extent even today, the use of polychlorinated biphenyls (PCB, askarel/chlophen) as flame-retarding dielectric liquids in transformers and capacitors has constituted a health hazard in its own right. PCBs are very toxic. They accumulate in the food chain, cause chronic disorders and are carcinogenic. Moreover, their incineration (due to, say, exposure to an accidental fire) produces highly toxic dioxins and furans.

With but few exceptions (e.g., for electric plants in underground mines), the use of PCB in electrical plants is now generally prohibited in many countries.

Tar-base impregnants for wooden poles constitute a health hazard in that they can cause skin ailments.

Such risks can be substantially reduced or even completely avoided by:

- **choosing plant components of the proper type and size,**
- **precluding unauthorized access to electrical plant and installing anti-climbing guards on high-voltage towers,**
- **reducing the danger of fire by using noncombustible dielectric liquids or dry transformers and refractory partitions,**
- **avoiding the use of dielectric liquids containing PCBs and of coolants in new installations; ensuring proper disposal and replacement of old transformers and the like,**
- **providing the operating personnel with appropriate safety clothing and suitable tools and test instruments,**
- **ensuring that the operating personnel receives the proper, duly qualified training,**

– educating the local populace about the dangers of electrical installations.

Effects of electric and magnetic fields on human health

According to information derived from prolonged observations and experiments in numerous countries, the electric and magnetic fields around power transmission and distribution facilities (exhibiting frequencies between 50 and 60 Hz) have no harmful effects on human health.

According to a WHO publication dealing with the effects of magnetic fields on human health, field strengths below 0.4 mT at 50 - 60 Hz induce no detectable biological reaction. The magnetic fields acting on the ground below overhead lines develop a maximum field strength of 0.055 mT for the above frequencies.

Noise nuisance

Substation and distribution-system transformers generate a monotonous buzzing sound that can be annoying in residential areas. The use of quiet-running transformers and/or appropriate structural measures (incl. adequate distances) can avoid such problems.

2.3 Optical impairment of the landscape

Overhead power lines amount to an optical disturbance. The extent of disturbance depends on:

- **the size, type and general configuration of the lines and towers,**
- **the concentration of overhead lines within a given area,**
- **the transmission route and/or visibility of the lines, i.e., how well the right of way has been accommodated to the landscape (color, "low profile"),**
- **the location (undeveloped/developed land, population density, industrial/residential areas, etc.).**

The recreational value of landscapes and affected areas is diminished by the optical impairment.

The aforementioned preventive measures apply in equal measure to the avoidance of optical impairment.

2.4 Socioeconomic and sociocultural impacts

Any direct consequences the installation and operation of power transmission and distribution facilities may have on the socioeconomic and sociocultural environment are of minor significance. Radio and television reception, for example, can be substantially disturbed by corona discharges [luminous discharge along undersized and/or improperly arranged conductors (bundle-conductor lines)].

Indirect consequences derive from the purpose of such facilities, namely to improve living conditions by supplying electricity to a region or center. Access to electricity increases comfort and convenience in private life (e.g., time saved and work facilitated) and in the public domain. In combination with other technical infrastructural measures, it can initiate or stimulate economic activities aimed at creating new jobs (i.e., reducing unemployment) or rationalizing production processes6).

6) The negative environmental effects of power generation can be aggravated by excessive demand resulting from artificially low (submarginal) supply tariffs.

On the other hand, past experience has shown that electrification and other forms of regional development can lead to a loss of traditional ways of life, modes of

behavior, cultural peculiarities and sociocultural ties and structures. Moreover, it can have a whirlpool effect on neighboring regions, giving rise to emigration and new congested areas.

3. Notes on the analysis and evaluation of environmental impacts and on occupational safety standards

Numerous different authorities, associations, public and private bodies both corporate and individual must be involved in defining the rights of way and the locations of substations. The process must include appropriate consideration of environmental interests.

Suitable structural measures (e.g., to prevent erosion) and technical measures (e.g., to prevent the escape of transformer oil) must be taken to avoid pollution of the soil and/or water.

Optical impairment of the landscape is unavoidable but should be minimized. The extent of impairment depends both on how the land is used (work - recreation) and

on its optical complexity. The right of way can be visually assessed with the aid of a computer.

Detriment to flora and fauna must be appraised with a view to the protection of endangered species and in consideration of local, national and international standards and regulations. Determination of the local and regional significance of biotopes must be based on a large-scale survey in which suitable measures for the protection of birds are included.

Internationally recognized and harmonized, detailed standards on safety clearances, protective measures against contact with and entry to, in addition to working on, live systems [e.g., the German Standards DIN 0800, DIN 0848, DIN 57106, Association of German Electrical Engineers' *VDE* guideline 0106, accident prevention provisions and implementing instructions for electrical equipment and operating equipment issued by the Verband gewerblicher Berufsgenossenschaften ("Elektrische Anlagen und Betriebsmittel" - VBG 4)] should be consulted in connection with the planning of power transmission and distribution facilities.

The use of PCB in closed systems (transformers, capacitors, etc.) has been prohibited in the EC since 1985, although the continued operation of existing PCB-filled

equipment is permitted for the duration of its service life. In the interest of environmental protection, however, such equipment should be replaced and properly disposed of (sodium-base dechlorination of the oil). Its incineration would produce dioxins!

4. Interaction with other sectors

The planning and installation of power transmission and distribution systems depend on decisions deriving from higher-level (national, regional) planning processes devoted to regional development, general energy development, town and country planning, general power supply measures, etc. (cf. corresponding environmental briefs).

There is a direct connection to the power generating sector (cf. environmental brief Thermal Power Stations). As soon as power transmission is correlated to a particular power source, the environmental impacts of the latter, i.e., of power generation, demand consideration; high transmission losses also have environmental consequences in that they necessitate the generation of additional power.

The rights of way for transmission lines are extensively determined by the relative locations of the power plant and the power consumers. Particularly valuable biotopes and landscapes must be protected by routing such rights of way around them.

Coordination with existing or still-to-be-installed technical infrastructure (roads, railways, waterways, other supply lines, etc.) is not only possible but even necessary for, say, crossing airports, waterways, roads, etc. and for the parallel routing of power transmission and telecommunication lines - all in order to ensure the safe, reliable operation of all facilities concerned.

With regard to the reprocessing and disposal of transformer oil (with or without PCB content), please refer to the environmental brief Disposal of Hazardous Waste.

5. Summary assessment of environmental relevance

The aforementioned environmental impacts and their consequences are evaluated below, and potential means of minimization and avoidance are proposed.

Landscape consumption in the form of pressure on natural resources (soil, vegetation) and destruction of landscape is generally unavoidable, though adequate attention to environmental concerns at the planning stage can at least diminish its consequences.

Appropriate structural measures can be adopted to reduce, but not eliminate, the hazard for birds posed by overhead power lines.

The danger of accidents for humans emanating from transmission and distribution installations can be reduced by strict adherence to existing, recognized rules, regulations and standards. Relevant training and sensitization are crucial in this area.

The emissions (noise, corona conduction) of power transmission and distribution installations can be reduced to negligible levels by appropriate technical means. The use of liquids containing PCBs in transformer substations still constitutes a substantial hazard potential in that such liquids are liable to escape to the environment as a result of equipment malfunction or accident (leakage, fire). Consequently, the use of components and equipment containing PCBs should be globally prohibited, and existing equipment should be replaced.

Compared to other means of energy conveyance (road, rail, water, pipeline) the transmission of electricity involves a modest, though by no means negligible, risk. Whenever new facilities for transmitting and distributing electric power are deemed absolutely necessary (e.g., if there is no possibility of opting for noncentralized power generation), appropriate low-impact approaches should be sought out.

The easiest and most effective way to minimize or completely avoid harmful environmental impacts is to conscientiously allow for environmental concerns from the planning stage on.

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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43. Renewable sources of energy

Contents - Previous - Next

Contents

2.2.1 Burning

2.2.2 Gasification

2.2.3 Biogas

2.2.4 Biofuels

2.3 Wind energy

2.4 Hydropower

2.5 Geothermal energy

3. Notes on the analysis and evaluation of environmental impacts

4. Interaction with other sectors

5. Summary assessment of environmental relevance

6. References

1. Scope

In addition to finite deposits of fossil and mineral fuels such as oil, gas, coal and uranium, the earth also offers various natural, auto-regenerative - or renewable - sources of energy that derive from sun insolation, geothermal activity and gravitational forces.

Theoretically, the global supply of energy from such renewable sources by far exceeds the earth's present total energy demand. The supply of energy is subject in part to pronounced technical and economic utility limitations, e.g., the disparity between the temporal/spatial demand for energy and the actually available supply of renewable energies, and the latter's modest power density compared to conventional energy vehicles.

The main renewable energy (RE) sources are:

1. Insolation, i.e., the direct radiant energy of the sun (made useful by collectors, solar cells, etc.)

2. Energy obtained from biomass; biochemical energy of photosynthetic products; made useful by

- **burning (of wood, straw, etc.)**
- **gasification (of wood, etc.)**
- **anaerobic digestion (= biogas)**
- **alcoholic fermentation**

3. The kinetic energy of wind

4. The kinetic energy of moving water:

- **low-pressure systems**
- **high-pressure systems**
- **micro-hydropower plants**
- **tides, waves, ocean currents**

5. Miscellaneous

- **geothermal energy**
- **thermal energy deriving from differences in seawater temperature**
- **osmotic energy deriving from concentration gradients between saltwater and freshwater.**

With a view to the proper and adequate sizing and, hence, limitation of the environmental consequences of renewable energy systems, the energy consumers' options for the conservation and rational use of energy should always be given full consideration, whereas boundary conditions in the form of prices, tariffs, etc. are major factors.

The environmental impacts resulting from utilization of the following renewable sources of energy are dealt with in this brief:

- **solar energy (heat and photovoltaics)**
- **energy from biomass**
- **wind energy**
- **hydropower**
- **geothermal energy.**

To the extent deemed relevant, other renewable sources of energy are dealt with in other briefs.

With regard to the general environmental consequences of energy systems and to the supradisciplinary aspects to be considered in connection with the planning of

energy policy and energy economics projects, the reader is referred to the environmental brief Overall Energy Planning.

2. Environmental impacts and protective measures

The utilization of energy, no matter what the source, is bound to have certain environmental consequences (land consumption, pollution, ...) that need to be identified and evaluated, preferably in advance.

2.1 Solar energy

The use of solar energy via collectors or photovoltaic systems places no immediate material burden on the environment. However, the collector system can be expected to contain a heat transfer medium (fluid), the escape of which could result in pollution. The acceptable media include such readily degradable substances as propylene glycols. Noxious additives serving as preservatives should be replaced by less harmful alternatives (carboxylic acid).

The use of solar cookers involves the danger of blinding, and solar energy collected by solar cells and stored in batteries demands proper handling and appropriate disposal of the spent batteries. The materials used for the battery case, as well as the hydrochloric acid and lead contents, can be recycled in suitable facilities.

Land consumption for small-scale systems can be avoided by installing them on roofs and facades. Well-considered integration can prevent optical/aesthetic impairment, and annoying reflections can be diminished by lumenizing and/or delustering.

With the exception of reduced reflections, no such measures can be applied to large-area systems. Consequently, optical/aesthetic expectations may stand in conflict with other natural surface potentials (soils for agricultural production, protection of species and biotopes; unless, of course, the site in question is located in the desert).

Depending on the local situation, the shading and altered albedo resulting from large-scale installations can affect the flora, fauna and microclimate (evaporation rates, airflow, temperature).

Solar cells and various collectors have a substantial space requirement relative to the amount of energy produced (per 100 MW: ~ 1 km for solar cells and ~ 3 km for solar-thermal power plants, compared to ~ 0.4 km for hard-coal power plants).

Additional environmental impacts derive from the manufacture of materials used in the production of collectors and solar cells. Steel, copper and aluminum, all of which are used frequently, cause environmental problems in the form of emissions, i.e., particulates, fluorine compounds, solid and liquid waste and high levels of energy consumption, particularly for aluminum.

Some rare and toxic metals such as cadmium, arsenic, selenium and gallium used in solar cells are mildly pollutive at the processing stage (wastewater, exhaust gases). These substances are characterized by high chemical stability, and the environmental risk remains confined to the production site. Thus, adequate monitoring and safety measures can minimize the risk; cf. environmental brief Non-ferrous Metals.

2.2 Biomass energy

Used as a substitute for metal, cement, plastic and diverse other raw materials,

biomass can help reduce the energy expenditures for processing and manufacturing such materials.

In the present context, however, our interest in biomass is limited to its being a source of energy.

Significant utilization of biomass presupposes that the biomass cycle of growth and extraction remains essentially intact, i.e., that the biomass source (a forest, perhaps), is always allowed to adequately regenerate.

2.2.1 Burning

The burning of biomass (wood, straw, dung, etc.) liberates pollutants -

- **from the fuel and the combustion air**
- **or which form as a result of incomplete combustion [CO, tar, soot and hydrocarbons, including carcinogenic polycyclic aromatic hydrocarbons (PAH)].**

The main cause of emission problems with biomass is incomplete combustion. The

following measures can help achieve complete combustion:

Combustion plant

- sufficiently large incinerator
- sufficiently hot combustion chamber

Those conditions are inherently satisfied by systems equipped with prefiring chambers or for bottom firing.

Fuel conditions

- use of dry fuel (< 20 % wood moisture).

Mode of operation

- full-load operation
- uniform fuel supply.

The exhaust gases, particularly in the case of straw, contain large amounts of solid particulates; large-scale systems therefore should include appropriate cyclone

separators or filters.

On a country-specific basis, biomass can cover as much as 90 % of the overall demand for energy. As a rule, wood, dung and straw are burned in open fires from which the aforementioned pollutants escape and can be inhaled by the users (primarily women and children).

This can amount to a formidable health hazard, particularly because of the carcinogenicity of polycyclic hydrocarbons. In addition, respiratory ailments can also result from such exposure.

The use of stoves with some form of chimney substantially reduces the indoor smoke nuisance and improves the combustion efficiency, thereby reducing fuel consumption and, hence, emission levels.

The use of straw and dung as fuel can lead to conflicts concerning agricultural production and the sustenance of soil fertility due to loss of nitrogen and reduced humification, because what has been burned cannot be returned to the soil. In some climate zones, using the ashes as fertilizer can cause a dust-evolution problem.

From an ecological standpoint, the use of scrap wood and various forms of wood residue calls for a somewhat sophisticated frame of reference: while tending felling can be both ecologically compatible and advisable, the safe extent of wood removal from forests and plantations depends on the climate, the soil conditions and the vegetation. The removal of wood residue impacts the nutrient cycle, humification, microflora and microfauna. This applies as well to large-scale stump-grubbing, which also makes the ground more susceptible to erosion.

Long-term natural wood production does not satisfy the "firewood criteria" of easy, short-term availability. Agroforestry projects involving certain harmonized plant species in certain spatial arrangements designed to make the individual species and combinations serve different functions (shading, soil amelioration, shelterbelting, improvement of water regimen, mulching, fuel, food/fodder, starting material), are able to more quickly satisfy fuel requirements by reason of brief rotation periods. Such - noncentralized - configurations facilitate the gathering of wood while abating environmental burdens in connection with road transport and helping to bridge over fuel shortages.

Intensive (energy farming) techniques based on fast-growing combustibles treated with high doses of pesticides and fertilizers can pollute, i.e., eutrophize, surface

waters due to nutrient loading, possibly in combination with erosion, a loss of diversity, and health hazards emanating from residual pesticides. The use of machines on sensitive ground (marginal soils) can induce erosion; cf. environmental brief Forestry.

Large-scale felling of trees (= land clearing) affects the water economy and microclimate, is harmful to flora and fauna, and can cause erosion, the extent of which depends on the type of soil, the climate and the angle of slope.

If cleared land is not appropriately reafforested, or if the soil is overused for a prolonged period, both the soil and the water regimen may sustain irreversible damage.

Any attempt to substantially expand fuelwood production without integrating the effort into the general agricultural scheme can generate conflicts over space requirements for food production; cf. corresponding environmental briefs on agriculture, such as Plant Production, Forestry etc.

2.2.2 Gasification

As a rule, any gas extracted from biomass by such means as pyrolysis is used as fuel, either for heating purposes or for driving gas-fueled power generators.

While the environmental effects of fuel extraction from biomass are dealt with in section 2.2.1, additional ecological impacts can derive from:

- **carburetion (accidents, deflagration);**
- **the gas itself (accidents, fire, poisoning due to leaks);**
- **wastewater from gas scrubbing;**
- **carbonization residue (ash, tar);**
- **combustion emissions (exhaust, cooling water, lubricant).**

Generator gas obtained from large plants (as opposed to small wood gasifiers, e.g., for tractors) should be cleaned and dedusted prior to use. The wastewater from gas scrubbing can be expected to contain ammonia, phenols, perhaps even cyanides and potentially carcinogenic polycyclic aromatic hydrocarbons (PAH). Consequently, they cannot be disposed of freely. To the extent possible, the incidental tars and oils should be returned to the gasification process. In addition to the mechanical extraction of solids, e.g., in a settling basin, the effluent can be put through a biological clarifying plant in which phenols are digested by suitable strains of

bacteria.

Solid residue from the gasification process is usually heavily polluted and therefore problematic with regard to its disposal. The harmful-substance contents require case-by-case determination, because they vary according to the raw material in question and the process employed.

The exhaust from generator gas combustion may also require treatment, depending on the quantity involved and its pollutive load. It is likely to contain oxides of nitrogen, PAH's, carbon monoxide or soot (plus negligible amounts of sulfur dioxide). The NOx and hydrocarbon contents can be extensively decomposed with the aid of catalytic converters.

2.2.3 Biogas

Biogas resulting from anaerobic bacterial fermentation of biomass consists primarily of methane (principal component), carbon dioxide, carbon monoxide and small amounts of hydrogen sulfide. Small biogas plants provide fuel for cooking, lighting, etc., while large-scale facilities can produce enough biogas for fueling gas motors.

Accidents can occur when a slurry pit or a fixed-dome digester has to be entered for cleaning (danger of asphyxiation).

Since hydrogen sulfide has toxic effects of humans, corrodes materials, and forms sulfur dioxide in the combustion process, its removal should be given due consideration. However, the precleaning process is rather complicated and generates end products with a pollutive potential. The chemicals used for cleaning biogas (e.g., iron oxide), as well as their reaction products (mixture of iron oxide and sulfur) demand proper storage, use and subsequent disposal.

Whereas biogas often requires interim storage, appropriate pertinent safety standards must be heeded (danger of poisoning, fire, explosion); cf. environmental brief Petroleum and Natural Gas.

The raw material may contain toxic heavy metals that are prejudicial to health. While such constituents (deriving from polluted soil) remain unaffected by the digestion process they nevertheless should be monitored (tested for). And while the digestion process does not kill off all pathogens and worm ova, the digested sludge nonetheless counts as safe and benign from the standpoint of epidemic control. Used improperly, its high nitrogen content can emburden both surface water and

groundwater. Thus, the use of biosludge as a fertilizer must be properly timed (availability for plants), effected with suitable equipment, and applied in accordance with the soil's nutrient reserves.

Considering methane's relevance as a greenhouse gas, its collection and combustion is ecologically advantageous as long as it is being generated by anaerobic digestive processes.

2.2.4 Biofuels

Various technical processes are available for deriving oil and alcohol from biomass and using them as substitutes for conventional fuels.

The cultivation of biomass as a raw material for obtaining fuel by alcoholic fermentation (e.g., of sugar cane) or by extracting oil from soybeans stands in direct competition with foodstuff farming. Large monocultures involving high levels of fertilization and pesticide spraying have environmental impacts of the kind discussed in section 2.2.1; cf. environmental brief Plant Protection.

The following environmental loads result from the production of ethanol and oil:

– exhaust gases deriving from the provision of process energy (e.g., distillation, burning or refining of crude oil) - cf. section 2.2.1;
– carbon dioxide as a product of fermentation;
– nontoxic but very pollutive organic sludge and wastewater (slops) from ethanol production, all containing large amounts of nitrogen-phosphorus and potassium components.

The slops, or distiller's wash, can serve as a fertilizer or fodder additive. If it contains enough residual sugar or starch, it is suitable for fermentation, i.e., biodigestion.

The biogas yield can serve as a substitute for part of the conventional process energy, while the organic substances remaining in the effluent must be decomposed in a clarifying plant.

The production of alcohol is very energy-intensive.

The use of ethyl alcohol (ethanol) as a fuel additive in internal-combustion engines produces relatively low pollution in the form of NOx, CO, soot and simple hydrocarbons, but is accompanied by certain aldehydes, some of which are carcinogenic.

Motors fueled by alcohol alone should be specially tuned and optimized in order to minimize harmful emissions. Catalytic converters, for example, reduce the aldehyde emission levels to that of gasoline engines. Compared to gasoline/petrol, ethyl alcohol contains practically no carcinogenic polycyclic hydrocarbons.

Like alcohol, biomass-base oil for diesel engines gives off no sulfur or lead but some amounts of soot, simple hydrocarbons and particulate emissions. Soot filters are conditionally suitable for cleaning the exhaust gases.

2.3 Wind energy

Even large wind power plants have modest environmental impacts. Their material and space requirements are also relatively modest. The manufacture of some steel and plastic components, however, does involve certain environmental problems.

The following substantial environmental problems arise in connection with their operation:

- **noise;**
- **landscape impairment;**

- **danger of accidents due to rotor-blade detachment;**
- **electromagnetic interference;**
- **negative effects on fauna, birds in particular.**

How much noise is produced depends on how fast the propellor is rotating. The faster the speed of rotation, the louder the noise.

Old aerogenerators have been known to produce sound intensities on the order of 130 dB(A). Small wind generators tend to make more "wind" noise than running noise. New facilities have aerodynamically optimized blades and encapsulated generators-cum-transmissions that minimize the noise nuisance. Nevertheless, a minimum distance of roughly 100 meters should be maintained between wind generators and residential areas. There is, of course, always the possibility that the safe clearances designated at the planning stage will eventually be transgressed by uncontrolled settlement (squatting).

Impairment of the landscape is unavoidable. The degree of impairment depends on local circumstances, including the intensity of wind-power utilization. Wind parks do more to impair the landscape than individual plants. Especially large aerogenerators with metal motors tend to disrupt natural electromagnetic fields and interfere with

radio reception. Modern wind power plants have fiberglass rotor blades and therefore cause no such interference.

The danger of accidents attributable to rotor-blade detachment can be minimized, if not precluded, by routine inspections and maintenance, plus adherence to the appropriate safety clearances.

2.4 Hydropower

Hydropower is the by far the most important renewable source of energy. The incidental reservoirs often serve other, additional purposes such as irrigation and the supply of drinking water.

The harnessing of hydropower entails substantial intervention in the environment (land consumption, altered hydrological regimen, etc.). Due to the importance of hydraulic engineering with respect to the environment, and with deference to the vast experience that has been accumulated in connection with such facilities, a separate brief has been devoted to that sector.

2.5 Geothermal energy

Geothermal sources of energy include:

- **warm and hot water in deep-reaching joint systems of crystalline rock formations or deep-lying groundwater stories within expansive sedimentary basins,**
- **hot-water and steam occurring deep within structurally disturbed zones or in regions marked by current or recent volcanic activity,**
- **exploitation of geothermal energy according to the dry hot rock process (DHR technology presently under development).**

DHR technology aims to establish artificial heat-exchange surfaces in hot rock (with temperatures > 200C) from which geothermal energy can then be extracted by pumping water into and back out of the artificial hot-rock joint system. Despite substantial research funding to date, however, the method's economic feasibility has not yet been established.

The environmental impacts of exploiting geothermal energy depend on the concrete situation. Environmental burdens can result from entrained pollutants (various salts, sulfur compounds, arsenic, boron) and gases in the geothermal fluids. In modern geothermal facilities the spent (cooled-down) fluids and their entrained

pollutants are pumped back into the ground, preferably to a point below the pay zone of the occurrence, while the incidental gases are released to the atmosphere.

The extraction of geothermal fluids, particularly in dry-climate regions, can negatively influence near-surface groundwater stories and, hence, their utilization (potable water, irrigation) by causing the groundwater table to recede (phreatic decline).

Sustained use of a particular geothermal reservoir can lead to gradual and extensive subsidence and frequent consequential damage to railroads, highways, power transmission lines and, particularly, the pipelines through which the geothermal fluids are pumped from the wells to the power plant/user. The local hydrological situation can be substantially influenced and modified by attendant phenomena such as the diversion of streams and rivers or even the formation of lakes in ground depressions.

The space requirements of geothermal installations (wells, pipelines) are quite modest - so much so that such facilities hardly interfere with agricultural utilization of the surrounding land.

The drilling of wells in a geothermal field is somewhat hazardous in that unforeseen eruptions of steam can occur without notice and then take weeks or even months to get under control. In the meantime, the environment may have become substantially contaminated by impurities in the steam.

3. Notes on the analysis and evaluation of environmental impacts

The main environmental consequences of renewable energy systems are the consumption of land area and the loss of plant and animal species and biotopes. Biomass utilization also involves solid waste, wastewater and air pollution.

The environmental consequences of renewable energy systems can be limited in quantity, but normally require qualitative analysis with due regard for avoidance effects (e.g., CO_2 emissions) in comparison with nonrenewable energy sources. To evaluate the environmental impacts of any such system, one must begin with an analysis of the biotic (flora and fauna) and abiotic (water, soil, air) ecological factors. For the biotic domain, mapping and charting activities are necessary. For the abiotic range, water, air and soil samples should be analyzed according to standard

techniques such as those described in DIN/EN and ISO standards, NIOSH standards, guidelines of the Association of German Engineers VDI, WHO recommendations, etc.).

The evaluation of environmental consequences is a deficitary matter in that, for example, no limit values can be quoted for the loss of animal species, biotopes, etc. Nor do any generally recognized standards of evaluation exist - quantitative or otherwise - for landscape impairment. The criteria need not always be as unequivocally quantifiable as "rarity" (e.g., as defined by international conventions within the pollutants' sphere of influence); it is also difficult to attach a particular value to consumed land area with allowance for alternative uses. For the abiotic domain, though, certain limit values and recommendations can be enlisted in connection with various types of pollution (wastewater, exhaust, noise).

To the extent available, effect-specific reference/limit values should be consulted for evaluating immissions (airborne pollutants, noise, ...) as a means of anticipating the sensitivity (reaction) of existing and planned forms of utilization (housing, farming) to the projected impairment.

For all forms of renewable energy utilization, the importance of immissions and

pollutant levels increases along with the size of the project.

In connection with the extraction of energy from biomass, any solid substances that are re-utilized instead of being treated as waste count as a positive effect that must be given due consideration.

4. Interaction with other sectors

If a planned renewable energy system will involve material emissions, the local prior load must be determined in advance of the project's implementation (e.g., condition of recipient water in conjunction with wastewater-producing processes).

In addition to the effects of renewable energy utilization listed in section 2, such secondary effects are also important. Apart from the project's consequences for the basic needs of certain sections of the population, its possible impacts on agriculture, water supplies, transportation and diverse aftereffects must also be accounted for (whereas allowance must be made for the fact that improving the supply of energy to or within a given region can have practically identical consequences for the

sectors in question):

- **The loss of farmland alters the food market structure and/or necessitates the agricultural utilization of formerly more or less "virgin" areas. For additional information, the reader is referred to the environmental briefs on agriculture (e.g., Plant Production).**
- **Any more intensive use of water resources naturally involves higher rates of water consumption, larger volumes of wastewater and, hence, changes in the water regimen. That, in turn, affects the soil, the microclimate, the composition of the microsystem, and the hygienic situation (salinization, spread of pathogens; cf. environmental briefs Rural Water Supply, Rural Hydraulic Engineering Large-scale Hydraulic Engineering, Water Framework Planning.**
- **Increased traffic due to transportation in connection with large-scale renewable energy applications (or simply attributable to an improved energy supply situation) necessitates more and better traffic infrastructure. Its provision, in turn, has primary and secondary development effects; cf. environmental briefs Road Traffic, Transport and Traffic Planning. The general environmental impacts of renewable energy exploitation systems are discussed in the environmental brief Overall**

5. Summary assessment of environmental relevance

This environmental brief summarizes the environmental consequences of renewable energy sources. Such consequences include gaseous and liquid emissions, solid wastes, noise evolution, use of sensitive materials, land consumption and other forms of impairment.

The renewable-energy utilization options involving little or no replacement or decomposition of material (solar, wind) and, hence, fewer direct consequences for the environment are deserving of preferential treatment.

The fact that long-term sustained use of renewable energy sources can fit neatly into the natural biochemical and energy cycles produces a situation in which combustion and digestion processes (wood, straw, biogas, alcohol), unlike those involving fossil fuels, add no carbon dioxide to the atmosphere, because the amount emitted is offset by the incorporation of equal amounts into the

***regeneration* of biomass. In other words, biomass enables the CO_2 - neutral generation of energy.**

On the other hand, again unlike fossil fuels, the continuous renewal process of biomass as an energy vehicle ties up land area, i.e., soil, that otherwise could be put to some other or additional use, e.g., for agricultural production or agroforestry.

Land consumption is unavoidable. Accordingly, valuable ecosystems must be protected - *instead* of simply being exploited as a renewable source of energy.

As long as the requisite facilities are properly maintained and serviced by skilled specialists, and as long as the operating personnel is well-trained, the use of renewable energy sources poses little danger of accidents.

Like most finite sources of energy, the majority of renewable energy sources can be exploited both on a large, centralized scale as well as through small, noncentralized facilities. Some renewable sources of energy (e.g., solar cells, solar collectors, biogas, wind power) are inherently suited to noncentralized forms of energy generation, particularly in connection with energy supply and development strategies for rural, village-level and regional development projects involving little or no transport costs.

Such constellations help minimize energy conveyance losses and avoid such secondary environmental problems emanating from the socioeconomic ramifications of centralized development strategies as urbanization, rural-urban drift and their consequential effects; cf. environmental briefs Spatial and Regional Planning, Overall Energy Planning, Planning of Locations for Trade and Industry.

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Trade and industry

Contents - Previous - Next

44. Nitrogenous fertilisers (raw materials, ammonia and urea production)

Contents

1. Scope

Worldwide demand for synthetic nitrogenous fertilisers currently stands at some 80 million tonnes per year. Practically the sole source of nitrogen for all synthetic nitrogenous fertilisers is ammonia - chemical formula NH_3 - which has a characteristic pungent odour, is gaseous under ambient conditions and liquid at -33C under atmospheric pressure.

Since 1913, ammonia has been produced on a large scale from atmospheric nitrogen and hydrogen by catalytic synthesis.

Naturally occurring hydrocarbons are converted with steam at high temperatures to produce hydrogen.

$C_n H_m + 2nH_2 O = (m/2+2n) H_2 + nCO_2$ (endothermic)

The following raw materials are used in ammonia synthesis gas production:

- **pit coal**
- **lignite**
- **peat**
- **non-volatile hydrocarbon residues**
- **light petrol**
- **natural gas and other gases.**

For economic reasons the electrolytic disintegration of water to produce hydrogen can only play a minor role in ammonia synthesis.

The synthesis gas produced is in all cases converted directly into ammonia:

$3 H_2 + N_2 = 2 NH_3$

As ammonia in liquefied gas form is only suitable for direct fertilisation under certain circumstances, and only at a considerable cost, some or all of the ammonia produced is processed in situ to produce urea or other nitrogenous fertilisers. Only a few production plants are totally export-oriented.

In this section of the brief, only the synthetic manufacture of urea from ammonia

and carbon dioxide (CO_2) - which occurs as a by-product of hydrocarbon reforming - will be considered.

Normal current production capacities ranges from approximately 400 to 2,000 t of NH_3/day and 600 to 3,000 t of urea/day.

Sites are not selected on the basis of any specific criteria; some plants are both raw material oriented and consumer and transport oriented.

The environmental impact of the production plants derives from waste gases, wastewater, waste heat, dust, solid residues and from noise, transport routes, space requirements (pressure on space) and general industrialisation phenomena.

We will not consider in this brief the impact on the environment from noise, transport, space requirement and other general industrialisation phenomena; this subject is dealt with in the environmental brief Planning of Locations for Trade and Industry.

We examine in the following the process materials, intermediate products, by-products and waste products which arise in the production processes and the

measures required to dispose of waste, to prevent any harmful impact on the environment and to keep within prescribed limits.

2. Environmental impacts and protective measures

2.1 Ammonia synthesis gas production (ASGP)

2.1.1 ASGP from light hydrocarbons

Because it is economical, the catalytic steam reforming of light hydrocarbons, such as natural gas, petroleum-associated gas, LPG, light petrol and other gases containing H_2, and hydrocarbons such as coke oven and refinery gas, has become generally accepted.

Some 80% of all ammonia synthesis gas plants use this highly endothermic process which can be illustrated - taking methane reforming as an example - by the following molecular formula:

CH_4 + 1.39 H_2O + 1.45 AIR = CO_2 + 2.26 (H_3 + N)

In the initial stage of this process, light hydrocarbons are catalytically reformed with steam at temperatures of between 750C and 800C with the addition of heat (primary reforming) and, in a second autothermic stage, with air at approx. 1,000C (secondary reforming); depending on pressure and temperature determined equilibrium conditions, this produces a mixture of H_2, CO, CO_2, N, CH_4 and traces of Ar. The nitrogen required for ammonia synthesis is introduced into the system by the air used for autothermic conversion in the secondary reformer. The carbon monoxide (CO) which forms is then converted catalytically into H_2 and CO_2 (usually in two stages) with steam at 300C to 450C.

***Figure 1* - Ammonia Production from Light Hydrocarbons**

Before catalytic reforming, sulphur, chlorine and other compounds, which toxify the catalysts, must be removed, and this is performed in a single or multi-stage gas purification process.

Once the carbon monoxide from the reforming gases has been converted to hydrogen, the carbon dioxide is separated by chemical or physical scrubbing, from

which a CO_2 stream can also be produced for urea synthesis.

The purity of the H_2/N mixture necessary for ammonia synthesis is obtained by a fine purification stage following CO_2 removal.

In most plants, the primary reformer is heated with the process raw material.

Thanks to the intensive utilisation of waste heat, almost all known processes involved in ammonia synthesis work autonomously, i.e. steam for heating and power from an external source is required or must be produced by an auxiliary boiler only at start-up. The total energy requirement of modern autonomous plants is less than 29 GJ/t NH_3.

Waste streams, pollutants and protective measures:

(a) Waste gases

- Carbon dioxide (CO_2):

It occurs at a concentration of around 98.5 % by volume, is used in full or in part as

a raw material for urea synthesis and can be released into the atmosphere untreated as in practice the only impurities contained are H_2, N_2 and CH_4.

- Flue gases from the primary reformer and steam boilers:

If the heating medium contains too much sulphur, it may undergo a purification process to keep SO_2 values in the flue gases to within admissible levels. Primary measures to reduce the NOx emission can be taken in the primary reformer. Flue gases are released into the atmosphere through a chimney so as to comply with the values of the TA-Luft [Technical Instructions on Air Quality Control] valid in Germany, for example.

- Other waste gases:

All other waste gases formed in the plant contain combustible components and are fed into the plant's heating gas system. If there is any unscheduled stoppage, process gases (H_2, CH_4, CO, CO_2, NH_3, N_2, steam) have to be burnt in a flare as a temporary measure so that only flue gases are released into the atmosphere.

(b) Wastewater

- Process condensate: is generally reprocessed and used as boiler feedwater.

- Blow-down water from steam generators: does not contain any toxic components and can be discharged untreated or fed into the cooling water circuit.

- Blow-down water from cooling water circuits: is to be treated before disposal depending on the degree of concentration and the content of corrosion inhibitors, hardness stabilisers and biocides.

- Wastewater from demineralisation plants for boiler feedwater conditioning: can be drained following a neutralisation stage.

- Spent lye from CO_2 scrubbing:

In normal operation, no waste streams are produced. Wash water is to be treated in the same way as wastewater from demineralisation plant or cooling water circuits. (On the general subject of wastewater, see also the environmental brief on Wastewater Disposal).

(c) Solids

- Sludges: The purification of blow-down water from cooling circuits can

produce sludge residues which then need to be dumped by a method appropriate to their composition.

- Spent catalysts and purification masses:

The useful life of catalysts used in ammonia production plants ranges from about 2 to 8 years depending on the particular use and method of operation. When the activity of catalysts falls below a predetermined level, they are replaced by new active ones. Most catalysts contain notable quantities of oxides and sulphides of the heavy metals Co, Ni, Mo, Cu, Zn and Fe, which are insoluble in water, while spent sulphur purification masses consist in the main only of water-soluble oxides and sulphides of Zn or Fe, and chlorine purification masses of NaCl/Na_2O on Al_2O_3. Some of these waste products are recovered by the manufacturers for reprocessing or are passed on to smelting works for metal recycling. Otherwise, they have to be dumped by a method appropriate to their composition; for example, the water-soluble HT conversion catalyst containing Cr must be dumped so that no soil or water pollution is possible.

(On the general subject of waste, see also the Environmental Briefs Solid Waste Disposal and Disposal of Hazardous Waste).

2.1.2 ASGP from heavy residual oils

The residual oils containing sulphur and heavy metals produced in crude oil processing should today no longer be burnt untreated for reasons of environmental protection. They can however be successfully used for the production of ammonia synthesis gas.

The residues are gasified by partial oxidation with oxygen from an air separation plant - in which the nitrogen required for ammonia synthesis is also produced - according to the following simplified molecular formula:

$$C_n H_m + n/2\ O_2 = n\ CO + m/2\ H_2$$

The hydrogen required for ammonia synthesis is produced by further conversion with steam and disintegration of contaminants - such as H_2S, COS, CNS, HCN, soot and metal residues - formed due to the raw material composition and the particular process conditions.

As the process generally consumes a large amount of energy, there is intensive waste heat utilisation and all combustible by-products and waste products formed

are used internally for reasons of economy.

Figure 2 - Ammonia Production from Heavy Residue Oils

Waste streams, pollutants and safety measures

Solid residues, such as ash and salts, and also liquid and gaseous by-products and waste products are formed during the process due to raw material composition and the gasification and purification processes.

Numerous processes are available for waste reprocessing and pollutant disposal, thus plants of this kind can even operate within the strict environmental regulations of the Federal Republic of Germany. Generally, the details given in section 2.1.1 apply to the reprocessing of the corresponding waste gases, wastewater and solid residues.

The following are also produced:

- H_2S as a conversion product of the sulphur contained in the raw material. Elementary sulphur is produced with a 98% yield by the Claus process (a 99% yield can even be achieved by means of additional stages); alternatively a 98% yield can likewise be obtained by wet catalysis of sulphuric acid.

- Process water contaminated with the metals contained in the raw material, such as Ni, V, Co etc., and the water-soluble compounds formed in the gasification process from other elements present in the raw material, such as H_2S, CNS, HCN, As, NH_3, Cl, MeOH etc. Before it can be discharged into drains, this wastewater must be purified by means of appropriate purification processes and biodegradation. In most cases provision must be made for a demetallisation stage, the heavy metals deriving from this being transported to special dumps or to special works where the metal is recovered.

2.1.3 ASGP from solid fuels

A crude gas consisting of H_2, CO, CO_2 and CH_4 is produced with steam at temperatures of over 1200C and by the partial oxidation of hard coal, lignite, coke, peat etc., with oxygen from an air separation plant in which the nitrogen required for ammonia synthesis is also produced.

As with the partial oxidation of liquid hydrocarbons (section 2.1.2), the impurities in the crude gas are largely determined by the raw material composition and process conditions (pressure and temperature), the sulphur in the raw material being present almost exclusively in the form of H_2S. In the subsequent purification and conditioning stages, which in principle correspond to the operations involved in the reprocessing of heavy oil residues (section 2.1.2), pure hydrogen is extracted and this is used for ammonia synthesis with the oxygen from the air separation process.

On a large scale, the following methods of solid gasification have proved successful:

- **moving bed process,**
- **fluidised bed process and**
- **entrained bed process.**

Feed and storage installations for the fuel and also conditioning stages tailored to the particular gasification process used, are always found upstream of the gasification process.

As the overall process consumes a great deal of energy, there is intensive waste heat utilisation.

Waste streams, pollutants and protective measures

In all processes, solid residues such as ash, slag and salts are produced, as are also liquid and gaseous by-products and waste products, in quantities and of compositions which are determined by the raw material composition and the gasification and gas purification processes.

A large number of processes can be used for waste recycling and pollutant disposal, thus plants of this kind can operate within the strict environmental regulations of the Federal Republic of Germany applicable in the energy supply sector.

The type and reprocessing of waste gases, wastewater and solid residues conform in principle to the provisions of sections 2.1.1 and 2.1.2.

***Figure 3* - Ammonia Production from Solid Fuels**

In addition the following are formed:

- **Dust, formed during fuel transport, storage and reprocessing. The problem of dust can however be controlled effectively by the implementation of measures which are commonplace in coal power**

stations and which have proved to be highly successful in overcoming the dust problem.

- Leakage water from the fuel store. Any harmful effects can be avoided by drainage and/or by covering the ground water area with an impermeable layer of clay.

- In many processes wastewater containing ammonia, phenol, cyanide and tar is formed, but there are also processes which can be used to separate these contaminants and recover them to a technically pure level.

- Ash and/or slag from the gasifiers. It is essential to check in each individual case whether this can be recycled, e.g. in the construction industry, and to determine what form of dumping is appropriate.

2.1.4 Water electrolysis and air separation

The feed product is fully demineralised water; this is produced in ion exchangers and mixed bed filters. Water electrolysis consumes a great deal of power and is thus an option only where cheap excess energy is available or where other raw materials are in short supply. The nitrogen required for NH_3 synthesis is obtained by air separation. In electrolysis, very pure oxygen, suitable for a large number of technical applications, is formed, whereas in air separation only an oxygen-enriched spent air

flow is generated which is normally released into the atmosphere.

Waste streams

Only wastewater from the demineralisation plant and blow-down water from the cooling water circuit are continuously formed; they must be treated as described in section 2.1.1. The precious metal catalyst for the removal of residual oxygen from the synthesis gas is only replaced at intervals of several years and can be returned to the manufacturer for reprocessing.

***Figure 4* - Ammonia Production by Water Electrolysis**

2.2 Ammonia synthesis and storage

Very pure hydrogen and nitrogen are converted catalytically in an exothermic process to ammonia at pressures of over 100 bar and temperatures of around 350C - 550C.

$3 H_2 + N_2 = 2 NH_3$

The conversion is not complete due to the equilibrium conditions. The ammonia formed is condensed by cooling (air, cooling water, cold) and released from the process in liquid form. Any gases not converted remain in a recycle. This results in an accumulation of inert components (CH_4, Ar, He) which must then be removed from the process by a continuous stream of purge gas. The purge gas stream, together with the flash gases from the ammonia produced, can be used as heating gas in the synthesis gas production plant, in which case NH_3, H_2, N_2 and Ar can first be separated in recovery plants.

The liquid ammonia goes either directly into processing plants or into a storage tank, storage taking place under pressure but at ambient temperature or slightly lower, or alternatively at atmospheric pressure and at a temperature of around -33C.

Waste streams, pollutants and protective measures

In normal operation, the plant does not release any pollutants into the environment. The continuously formed waste gas streams are processed internally or in the synthesis gas production plant.

No problems arise with the disposal of the catalyst, consisting of iron with small quantities of Al_2O_3, K_2O, MgO, CaO and SiO_2, an operation which takes place at intervals of around 5 to 10 years (e.g. smelting, road-building).

As ammonia fumes are highly irritant and the liquid is caustic and causes freezing, appropriate safety precautions - particularly during storage - need to be taken, such as double-shell tanks, collecting basins and water spray curtains.

2.3 Urea synthesis and granulation

Urea is produced from ammonia and the carbon dioxide which is a by-product of ammonia synthesis gas production from hydrocarbons, in a 2-stage process at pressures of 140 to 250 bar.

1st stage: Ammonia carbamate synthesis (exothermic)

$$2NH_3 + CO_2 = NH_2 - CO - ONH_4$$

2nd stage: Thermal carbamate decomposition to urea (endothermic)

NH_2 - CO - ONH_4 - $CO(NH_2)_2$ + H_2O

The urea is present in the form of an aqueous solution in a concentration of some 70 to 80%, from which a pumpable melt is extracted for further processing by the vacuum evaporation of the solution water.

It is then processed to granular urea fertiliser either by prilling in towers using a countercurrent of cold air or by fusion granulation on rotary plates or other cooled installations and by the fluidization technique.

The granular product is then poured directly into bags and/or stored temporarily in warehouses as bulk product.

Waste streams, pollutants and protective measures

(a) Waste gases:

- Waste gases from synthesis contain only CO_2 and air, together with traces of the gases dissolved in the ammonia: H_2, CH_4, Ar, as all waste gases have to be scrubbed before they are released into the atmosphere.

- Waste gases from prilling towers or granulation installations always carry a certain amount of product dust with them, the release of which must be contained by filtration to prevent "overfertilisation" of the environment with the repercussions this has on soil and water quality.

(b) Wastewater:

- Wastewater derives mainly from the gas scrubbing operations and contains NH_3, CO_2 and urea. All wastewater is recycled in the process itself, to keep the addition of water to the process as low as possible and to minimise raw material and product losses. The wastewater which does arise can be simply biologically purified.

(c) Solids:

- Residue produced during waste gas dust extraction, which is practically pure product, is returned to the process.

***Figure 5* - Urea Production and Granulation**

3. Notes on analysis and evaluation of environmental impacts

In the fertiliser production plants described here, environmental impacts, in the form of emission into the atmosphere, watercourses and soil, as well as noise emissions, may be anticipated. However, there are process stages for all production plants which can be implemented to contain this impact.

In Germany, the TA-Luft [Technical Instructions on Air Quality Control] is the main instrument as regards air quality. Pollutant limit values relating to specific plants and substances are listed in the Allgemeine Verwaltungsvorschrift zum Bundesimmissionsschutzgesetz [General Administrative Regulations pertaining to the Federal Immission Control Act] of 27.02.1986. It also contains a series of Richtlinien des Vereins Deutscher Ingenieure (VDI-Richtlinien - guidelines of the Association of German Engineers) regarding process and gas purification techniques and emission measurement techniques, which must be complied with. There are similar provisions in other countries, e.g. the Clean Air Act in the USA or its Swiss equivalent, the Luftreinhalteverordnung.

In countries which do not have their own regulations, reference is frequently made to the TA-Luft or other foreign regulations at the planning stage.

Most atmospheric pollution in such plants derives from SO_2 in the waste gas. Under TA-Luft, a sulphur emission level of 3% down to 0.5%, depending on plant size, must not be exceeded in sulphur extraction plants. Not all purification processes achieve this, but they are nonetheless used where less stringent regulations are in force.

In wet catalysis for sulphuric acid extraction, a minimum conversion level of 97.5% must be complied with. Sulphur trioxide emissions in the waste gas must not exceed 60 mg/m^3 under constant gas conditions, and must not exceed 120 mg/m^3 otherwise.

Limits which can also be adhered to are established in TA-Luft for NOx emissions in furnace flue gas streams - tube furnaces, steam generators, booster heaters.

Dust emissions from UREA fertiliser production facilities are restricted to 50 mg/m^3, while the free ammonia content in waste gases must not exceed 35 mg/m^3. The dust load is measured gravimetrically with filter head equipment and the free

ammonia is determined by titration.

The wastewater treatment processes used are subject to local regulations. In Germany, the Wasserhaushaltsgesetz (WHG) [Federal Water Act] applies, with its associated Verwaltungsvorschrift [Administrative Regulation] relating to minimum requirements for the disposal of wastewater in drains. In fertiliser production plants, the associated 44. Verwaltungsvorschrift [44th Administrative Regulation] can be observed.

In the extreme case of wastewater treatment, no wastewater is produced, merely combustion residues which are finally disposed of on special dumps where no leaching can occur, or concentrated residual solutions which require disposal in deep wells, for example, may be formed.

The catalyst and purification mass residues, most of which are formed at intervals of two years or more, do not cause any problem in terms of quantity and, as already stated, are passed on to smelting works for metal recycling or must be dumped as special waste.

With regard to the ash and slag from solid-fuel ammonia production, the possibility

of recycling or dumping has to be examined in each individual case.

The TA-Lrm [Technical Instructions on Noise Abatement] which is the comparable administrative regulation for noise protection, specifies immission values which are graded by location and time for areas, based on a variety of uses. The determining criterion is that of total impact level. Noise protection measures must be taken into account at planning stage as they are costly if implemented at a later date. In site planning, therefore, adequate distances from protected property, such as residential housing development, and a shortening of this distance must be prevented.

In Germany the TRgA 900 7) for limiting the maximum pollutant concentration at the workplace (MAK/TRK values 8)), the Arbeitsstttenverordnung [Ordinance on Workplaces] including workshop guidelines for workplace design and the accident prevention regulations Unfallverhtungsvorschriften of the Berufsgenossenschaften (employers' liability insurance associations), as being the body responsible for insuring accidents at work, apply to workplace conditions in terms of pollutant concentration, noise nuisance and industrial safety. Comparable regulations exist in other countries, e.g. in the USSR, with Health Standards for Industrial Concerns (SN 245-71).

7) TRgA - Technische Regeln zur Arbeitsstoffverordnung [technical regulations on the industrial substances decree]

8) MAK - Maximale Arbeitsplatzkonzentration [maximum workplace concentration]

TRK - Technische Richtkonzentration [technical approximate concentration]

4. Interaction with other sectors

In view of the high energy and raw material requirement, ammonia and urea production plants are normally built close to raw material sources or transport routes; these include natural gas and crude oil conveying plants, refineries, pipeline terminals, LNG stores, coal mines, power stations and coking plants - or hydroelectric power stations with high excess energy (for water electrolysis).

Proximity to other fertiliser production facilities is also useful, e.g. NP or NPK fertiliser production.

Less practical, in contrast, are purely consumption-oriented sites if these do not also enjoy favourable conditions for the supply of raw materials or energy (e.g. port installations, power stations).

5. Summary assessment of environmental relevance

In ammonia and urea production plants, mainly gaseous by-products and residues are formed due to the raw materials used, together with wastewater, waste heat and spent catalysts resulting from the processes used. Moreover, noise and other industrial influences also occur.

Because of the high energy requirement for ammonia production, which is about 29 GJ/t of NH_3 in modern natural gas fed plants and over 70 GJ/t of NH_3 where coal is the raw material, the environmental impact is comparable to that of power stations (cf. environmental brief Thermal Power Stations).

With today's gas and water purification methods, even the most stringent environmental protection regulations can be complied with, the lowest costs being

incurred where natural gas is the raw material, and the highest being incurred for coal - due to its complex composition. In the manufacture of granular urea fertiliser, particular emphasis must be placed on effective dedusting techniques. Likewise, suitable wastewater purification plant and environmentally friendly dumping facilities must be available.

In industrial conurbations, air coolers or dry cooling towers may be required to prevent the environmental pollution which can occur where cooling water is used to deal with waste heat.

The population affected should be involved at the planning phase; likewise, the population resident in the area of the project should have access to medical care.

In the case of new planning measures without any differentiated (state) monitoring system in the environmental field, the aim must be to choose a technique which is best adapted to the particular circumstances.

It is extremely important for plants of this kind to be systematically monitored and maintained to guarantee correct operation - a point which is all too easily ignored. Thus, a works environmental protection officer with appropriate powers must be

appointed who will also be responsible for increasing the awareness, and for the education and training of operating personnel with regard to environmental issues.

It may generally be stated that apart from the pollutants due to waste heat and contained in the raw materials, very little environmental impact need be feared from ammonia and urea production provided that environmental protection aspects are taken into account during planning and operation.

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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45. Nitrogenous fertilisers (starting materials and end products)

Contents - Previous - Next

Contents

1. Scope

Nitrogenous fertilisers in the strict sense of the term include the following, which are considered in the context of this environmental brief:

- **ammonium nitrate (abbreviation AN)**
- **calcium-ammonium nitrate (abbreviation CAN)**
- **ammonium sulphate (abbreviation AS)**
- **calcium nitrate (abbreviation CN)**
- **nitrogen solutions (abbreviation N solutions)**
- **ammonium chloride**
- **ammonium phosphates.**

The nitrogenous fertilisers examined here are produced for agriculture in a granulated or prilled form with the exception of nitrogenous solutions, the use of which requires a system of mixing and distributor stations.

The primary products required for the manufacture of these fertilisers comprise:

- **ammonia, covered by the environmental brief Nitrogenous Fertilisers (raw materials, ammonia and urea production)**
- **nitric acid**
- **sulphuric acid**
- **urea**
- **limestone.**

The capacities of individual plants vary considerably; the upper limit for nitric acid, for example, is 2000 t HNO_3/day, for sulphuric acid 3000 t H_2SO_4/day and for ammonium nitrate and calcium-ammonium nitrate 2000 t/day on one line.

2. Environmental impacts and protective measures

With the use of modern processes, environmental impacts can be confined to gaseous emissions in the overwhelming majority of cases. Any liquid emissions produced can usually be avoided by internal recycling, although in a few cases solid waste cannot be avoided, and noise emissions occur with most processes.

Figure 1 - Nitrogenous Fertiliser Production

2.1 Nitric acid production

Industrial production of nitric acid is based on the catalytic oxidation of ammonia and subsequent absorption of the nitric oxides, formed during oxidation, in water. The various processes used in industrial production differ mainly with regard to the pressure used in the burning or absorption stage and the efficiency of the heat recovery system. The acid produced for further processing into fertilisers is an aqueous solution containing up to about 60% HNO_3.

Pollutants produced and counter-measures

The process does not give rise to continuous liquid emission flows. Where liquid ammonia is used, an oily waste is produced intermittently depending on the oil content of the ammonia, which is collected and burnt in a suitable incineration plant. Gaseous emissions are the tail gas containing ($NO + NO_2$) = NO_x from the absorption column.

The higher the NO_2 content, the more intense the brown colour of the waste gas, as

is plain to see for miles around.

While the NOx content in older plants can be several thousand mg NO_2/m^3, modern facilities are designed for around 400 mg NO_2/m^3. There are a number of ways of removing nitrogen oxides completely, e.g. catalytic tail gas burning with hydrogen, ammonia or methane.

If neither fresh water nor seawater can be used as cooling water, blow-down water from the cooling water recycle arises which, in compliance with local provisions, cannot always be discharged directly as wastewater because of its increased salt concentration and other additives. In this case, it is conditioned in the wastewater treatment plant together with the other wastewater flows in the works. The residues must then be taken to a controlled dump or, in the case of biological wastewater purification, can be incinerated. Where fresh water is used for cooling purposes, the heat transferred to the river or lake must be taken into account; if necessary, measures are to be taken to cool it before it is discharged.

2.2 <u>Sulphuric acid production</u>

Today sulphuric acid is produced on an industrial scale almost exclusively using the contact process in which gases containing sulphur dioxide are channelled through a vanadium catalyst. The gases containing sulphur dioxide required as the primary product for sulphuric acid production come mainly from:

- the burning of elemental sulphur,
- roaster gases from pyrite,
- roaster gases from sulphide ores of non-ferrous metals.

A modern sulphuric acid plant can be identified by optimum use of the reaction heat in the individual process stages. Most surplus steam is used for energy production, and in some plants, the low-temperature energy produced in the acid coolers is already being utilised.

The SO_3 formed in catalytic SO_2 oxidation is absorbed in 98% to 99% sulphuric acid, which yields H_2SO_4 in a reaction with water.

Pollutants produced and counter-measures

There are no process-specific liquid emissions if sulphuric acid is produced by

sulphur oxidation.

The tail gas from sulphuric acid facilities contains SO_2 and SO_3.

For sulphuric acid facilities, emissions of sulphur trioxide in the waste gas, at constant gas conditions, are limited to maximum 60 mg/m^3. Moreover, the emissions can be further reduced by the use of the peracidox process, a fifth tray stage (5th catalyst level) or equivalent measures.

Where roasters are installed upstream, small quantities of contaminated sulphuric acid are produced in the form of washing acid, which, if it does not contain any harmful pollutants, can be concentrated and used, for example, in a fertiliser plant. If it contains harmful pollutants from the raw materials which have not been removed by the waste gas plant upstream, the acid must be neutralised and the residue dumped.

The slag may, depending on the feedstock analysis and possibly following an intermediate stage in which elements of any value are extracted, be passed to the steel industry or dumped. The remarks made in section 2.1 apply with regard to the cooling water problem.

In Germany, pure liquid sulphur is used almost exclusively. In the rare cases in which the sulphur contains arsenic or selenium, purification is essential and filtration residues must be dumped with care. Where the dumps are in the open, it must be ensured that the sulphurous acid formed by oxidation of the sulphur in the atmosphere does not percolate into the ground water with rainwater.

2.3 Ammonium nitrate production

Along with urea, ammonium nitrate is one of the most frequently used nitrogenous fertilisers worldwide. It is mainly produced by the neutralisation of 45 - 65% nitric acid with ammonia.

Ammonium nitrate is also a by-product of the nitrophosphate process in which NP or NPK fertilisers are made by the nitric acid decomposition of crude phosphates. The neutralisation reaction yields 95 to 97% solutions of ammonium nitrate.

The solution is processed further to obtain a marketable product by granulating or, after concentrating further to 99.5%, by prilling.

Pollutants produced and counter-measures

Where the prilling process is used, the prilling tower in the dry part of the plant can give rise to serious emission problems, as the relatively large quantities of discharged air are extremely costly to purify. In time, ammonium nitrate dust kills vegetation in the surrounding area. Such problems can be dealt with far more easily in granulation installations. Thus, this aspect should be studied in depth before any new investment is made and before any decision is taken on the process to be used.

With granulation, the process gas flows must be purified in effective wet scrubbers before they are discharged into the atmosphere. The installation should be fitted with a dust extraction system to ensure the safety of operating personnel.

Waste fumes from neutralisation and evaporation also must be scrubbed if they are to be discharged into the atmosphere as vapour. The preferred solution is the condensation of purified fumes, which yields condensates polluted with ammonium nitrate and ammonia, some of which can be used as process water for an adjoining nitric acid plant. Condensate which contains small amounts of impurities can be fed through an ion exchanger installation and reprocessed to boiler feed water.

2.4 Calcium-ammonium nitrate production

While the ammonium nitrate considered in section 2.3 has an N content of 33.5 - 34.5%, the nitrogen content of calcium-ammonium nitrate is 20.5 - 28%, and EC regulations do not permit a nitrogen content of over 28%. The nitrogen content is reduced by the addition of crushed limestone. With the exception of this addition of crushed limestone and mixing with the ammonium nitrate melt immediately before the prilling or granulation process, calcium-ammonium nitrate is made in the same way as ammonium nitrate. For this reason, the comments made in section 2.3 regarding pollutants and counter-measures apply here too but, in addition, because of the crushing plant for the lime, increased noise emissions must be anticipated. An effective dedusting unit is to be provided for the crushing process. Where there is a constant electricity supply and the plant is maintained to West European standards, continuous dust removal to less than 50 mg/m can be achieved.

2.5 Ammonium sulphate

In view of the popularity of more highly concentrated nitrogenous fertilisers, the consumption of ammonium sulphate with just 20.5% N is constantly declining and now, worldwide, accounts for just 6% of nitrogenous fertiliser consumption. The strong physiologically acidic effect of this fertiliser is also to blame for the decline in its use.

The main industrial-scale production methods are:

- from coke-oven or coal gasification;
- from ammonia and sulphuric acid;
- as a by-product of organic syntheses, e.g. caprolactam manufacture;
- from gypsum, either from natural deposits or as a by-product of other processes, by reaction with ammonia and carbon dioxide.

2.5.1 Production from coke-oven or coal gasification

In both dry distillation and pressure gasification, some of the nitrogen in the coal forms ammonia. This ammonia is also found in the aqueous and carbon dioxide-rich condensate produced when the gas is cooled. The gas condensate also contains tar, phenols, pyridins, hydrogen sulphide, hydrocyanic acid etc., which cause serious problems when it comes to ammonia recovery and wastewater purification. When the tar has been separated and the phenols

removed, the volatile components of the gas condensate are stripped in a column by steam injection. The fumes from the stripper are scrubbed with sulphuric acid in coking plants, and the acidic gases remaining after sulphuric acid scrubbing are

either processed to sulphur in a Claus plant or converted directly to sulphuric acid in a wet catalysis installation. Fume burning could well be an option for consideration where only small quantities are produced, but this must be in line with sulphur emission regulations.

The wastewater must undergo a biological treatment as it contains various sulphur compounds, phenol and other organic compounds.

Pollutants produced and counter-measures

The problems arising from ammonia production have already been examined in the previous section and should be the topic of a separate study - on coal. The dust needs to be removed from waste gases produced by ammonium sulphate drying before they can be discharged into the atmosphere, as otherwise they lead to overfertilization with the associated negative consequences for soil and water quality.

2.5.2 Production from ammonia and sulphuric acid

Neutralisation and crystallisation are carried out under vacuum or at atmospheric

pressure. Crystallised ammonium sulphate is removed from the resulting mash in centrifuges and then dried.

Pollutants produced and counter-measures

The fumes produced by the exothermic reaction of sulphuric acid and ammonia, in particular the ammonia in the waste gas which can cause caustic burns to man, animals and plants, may contain impurities depending on the process used, and should be fed though a scrubber before being discharged into the atmosphere.

Dedusting systems are needed to remove the dust content from drying plant waste gases before they are released into the atmosphere.

2.5.3 As a by-product

Ammonium sulphate is obtained from the liquid waste of some organic processes, e.g. the production of caprolactam or acrylonitrile which yields a dilute ammonium sulphate solution, by evaporation, crystallization, centrifuging and drying.

For information on pollutants and counter-measures, see section 2.5.2.

2.5.4 Production from gypsum, ammonia and CO_2

The feedstock is finely ground natural gypsum or anhydrite, or alternatively calcium sulphate - a by-product, for example, of phosphoric acid production - which is converted with ammonia and carbon dioxide. The calcium carbonate obtained from the reaction is filtered off and the ammonium sulphate solution evaporated, crystallised and treated as described in section 2.5.3.

Pollutants produced and counter-measures

In principle, the same factors as stated in 2.5.2 need to be considered. Where natural gypsum is used, there is the added nuisance of noise from the grinding plant. The details given in 2.4 apply with regard to the dust produced in the grinding process.

2.6 Calcium nitrate production

$Ca(NO_3)_2$ is produced either directly via the reaction of nitric acid with limestone or, alternatively, produced as a by-product of the nitrophosphate process.

In direct manufacture, limestone is dissolved in dilute nitric acid and granulated or prilled after evaporation of the dilute calcium nitrate solution.

In the nitrophosphate process, in which crude phosphate is decomposed with nitric acid, the calcium nitrate is crystallised by cooling, separated and, after appropriate treatment, granulated or prilled.

Pollutants produced and counter-measures

In direct manufacture, the dissolution process yields gases which contain NOx and need to be extracted and absorbed, mainly to protect the health of operating personnel, although the gases are also responsible for corrosion of equipment and buildings.

Either appropriate precautions have to be taken at the design stage, or a scrubber installation is to be provided to reduce the pollutant content of the fumes produced during evaporation. Any purification stage installed after dissolving generates a moist waste which - depending on its composition - can be used in other plants or must be dumped.

Dust-laden gases must be cleaned before discharge into the atmosphere. Any washing solutions produced by these cleaning operations are to be concentrated and recirculated.

2.7 Production of nitrogen solutions

The following are used as liquid nitrogenous fertilisers:

- **liquid ammonia;**
- **aqueous ammonia solutions (e.g. 25%);**
- **solutions which contain free ammonia together with either ammonium nitrate or urea, or both;**
- **solutions of ammonium nitrate or urea, or both.**

Liquid ammonia is used directly as a fertiliser principally in the United States, where it is injected 15 - 25 cm deep into the soil with special equipment.

Where applied in this way, storage, transport and transfer equipment are the basic essentials, and the precautionary measures stated in the first section with regard to ammonia are to be observed.

These same precautionary measures are also to be taken in a somewhat diluted form for other nitrogenous solutions containing free ammonia.

The long-term implications - especially on soil microorganisms and the humus layer - should be examined for the particular soil type concerned before liquid ammonia or nitrogenous solutions containing free ammonia are used.

2.8 Ammonium chloride production

This salt, which - at 26% N - has a somewhat higher nitrogen content than ammonium sulphate, is not used alone as a nitrogenous fertiliser in Germany. Its main areas of use are China, Japan and India, principally in rice paddies as an alternative to ammonium sulphate, which decomposes into toxic sulphides where rice is attacked by fungus. The use of ammonium chloride is now on the decline as soils become overchlorinated if chloride is used for prolonged periods.

By far the largest share of ammonium chloride made for use as fertiliser is produced in solvay plants modified for soda production. After separating the sodium bicarbonate, ammonium chloride is crystallised out of the remaining solution by additional process stages, thus obviating the need for the usual ammonia recovery

with its attendant yield of relatively useless calcium chloride, and instead ammonium chloride fertiliser is obtained as a by-product.

Environmental impacts and counter-measures

As facilities of this kind yield ammonium chloride as a by-product of soda manufacture, the main measures applicable are those relating to soda works. The additional equipment required for ammonium chloride production must be fitted with efficient dedusting systems, especially for waste gases from driers.

2.9 Ammonium bicarbonate

To complete the picture, mention must also be made of this nitrogenous fertiliser, which is only produced and used in China. According to statistics, of the 11.1 million tonnes made in China in 1983, 6.4 million tonnes went to the fertiliser market in the form of ammonium bicarbonate. The reason for this one-off development lies in the rapid establishment of nitrogenous fertiliser production from 1960 on, with the creation of a large number of small facilities for ammonia production using carbon gasification. The CO_2 obtained as a by-product is used directly for neutralisation of the ammonia produced.

Please refer to the section on ammonia synthesis using coal gasification for information on environmental impacts and counter-measures.

2.10 Transport, storage and bagging of solid fertilisers

Because they are water soluble, and in view of their hygroscopicity, fertilisers must be stored in bulk goods stores which are roofed and enclosed on all sides and then transferred to a bagging and transfer station in the immediate vicinity for dispatch. The delivery, removal and transfer points are to be of an as dust-tight as possible design, and - as in production plants - at critical points, where enclosure is not feasible, dust-laden waste gases must be collected and transferred to a dedusting installation.

3. Notes on the analysis and evaluation of environmental impacts

The basic regulations to be considered for this environmental brief are found, in Germany, in the *1. Allgemeinen Verwaltungsvorschrift* [1st General Administrative Regulation] to the *Bundes-Immissionsschutzgesetz* [Federal Immission Control Act]

(*Technische Anleitung zur Reinhaltung der Luft* [Technical Instructions on Air Quality Control] - *TA-Luft*) of 27.02.1986.

It is often the case in countries without firm regulations that the relevant German provisions are used when designing such facilities.

The NO_x emission for new nitric acid facilities is now restricted to 0.45 mg/m^3, expressed as nitrogen dioxide, and waste gases must be colourless before discharge. NO_x is determined analytically by titration or photometry.

In sulphuric acid plants, sulphur trioxide emissions in waste gas, at constant gas conditions, are restricted to 60 mg/m^3 maximum. The sulphur dioxide content of the tail gas is determined by the conversion level, which must be at least 99.6% in the double-contact process, with a minimum sulphur dioxide volume content of 8% in the input gas and at constant gas conditions. Furthermore, emissions are to be further reduced by the use of the peracidox process, a fifth tray stage or equivalent measures. Sulphur dioxide can be determined iodometrically, titrimetrically, gravimetrically or colorimetrically. For continuous measurement, recording analyzers are used, working on the basis of optical absorption in the infrared or ultraviolet

spectral range or the electrical conductivity of the sulphur dioxide.

For fertiliser plants, dust emissions from granulation and drying installations for multinutrient fertilisers with an ammonium nitrate content of over 50% or a sulphate content of over 10% are restricted to 75 mg/m^3 maximum. This category includes, for example, the following fertilisers: ammonium nitrate, calcium-ammonium nitrate and ammonium sulphate. For other fertiliser plants, the dust emission is to be kept at no more than 50 mg/m^3. Operating licenses set values of 35 mg/m^3 maximum for the free ammonia content of waste gases. Dust is analyzed gravimetrically with filter head equipment. Compliance with sampling technique rules is of utmost importance for the reliability of analyses and thus compliance with statutory limits. Free ammonia is determined by titration.

4. Interaction with other sectors

Today, it is frequently the case that complexes are not confined solely to the production of nitrogenous fertilisers but make NP and NPK fertilisers, too. In this

case, the sulphuric acid obtained is used for phosphoric acid production. The phosphoric acid is then neutralised with ammonia to ammonium phosphates which are processed in granulation operations to DAP fertilisers or, after adding potassium salts and micronutrients as necessary, to NPK fertilisers. This sort of combined economic management is characterised by a high level of flexibility with regard to fertiliser type. Furthermore, individual plants, including any ammonia synthesis upstream, can have increased capacities and thus manufacture their products economically; finally, a complex of this kind is self-sufficient in electricity because of the extra energy provided by the sulphuric acid installation. A further possibility is that of using the Mller-Khne process or a modern variation of it to reconvert into sulphuric acid the gypsum produced in the phosphoric acid plant, which in many instances represents a major dumping problem.

The slag from a roaster plant can be a raw material for non-ferrous metal and/or steel works.

Use of the nitrophosphate process obviates the need for sulphuric acid, in which case calcium nitrate is a by-product that can be converted to ammonium nitrate and fertiliser lime or calcium-ammonium nitrate where cheap carbon dioxide is available, e.g. from an adjoining ammonia synthesis plant.

The special variant of the solvay process for soda production practised in the Far East, of which ammonium chloride is a by-product, has already been mentioned.

For high-capacity nitrogenous fertiliser facilities, having ammonia synthesis close by is always worthwhile unless the plant enjoys an excellent transport infrastructure (e.g. ports and harbours, cf. environmental brief) and can also conclude favourable long-term supply contracts.

References are given in the relevant environmental briefs.

5. Summary assessment of environmental relevance

In nitrogenous fertiliser production facilities, the implications for the environment concern in the main gaseous waste (dust, ammonia, nitrous gases, sulphur dioxide), and noise, plus, in the case of roaster installations, process-specific by-products and residues.

Nitric acid installations can be operated such that gaseous emissions are practically

colourless, i.e. NOx-free, by the use of catalytic tail gas treatment where the NOx design value is not sufficient.

In sulphuric acid plants, the officially prescribed emission values listed in section 3 are to be further reduced by the installation of a fifth tray stage, the use of the peracidox process or equivalent measures. Where roasters are installed upstream, the slag, if it cannot be further used, must be dumped, the washing acid neutralised and residues dumped if further utilisation is not possible in view of the impurities they contain.

In plants for the production of salt, prilled or granulated fertilisers, an efficient dedusting system is of prime importance. This requires the separate treatment of the individual waste gas flows in specific dedusting installations. As stated, liquid waste from gas scrubbers is returned to the process. With modern technology, the harm to the environment can be kept low in the processes described here.

On the process management side of such plants, all waste gas purification installations must be systematically monitored and maintained. In particular, regular maintenance - which includes the cleaning of machines, motors and plant - is a major determining factor in the operating efficiency of such systems. Another

important factor is the timely provision of the necessary spare parts. Monitoring also includes regular analyses by an efficient laboratory so that appropriate measures can be taken promptly when values drift out of the permitted range. Works environmental safety officers should also be appointed; they should have the appropriate powers and should be responsible for the training and upgrading of personnel and for raising their awareness with regard to environmental matters.

Retention basins are also to be provided so that, if there should be any process incident resulting in an unforeseen production of wastewater, the plant does not have to be immediately shut down.

Although the dusts and gases produced are fertilizing substances, attention must be paid to compliance with prescribed emissions as, in the long-term, excessive immissions can be harmful to plant crops or trees in the surrounding area.

The affected population should be involved at the planning stage, and access to medical care must be guaranteed.

6. References

Abfallbeseitigungsgesetz, 04.03.1982.

31. Abwasser VwV Wasseraufbereitung, Khlsysteme, 13.09.1983.

American National Standards Institute Safety Requirements for storage and handling of anhydrous ammonia, ANSI K 61.1., 1972.

1. Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz (Technische Anleitung zur Reinhaltung der Luft - TA-Luft), 27.02.1986.

44. Allgemeine Verwaltungsvorschrift ber Mindestanforderungen an das Einleiten von Abwasser in Gewsser, Herstellung von mineralischen Dngemitteln auer Kali, 44. Abwasser VwV, 05.09.1984.

Arbeitsstten-Richtlinien (ASR).

The relevant accident prevention regulations of the employers' liability insurance associations (Berufsgenossenschaften) relating to the handling of hazardous

materials.

Gesetz zur Ordnung des Wasserhaushalts, Wasserhaushaltsgesetz, 16.10.1976.

Gesetz zum Schutz vor schdlichen Umwelteinwirkungen durch Luftverunreinigungen, Gerusche, Erschtterungen und hnliche Vorgnge, Bundes-Immissionsschutzgesetz BImSchG, 04.10.85, and the associated enforcement ordinances and general administrative provisions.

Katalog wassergefhrdender Stoffe, German Federal Ministry of the Interior (BMI) publication, 01.03.1985.

Merkbltter Gefhrliche Arbeitsstoffe (codes of practice for hazardous materials), e.g.:

Blatt S 24 Nitrogen dioxide (Stickstoffdioxyd)

Blatt S 33 Nitrogen oxide (Stickstoffoxyd)

Blatt S 03 Nitric acid (Salpetersure)

Blatt A 64 Ammonium nitrate (Ammoniumnitrat)

Blatt A 59 Ammonia solution (Ammoniaklsung)

etc.

Technische Anleitung zum Schutz gegen Lrm (TA-Lrm), 16.07.1968.

Technische Regeln zur Arbeitstoffverordnung TRgA 511, Ammoniumnitrat, September 1983.

TRgA 951 Ausnahmeempfehlung nach 12 Abs.2 in Verbindung mit Anhang II, Nr. 11 of the ArbStoffV fr die Lagerung von Ammoniumnitrat und ammoniumnitrathaltigen Zubereitungen, October 1982.

Ullmanns Enzyclopdie der technischen Chemie, 4. Auflage.

VDI guidelines, e.g.:

VDI-2066 Staubmesssungen in strmenden Gasen, pages 1 (10.75), 2 (6.81), 4 (5.80)

VDI-2456 Messung gasfrmiger Emissionen; Messen der Summe von Stickstoffmonoxyd und Stickstoffdioxyd, pages 1 + 2 (12.73).

Messen von Stickstoffmonoxyd, Infrarot-absorptionsgerte URAS, UNOR, BECKMANN, Modell 315, page 3 (4.75).

Messen von Stickstoffdioxydgehalten, Ultraviolettabsorptionsgert -LIMAS G, page 4 (5.76).

Analytische Bestimmung der Summe von Stickstoffmonoxyd und Stickstoffdioxid, Natriumsalicylatverfahren, page 8 (11.83).

VDI-2298 Emissionsminderung in Schwefelsureanlagen.

Verordnung ber gefhrliche Arbeitsstoffe, Arbeitsstoffverordnung - Arbstoff V., 11.02.1982.

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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46. Cement and lime, gypsum

Contents - Previous - Next

Contents

1. Scope

Companies in the cement, lime and gypsum industries produce mainly powdery products which are mouldable when water is added to them and set after a certain reaction time. The following production stages are required to manufacture the products:

- **Extraction: Transport, crushing, dosing of additives, storage, dressing of the raw materials;**

- Burning;
- Storage and crushing of the burnt products;
- Addition of additives: e.g. gypsum in the case of cement or water in the case of lime;
- Packing and dispatch

In the cement industry there are essentially two production processes which are used to dress and burn the raw material, the so-called wet process and the dry process. In most cases the raw material consists of a mixture of limestone and clay in the ratio of approximately 4:1.

- In the wet process the raw material is ground, with the addition of water, to form a sludge which contains 35-40% water. During burning the water evaporates. The amount of energy required for this is 100% greater than in the dry process. Because of the conditions of the wet process the specific waste gas flow rate is higher. New furnaces for the wet process are now only being constructed for extreme raw material conditions, whilst older plants are being converted increasingly to the energy-saving dry process.

- In the dry process the raw material is crushed whilst being dried,

preheated by the counterflow process in a heat-exchanger by the hot kiln waste gases and in most cases burnt in a rotary kiln at the required sintering temperature of approx. 1400C. Some of the modern plants have capacities of over 5000 t/day, whilst the capacity of the wet kilns rarely exceeds 1000 t/day. Shaft kilns are only used occasionally in special cases where market or raw material conditions dictate, and for the most part their capacity is less than 200 t/day.

In the lime industry both shaft and rotary kilns are used for burning the limestone, the combustion temperature being 850-1000C. In some cases ring kiln and similar internally developed shaft kiln processes are still used. Compared with the cement industry the capacities of the lime kiln plants are lower, rarely above 1000 t/day. Small producers with simple shaft kilns having a capacity of only a few tonnes per annum are commonly found in many countries.

Gypsum is dewatered at temperatures of 200 - 300C max. and converted from dihydrate to hemihydrate. Direct current rotary kilns, calcining mills or calciners and boilers are used for burning. The capacities of modern gypsum works are between 600 and 1100 t/day, but some of the plants still have relatively low capacities.

Anhydrite accompanied by gypsum is found in nearly all gypsum deposits. Anhydrite is an anhydrous form of calcium sulphate ($CaSO_4$) which, after crushing and classifying, can sometimes be used as a quick binding agent without prior thermal treatment.

2. Environmental impacts and protective measures

2.1 Air

2.1.1 Waste gases/flue gases

No waste gases are produced in the extraction and crushing of cement, lime and gypsum raw materials (principally limestone, gypsum and anhydrite), processes which are mainly carried out in the quarries.

The cement raw materials are frequently dried during dressing and crushing so that the moisture produced can be driven off as harmless water vapour. During the burning of the raw materials for cement production, calcium carbonate is converted

to calcium oxide when the carbon dioxide (CO_2) contained in the limestone is driven off. Sulphur compounds (mostly in the form of SO_2) and nitrous oxides (NO_x) may also be contained in the waste gas. Chlorine and fluorine gas and vapour emissions are prevented in the normal process by the fact that these impurities are deposited in the burnt product.

Water vapour and CO_2 emissions are process-related, whilst the occurrence of sulphur compounds can be greatly reduced by the use of suitable raw materials and fuels and control of the burning process. Up to certain limits, sulphur components are bound by the cement clinker during burning. Only under extraordinary operating conditions, e.g. where there is an excess of sulphur in the raw material and fuel, or in the case of reducing burning, will there be occasional short-term emissions of appreciable quantities of SO_2.

The flame temperature at which cement is manufactured may be as high as 1800C, with the result that more nitrous oxides are formed by oxidation of the atmospheric nitrogen than in lime burning.

The NO_x values of 1300 - 1800 mg/Nm^3h permitted in the waste gas in Germany

(TA-Luft - Technical Instructions on Air Quality Control - Table 1) will probably become subject to more stringent requirements in the next few years. At the present time, possible ways of reducing the NOx values are the subject of large-scale trials, and there currently appear to be four potential methods:

- **non-catalytic combustion;**
- **plants with activated carbon filters;**
- **optimisation of the burning operation;**
- **conversion of plants to a two-stage calcining installation (oxidising, reducing).**

These processes require different levels of investment and they all presuppose continuous operational monitoring.

In the cement industry oils, solvents, paint residues, old tyres or other combustible waste materials are frequently used as additional fuels. Some of these waste products introduce contaminants which are normally bound by the clinker and do not reach the waste gas. If such fuels are used, the process must be monitored by special safety inspections to prevent the emission of additional contaminants.

In lime burning, which takes place in much smaller plants than in cement production, CO_2 is also emitted with the flue gas, but the quantity of waste gas is much smaller than in cement works because of the size of the plant and because of the lower combustion temperatures in the process.

In lime slaking calcium carbonate is converted to calcium hydroxide with the addition of water, some of the water added being discharged again as water vapour, since the process is exothermic. However, this water vapour is harmless.

In gypsum burning water vapour and small quantities of flue gas are discharged into the atmosphere. Since the combustion temperatures of 300-400C are not very high, and since in most cases the mass flows are very low, these burning plants only cause slight environmental pollution.

Anhydrite from natural deposits is only crushed before use, but anhydrite from phosphoric acid production must be dried before further use, in which case water vapour will be given off. However, this anhydrite is rarely suitable for industrial use, because it is often toxic.

2.1.2 Dust

During the extraction and further processing of cement, lime and gypsum dust is produced in various stages of the work due to process conditions. In the case of cement this dust is a mixture of limestone, calcium oxide, cement minerals, and sometimes even completely burnt cement, whilst in the case of gypsum the dust contains anhydrite and mainly calcium sulphate. With the exception of the pure CaO dust, which is produced during lime burning, the dust is harmless, but on the other hand it does give rise to considerable nuisance. In the case of the individual production units and conveying installations of a cement works 6-12 m^3 of spent air and waste gas per kg of material have to be extracted and dedusted. The major sources of dust in a plant include:

- **crushing and mixing of the raw material;**
- **burning of the cement;**
- **crushing of the cement (clinker + gypsum);**
- **slaking of the lime.**

The proper use of high-performance extraction plants and dedusting installations, such as electrostatic separators, fabric and gravel bed filters, and often cyclones used in conjunction with these, is essential, otherwise correct process management cannot be guaranteed, costs due to machinery wear rise disproportionately and

high dust levels impair working conditions, simultaneously causing loss of production.

The separated dusts are mainly recycled, provided no enrichment of heavy metal components such thallium is expected in the waste gas. Only under unfavourable raw material and fuel conditions will it perhaps be necessary to separate and eject partial quantities of the dust because of the excessive concentration of detrimental components in the product, e.g. alkaline chlorides. Occasionally the use of these dusts is possible in other branches of industry. If the dusts are dumped, the groundwater protection requirements must be met due to the water solubility of individual components.

In lime production the quantity of dust produced is smaller because a powdery product is only involved during the slaking, packing and loading of the lime. In the gypsum and anhydrite industry the amount of dust produced is also small.

High quality filters (electrostatic or fabric filters) now make it possible to achieve a dust concentration of less than 25 mg/Nm^3 in the spent air in the cement, lime and gypsum industry. At present, values of below 25 mg/Nm^3 are being discussed by the

European authorities for new plants, whereas the German TA-Luft (Technical Instructions on Air Quality Control) still requires 50 mg/Nm^3.

2.2 Noise

Cement works emit far higher noise levels than lime and gypsum works, but the latter also have production areas giving off considerable noise.

In the extraction of raw materials, noise and associated vibrations may occur as a result of blasting, but such noise emissions can be substantially reduced by means of suitable ignition processes. Moreover, the machines used for mining can be soundproofed to such an extent that they meet the requirements of the German TA-Lrm (Technical Instructions on Noise Abatement).

During dressing, noise pollution is liable to occur e.g. through the use of rebound crushers and mills for the crushing of hard materials. These crushing installations and the adjoining dressing installations can be enclosed in such a way as to protect the environment from oppressive noise. The noise generated by the majority of rock- and cement-crushing plants is so intense that they have to be installed in soundproofed premises in which personnel cannot work on a permanent basis.

Burning plants require numerous large fans which generate extremely penetrating noise, with the result that noise protection measures, e.g. in the form of enclosures, are also necessary.

In order to avoid nuisance, plants in the lime, gypsum and particularly the cement industries must be erected at least 500 metres from residential areas. The immissions values for nearby residential areas should not exceed 50 to 60 dB(A) during the day, and 35-45 dB(A) at night.

2.3 Water

In the vicinity of pits in the German cement, lime and gypsum industry the wastewater may contain up to 0.05 ml/l of total suspended solids. To avoid exceeding this value the pit water produced must be discharged via stilling basins. Water used for washing limestone must always be discharged via sedimentation ponds, and the surface water produced in the area surrounding the pits must be discharged separately.

Some cement and lime works are major water consumers, but because of the process involved they cause no water pollution. In cement works approximately 0.6

m^3 of water per tonne of cement is required to cool the machines. Most of this water is in circulation, thus only the water losses need be made up. In plants involved in the drying process, water is also used for cooling the kiln exhaust gases, resulting in a calculated net consumption of approx. 0.4 - 0.6 m^3 of water/t of cement. In plants using the wet process an additional 1 m^3 of water/t of cement or so is required for the sludge milling. This water is discharged again by evaporation.

In the lime industry water is required for slaking burnt lime (approx. 0.33 m^3/t of lime). Some lime works consume an additional 1 m^3 or so of water per tonne of lime for washing the raw limestone when extremely pure qualities are required. After use, this washing water is fed to settling basins or settling ponds where the fine particles are deposited and the residual water evaporated or partially re-used.

The gypsum industry requires relatively little water because the processes take place at low temperatures, with the result that no cooling energy is required. In plasterboard production, water is added to the raw gypsum and remains in the product to set the gypsum (conversion of hemihydrate to dihydrate).

Water demand can be reduced by increasing the proportion of circulating water or

by minimising the water losses.

In dry areas the cooling water demand can be reduced by installing special electrostatic precipitators which are operational at higher exhaust gas temperatures.

Any sanitary water produced must be discharged and disposed of separately.

2.4 Soils

In the area surrounding cement, lime and gypsum works the soils may be impaired by falling dust where the dedusting plants are inadequately maintained.

Although potentially environmentally relevant trace elements can be introduced into the cement production process by special raw material components such as iron ore and, more recently, by the increased use of combustible waste materials, these hazardous substances are almost completely absorbed by the cement clinker in the molten state, chemically bonded and therefore rendered harmless. To rule out the possibility of adverse effects when using special raw material components or waste products from other industries as fuel from the outset, analyses must be

carried out te detect environmentally relevant trace elements such as lead (Pb), cadmium (Cd), tellurium (Tl), mercury (Hg) and zinc (Zn), which are deposited in the filter dusts. If necessary, technical measures such as dust separation must be applied to prevent the accumulation of hazardous substances in the process.

2.5 Workplace

Numerous machines generating noise levels of 90 dB(A) are still operated in cement, lime and gypsum works, even with the present state of the art. Noise levels can generally be reduced by means of static devices. Permanent workplaces inside the plants, e.g. control platforms, must be soundproofed, but if continuous noise levels of 85 dB(A) are still produced, hearing protection must be made available. At noise levels in excess of 90 dB(A) this protection must compulsorily be worn to avoid hearing impairment. Even where personnel remain in high-noise process areas for short periods, hearing protection is recommended.

In exceptional cases, e.g. during repair work or when rectifying faults, personnel may be exposed to high temperatures and higher levels of noise and dust for long periods, and suitable protective devices and protective clothing must be provided for these tasks. Moreover, work in the danger area must be restricted and

supervised.

2.6 Ecosystems

Cement, lime and gypsum works require raw materials close to the surface, thus interference with the surrounding landscape cannot be avoided in the extraction of raw materials. The environmental effects of extraction are described in the environmental brief Surface Mining.

When selecting locations for cement, lime and gypsum works, due consideration must be given to the environmental aspects. In the case of locations in areas previously used for agriculture, possibilities for alternative employment must be examined, particularly for affected women. Besides complying with the regulations concerning waste gases, dust, noise and water, the conditions as regards the building land, integration in the landscape, and the infrastructure of the location must also be examined. Infrastructural considerations include, amongst other things, the recruitment and housing of employees, transport systems and traffic density and the existing and planned industrialisation of the area.

Since the environmental impact is not limited to the factory area, the local

population, including women and children in particular, should be given access to medical care.

In cement production approximately 1.6 t of raw material per tonne of cement and additional quantities of gypsum are required, bringing the total raw material requirement to approximately 1.65 tonnes. In lime production the raw material requirement of approx. 1.8 t per tonne of finished product is about 10% higher than for cement production. In calculating this raw material requirement, the overburden, which varies considerably from deposit to deposit, is not taken into account. In Germany most of the gypsum requirement could now be covered by the gypsum produced in flue gas desulphurisation plants, so that producing this raw material would no longer affect the landscape.

It is advisable to build up financial reserves for the subsequent recultivation of a quarry, even while the quarry is operational.

3. Notes on the analysis and evaluation of environmental impacts

Limit values for exhaust gas, dust and water have been formulated for dischargers of wastewater in the provisions of TA-Luft and TA-Lrm (Technical Instructions on Air Quality Control and Technical Instructions on Noise Abatement), in the Guidelines adopted by the Association of German Engineers (VDI) and in the administrative regulations specific to the various industries. Similar values are being adopted by most European countries. The US regulations published by the Environmental Protection Agency (EPA) are frequently more stringent than the German regulations, particularly in California.

For countries without their own environmental protection laws, these values must be examined and adapted in the individual case, taking the prevailing environmental conditions into consideration. In exceptional cases, particularly for rehabilitation of plants, special regulations must be established, but new plants should conform to the European standard values for environmental protection.

The Compendium of Environmental Standards offers advice on assessing environmental relevance for individual substances.

***Table 1* - Limitation of hazardous substances under TA-Luft (Technical Instructions on Air Quality Control) and the 17th Administrative Regulation according to 7a of**

the Federal Water Act

		Air	Water		
Cement and lime, gypsum		mg/Nm3	Direct discharger g/m3	Sample type	Indirect discharger** g/m3
Dust		50			
NO_X nitrous oxide grill preheater	NO_X	1.500			
NO_X nitrous oxide cyclone preheater	NO_X				
and exhaust gas heat utilisation		1.300			
NO_X nitrous oxide cyclone preheater	NO_X				

without exhaust gas heat utilisation		1.800			
NO_x nitrous oxide grill preheater	NO_x				
SO_x sulphur oxide as SO_2	SO_x	400			
Fluorides	F	5			50
Chlorine	Cl	30			
Filterable solids			100	1)	1
Total suspended solids	TSS		0.5	2)	1
Chemical oxygen demand	COD		80		
Antimony	Sb	5			
Arsenic	As	1			
Lead	Pb	5	0.50	2)	2
Cadmium	Cd	0.2	0.07	2)	0.5
Chromium	Cr	5	0.10	2)	2

Cobalt	Co	1	0.10	2)	
Cyanides (*)	-CN	5			0.2
Copper	Cu	5	0.10	2)	2
Manganese	Mn	5			
Nickel	Ni	1	0.10	2)	3
Palladium	Pd	5			
Platinum	Pt	5			
Mercury	Hg	5			
Rhodium	Rh	0.2			0.05
Selenium	Se	1			
Tellurium	Te	1			
Thallium	Tl	5			
Vanadium	V	0.2			
Zinc	Zn		2.00	2)	

Tin	Sn	5			

*	May be formed in reduced burning	COD	Chemical Oxygen Demand
**	Law applicable in the German state of Baden-Wrttemberg	TSS TA-Luft	Total Suspended Solids Technical Instructions on Air Quality Control
1)	Two hour mixed sample	VwV	Administrative Regulation
2)	Random sample	WHG	Federal Water Act

In developing countries dust emissions of 100 mg/Nm^3 of exhaust gas or spent air should on no account be exceeded. Higher dust emissions will cause both internal and external environmental burdens.

Similarly, wastewater disposal should meet the minimum requirements imposed by the regulations laying down limits for dischargers of wastewater into receiving bodies of water.

The noise problem is underrated in many countries, but constant noise can lead to permanent damage. Here too, therefore, the prescribed noise limits must be

adhered to in the workplace and in the surrounding residential areas (Section 2.2), and encroachment on residential areas must be prohibited.

All parameters must be regularly checked by means of internal audits, for which purpose training must be given and personnel generally sensitised to environmental matters if necessary.

The use of land by the cement, lime and gypsum industry must be kept within definable limits by forward-looking and detailed planning covering the areas of mining, recultivation and water management. The high costs often mean that there is no money available for recultivation of pits, often resulting in direct or consequential damage that may be difficult to repair (see environmental brief Surface Mining)

3.1 Inspection and maintenance of environmental protection installations

A control centre independent of the production process must be established to comply with existing environmental protection regulations. The responsible personnel must be enabled to perform and monitor all inspection functions including measurements relating to environmental protection in the works. They

should be available for consultation on investments and take charge of negotiations with environmental protection authorities. Moreover, this department is responsible for ensuring that all environmental protection installations are regularly maintained and upgraded. This internal environmental department is also responsible for staff training.

4. Interaction with other sectors

Cement production may touch on other project areas, particularly where additional raw material components are used. For example, use is made of materials produced in lime works with inadequate lime content, other waste materials such as crystallised calcium carbonate from the chemical industry or ferrous residues from sulphuric acid production. Up to 5% gypsum per tonne of cement is required to control the rate of setting in the cement, and a major proportion of this gypsum requirement is now met in Europe by gypsum from flue gas desulphurisation plants. Up to 85% of fly ashes from power station dedusters and slags can also be added to the clinker to produce cement varieties with special properties.

Because of the high temperatures and comparatively long holding times of the materials in the relevant areas, cement kilns in particular are ideal for disposing of combustible waste. This possibility is increasingly important in countries where large quantities of vegetable waste with high potential energy, such as rice chaff, are produced in the region.

In the cement, lime and gypsum industry, secondary activities such as quarries, fuel stores, workshops etc. also exert environmental impact.

***Table 2* - Environmental impacts of adjacent project areas - cement, lime and gypsum**

Interacting project areas	**Nature of intensification of impact**	**Environmental briefs**
Extraction/storage of raw materials and fuels	- Landscape impairment - Pollution of bodies of water - Waste storage in former pits	Surface Mining Planning of Locations for Trade and Industry Urban Water Supply Rural Water Supply

Disposal of solid and liquid waste	- Discharge of deposited solids e.g. filter dusts - Pollution of bodies of water by wastewaters	Solid Waste Disposal Disposal of Hazardous Waste
Maintenance of workshops and transport facilities	- Risks of handling water pollutants (e.g. solvents) - Impacts of transport and traffic (noise, link roads)	Mechanical Engineering, Workshops Road Building and Maintenance Planning of Locations for Trade and Industry

5. Summary assessment of environmental relevance

The environmental impacts of cement, lime and gypsum works are caused by exhaust gas, dust, noise and water. The following table assigns values to the individual process stages as regards the environmental burden which they impose.

Table 3 **- Environmental impact of process stages (cement/lime/gypsum)**

Process	Air		Noise	Water1)	Soil	Work-place
	Exhaust gas /flue gas	Dust				
Extraction	1	1	2	2	3	2
Precrushing	1	1	3	1	1	2
Rough milling/mixing	2	3	4	2	2	3
Burning	3	3	3	2	2	3
Cement	1	3	4	2	2	2
milling	2	3	2	3	3	2
Lime slaking	1	2	1	1	1	1
Packing	1	2	1	1	1	1
Loading						

Key: 1 very slight; 2 slight; 3 moderate; 4 considerable

1) dry process only

Proven technologies have been available for a good many years to reduce pollutant loads. In new plants for the cement industry in the industrialised countries, the costs of environmental protection measures, in the widest sense of the term, already account for as much as 20% of the total investment cost, and in the future this proportion will increase still further.

The more sophisticated the dedusting method, the greater the importance of systematic monitoring and maintenance for the continuing reliability and efficiency of the plants. Besides dedusting plants, changes in burning technology are becoming increasingly important for reducing NOx values.

Catering for the needs of the environment when planning and erecting cement, lime and gypsum works can also save money. The dusts generated are mainly preliminary, intermediate or end products which can reduce the direct production costs if recycled and returned to the process. Reduced ejection of dust also reduces wear on machines, thereby increasing their availability and saving repair costs.

The cement industry is becoming increasingly important as a recycler of waste

materials such as food, waste oil or rubber tyres, thereby reducing the need for dumping. The initial fear that this disposal might lead to an increased emission of environmentally relevant trace elements has been allayed by measurements carried out during operation. When the materials are burnt, particular attention must be paid to correct firing, design and monitoring of the plants. Therefore the regulations concerning waste gas emissions and monitoring of such plants have been made more stringent.

The designers of a new plant must consider what environmental protection measures are necessary and appropriate as early as the planning phase. Suitable guidelines must also be established during the planning phase for countries which do not have their own regulations in this area.

Early involvement of neighbouring population groups in the planning and decision-making processes will enable measures to be devised to deal with any problems arising.

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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47. Ceramics - Fine, utilitarian and industrial

Contents - Previous - Next

Contents

1. Scope

Fine, industrial and utilitarian ceramics cover the following industrial sectors:

- **Ordinary ceramics: tiles, roof-tiles, earthenware, expanded clay, wall tiles and floor slabs, refractory products**

- Fine ceramics: earthenware, pottery, fine earthenware, porcelain, electrical porcelain, sanitary products, grinding discs and abrasive wheels

- Technical ceramics

Most ceramics companies are established in the vicinity of clay deposits. (This environmental brief deals only briefly with the extraction of raw materials; for further details refer to the environmental brief Surface Mining. Advice on processing and transportation of raw materials is also given in the relevant environmental brief. The size of ceramic plants and their daily throughputs vary from a few kilograms for technical ceramic plants, normally 10 to 50 t/day for fine ceramics, to as much as 450 t/day in the tile industry. Since many companies operate different types of production, the total output of the works is often higher than the typical daily output of a specific product.

The fine, industrial and utilitarian ceramics industries use all types of clays, kaolins and fireclays (burnt clay), feldspars and sands as a raw material base. The refractory, abrasives and technical ceramics industries also use numerous high-temperature-resistant and abrasion-resistant oxides such as corundum (Al_203), zirconium oxide (ZrO_2) and silicon carbide (SiC).

Besides using their own, readily available raw materials, many companies are increasingly purchasing ready-processed raw materials, particularly for refractory products, abrasives and technical ceramics, as well as the raw materials required for glazes and frits.

The following process sequence is typical of the production processes in industrial, utilitarian and fine ceramics:

- **extraction, processing, forming, drying, partial glazing or enamelling, firing, sorting/packing and transportation.**

Execution of the individual process stages varies according to the selected method. Generally speaking, casting, plastic or drying processes are employed, with smooth transitions between the process stages.

***Table 1* - Production processes**

Casting processes	**Plastic processes**	**Dry pressing processes**
- Porcelain - Sanitary products	- Tiles - Roof tiles	- Refractory products - Wall tiles, floor slabs

- Electrical porcelain - Refractory	- Expanded clay - Cleaving tiles - Electrical porcelain - Pottery - Earthenware	- Pottery - Earthenware tiles - Technical ceramics - Steatite - Abrasive wheels

- In the casting process the raw materials are dosed, wet-ground and poured into plaster moulds as so-called slip. During pressure casting, the slip is shaped to produce the blank under pressure in machines.
- In the plastic process the raw materials are normally prepared in the wet state, mixed and shaped with moisture content of 15 - 20% water.
- In the dry pressing process used in fine ceramics, the raw materials are frequently prepared in the wet state, then dried in a spraying tower to a residual moisture content of 5-7%. In the refractory industry the raw materials are mixed dry and are often processed with pressing moisture content of less than 2%, also using organic and inorganic binding agents.

The moulded products are dried and then fired. They are generally fired in high-power tunnel kilns; special products are fired mainly in individual, hood-type or batch kilns, while fast-burning products are fired in roller hearth kilns of various

designs. In many countries, tile products in particular are often fired in self-built single-chamber and ring kilns or in charcoal kiln systems.

Many fine ceramic products are glazed or enamelled before firing.

Depending on the raw materials used, the firing temperatures in industrial, utilitarian and fine ceramics begin at 950C for some tile products, for example, whereas most fine ceramic products are fired at between 1100C and 1400C. Refractory and technical ceramic products have firing temperatures of 1280 to 1900C. (Pure glaze baking is done at lower temperatures.) The dual firing process is sometimes used for porcelain and very rarely for wall tiles.

Energy consumption depends on the product and the process; in the tile industry, because of the low firing temperatures, it is between 800 and 2100 kJ/kg of manufactured product, but in almost all other areas of industrial, utilitarian and fine ceramics it is on average much higher per manufactured product, and may be as much as 8000 kJ/kg of product.

After firing the products must be sorted and sometimes reworked, which will involve varying labour costs depending on the product.

2. Environmental impacts and protective measures

2.1 Air

2.1.1 Waste gases/flue gases

Hardly any waste gases are produced in the extraction, processing and moulding of ceramic products. Exceptions to this are the demoisturisation in the spraying tower, e.g. during the production of tiles, and the dry crushing plants used in clay processing, where harmless water vapour is given off.

During the glazing process, care must be taken to prevent glazing vapours, some of which contain heavy metals and other toxic substances, being discharged to the environment or being inhaled by personnel. Therefore only glazing plants which are equipped with the necessary extraction and wastewater discharge equipment should be licensed. Operating or maintenance personnel working in this area must be protected by breathing filters. When the glazed products are dried, mainly harmless water vapour is given off.

The amount of flue gas produced during firing depends on the emission of the fired product and on the type of fuel used. Volatile components are sometimes given off from the product mass and from the fuel.

The adverse environmental effects of fluorine emissions from the ceramics industry have come to be recognised as a serious problem, particularly in recent years, in view of the damage occurring in the vicinity of ceramic works (animals and plant diseases). Fluorides are present in all ceramic raw materials and are sometimes emitted in the waste gas during firing. Because of this, fluorine emissions from new plants built in Europe must be less than 5 mg/Nm^3.

Because ceramic firing plants operate continuously, residual substances from other sectors such as waste oils or organic components from water treatment plants are sometimes used as fuel additives. Plants which use such materials are subject to special regulations because dangerous oxides may be introduced via these waste substances and re-emitted with the flue gas.

German companies must conform to the following values when burning waste substances:

- Total dust 10 mg/Nm^3 max.

Sulphur dioxide 50 mg/Nm^3 max.

Cd, Tl, Hg, 0.1 mg/Nm^3 (per element)
(cadmium, tellurium, mercury)

Other heavy metals 1 mg/Nm^3

Because of these conditions, waste substances cannot be used in the ceramic industry without the installation of additional water-spray separators.

Nitrous oxide emission during firing appears not to be a problem in most plants which are operated at relatively low temperatures, but special solutions must be found for high-temperature firing plants in the refractory industry for denitrifying the waste gases.

No waste gases are generally produced during sorting, packing, internal conveying, processing or refining. Only in very rare cases, e.g. during subsequent colouring or printing, may environmental pollution be caused by waste gases. These problems

must be solved on a case-to-case basis.

2.1.2 Dust

Dust presents a latent risk in fine, industrial and utilitarian ceramic plants, particularly for the labour force. Fine quartz dusts < 5 m may cause silicosis.

Depending on the geological and meteorological conditions, dusts may occur in pits during extraction of the raw materials which can be reduced by wetting and by the use of appropriate extracting and conveying methods. (See environmental brief Surface Mining).

Whilst hardly any dust is produced in the wet medium of the plastic processes, in the preparation, moulding and drying processes a variety of methods can be adopted to minimise dust formation, such as continuous cleaning of the works, concreting and sealing of floors, efficient dedusting systems and wet grinding of porcelain and sanitary products.

Silicosis in the German porcelain and refractory industry, particularly in the case of silicate products, has been successfully minimised by systematic dust control in all

working areas, but in many countries it is still a problem. The statutory limits for quartz dusts impose a maximum allowable concentration (MAK) of 0.15 mg/Nm^3 of fine dust, and the air may contain no more than 4 mg/Nm^3 of fine dust containing more than 1% by weight of quartz.

In Germany according to TA-Luft [Technical Instructions on Air Quality Control] the total dust content must not exceed 50 mg/Nm^3 in the waste gas at a mass flow of more than 0.5 kg/h, or 150 mg/Nm^3 at a mass flow up to and including 0.5 kg/h.

During firing the dust burden is generally very slight. Dry filters are now frequently installed in kilns, water-spray separators more rarely. Dry absorption systems may create dust, thus care must be taken to ensure that when such systems are used the maximum dust quantity of 50 mg/Nm^3 in the flue gas is not exceeded. These plants require regular maintenance to preserve their efficiency (see 3.1).

2.2 Noise

In most production processes in the ceramic industry, noise is emitted but rarely exceeds 85 dB(A) (see 2.5 - Workplace).

During the extraction of raw materials, noise and associated vibrations may occur for a short time as a result of blasting, sometimes causing a serious nuisance to residents living close by. However, such noise can be substantially reduced by means of suitable detonation methods. The machines used for mining can now be soundproofed to such an extent that they meet the noise protection requirements. (See environmental brief Surface Mining).

During dressing, noise pollution is liable to occur e.g. through the use of rebound crushers and mills for the crushing of hard materials. These crushing installations and the adjoining dressing installations can be encapsulated or soundproofed in such a way as to protect the environment from oppressive noise.

During the drying and firing phases, fans are used which may generate noise levels in excess of 85 dB(A). These noise sources must be installed outside permanent workplaces. During special ceramic production processes, e.g. when splitting cleaving tiles and when using sheet metal plates, frames or pallets for internal conveying systems, typical noise problems arise. However, such noise levels can be reduced by taking appropriate measures, e.g. encapsulating permanent workplaces and buffering mobile conveying systems with rubber.

To avoid noise nuisance the immission values for the residential areas located close to the ceramic production centres should not exceed 50 - 60 dB(A) during the day and 35 - 45 dB(A) at night. Housing developments should be sited at least 500 m from a ceramic factory.

2.3 Water

In Germany, ceramic works must comply with the administrative regulations regarding permitted substances in the wastewater.

Works laboratories must be established to monitor the works in question.

Table 2 **- Maximum permissible values for direct dischargers according to the 17. VwV of the WHG**
[17th Administrative Regulation of the Federal Water Act]

Parameters	**Maximum value**
Filterable solids from the 2-hour mixed sample Total suspended solids from the random sample	100 ml 0.5 mg/l

Chemical oxygen demand (COD) from the 2-hour mixed sample	80 mg/l
Lead content from the 2-hour mixed sample	0.5 mg/l
Cadmium content from the 2-hour mixed sample	0.07 mg/l

To avoid exceeding the applicable values, the water produced in the area of the pit must be fed through stilling basins, with the addition of sedimenting agents if necessary. The surface water occurring in the area surrounding the pit must be discharged separately.

Fresh water consumption in modern ceramic plants is low because the water required for the process is circulated internally. Some of the water used is driven off again as water vapour in the production of granulates in the spray tower and in the drying of the products. Wastewaters produced contain clay, flux and other ceramic raw materials which are precipitated and returned to the process by internal circulation.

Sanitary water produced in fine, industrial and utilitarian ceramic works must be discharged and disposed of separately.

2.4 Soils

Nowadays old clay pits are frequently used for storing waste products of all kinds, because of their relatively low water permeability. Soil damage may occur due to elutriation and water accumulation in old pits, because when the pit was worked, water management was not normally up to present-day environmental standards.

Soil is rarely impaired by spoil from ceramic works because the waste generated during production is reused in the plant's own production or in other ceramic works, so that spoil dumps are only formed where the plant is operated inefficiently. Exceptions to this are the small quantities of gypsum produced during porcelain, sanitary and roof tile production, which have to be properly disposed of.

2.5 Workplace

Personnel working in ceramic plants may be endangered or oppressed by noise, dust and heat in certain work areas.

Permanent workplaces near sources of loud noise must be soundproofed. If the noise level is still not less than 85 dB(A) despite soundproofing measures, hearing

protection must be made available, and from 90 dB(A) upwards it must be compulsorily worn to prevent resulting hearing impairment. Hearing protection must also be worn by personnel working in high-noise production areas for short periods.

During firing in tunnel, reciprocating, roll-over or bogie hearth kilns, temperature stress on personnel is relatively low in modern plants, but in plants with old single chamber and ring kilns, there may be considerable exposure to heat when the product is inserted and removed. In special cases, e.g. if a tunnel kiln car caves in, work must be carried out for a short time under conditions of extremely high temperature. In this case, strict protective measures, e.g. the wearing of thermal suits, must be complied with. Moreover, such work must only be carried out under appropriate supervision.

In fine ceramic works, particularly in the porcelain and silicate industry (refractory products), personnel may be at risk from continuous exposure to quartz dust. In addition to technical precautions, regular medical check-ups are essential here to ensure that fibrotic changes (changes in the pulmonary alveoli) are detected early, so that the employee in question can be protected from permanent injury through redeployment.

2.6 Ecosystems

When raw materials are extracted the landscape is impaired and there is an alteration to the surface (see environmental brief Surface Mining). Since the raw material requirement per plant is not very high, the individual mining areas are generally also relatively small. Many different types of clay are present in each clay pit, and with the introduction of suitable processing methods even low quality clays have been successfully processed in recent years, thereby reducing the amount of spoil in the vicinity of clay pits.

When selecting a site for a ceramic plant, due consideration must be given to the environmental aspects. In the case of locations in areas previously used for agriculture, possibilities for alternative employment must be examined, particularly for affected women. Besides complying with the regulations concerning waste gases, dust, noise and water, the conditions as regards the building land, integration in the landscape, and the infrastructure of the location must also be examined.

Infrastructural considerations include, amongst other things, the recruitment and housing of employees, transport systems and traffic density and the existing and planned industrialisation of the area.

Since the environmental impact is not limited to the factory area, the local population, including women and children in particular, should be given access to medical care.

Recycling of fine ceramic consumer goods, after use on or in buildings or in the home, is hardly feasible because of the variety of materials and small quantities involved at the points of consumption. On the other hand, in the refractory industry, particularly in steel works, over 30% of the refractory products are recycled.

3. Notes on the analysis and evaluation of environmental impacts

Emission limits for waste gas, dust and water have been formulated in the provisions of the German TA-Luft and TA-Lrm [Technical Instructions on Air Quality Control and Technical Instructions on Noise Abatement], in the guidelines adopted by the Association of German Engineers (VDI) and in the regulations specific to the various industries for dischargers (under the WHG - German Federal Water Act) and MAK (maximum allowable concentration) values have been established by the

Berufsgenossenschaft (employers' liability insurance association) of the ceramic and glass industry for avoiding silicosis. These emission limits are being adopted in similar form by most European countries. The US regulations published by the Environmental Protection Agency (EPA) are frequently even more stringent than the German regulations, particularly in California.

For countries without their own environmental protection laws, these values must be examined taking into consideration the prevailing environmental conditions in the individual case and adapted to the particular circumstances. In exceptional cases, particularly for rehabilitation of plants, special regulations must be established, but new plants should conform to the standard values of environmental protection.

The Compendium of Environmental Standards offers advice on assessing environmental relevance for individual substances.

Table 3 - Limitation of hazardous substances under TA-Luft (Technical Instructions on Air Quality Control) and the 17th Administrative Regulation according to 7a of the German Federal Water Act

		Air	**Water**		
Ceramics		**mg/Nm^3**	**Direct discharger g/m^3**	**Sample type**	**Indirect discharger** g/m^3**
Dust		50			
Sulphur dioxide as SO_2	SO_2				
at a mass flow < 10 kg/h		500			
Sulphur dioxide as SO_2	SO_2				
at a mass flow > 10 kg/h		1,500			
Nitrous oxide NO_x	NO_X	500			
Fluorides	F	5			50
Chlorine	Cl	30			
Filterable solids			100	1)	1
Total suspended solids	TSS		0.5	2)	1
Chemical oxygen demand	COD		80		

Antimony	Sb	5			
Arsenic	As	1			
Lead	Pb	5	0.50	2)	2
Cadmium	Cd	0.2	0.07	2)	0.5
Chromium	Cr	5	0.10	2)	2
Cobalt	Co	1	0.10	2)	
Cyanides (*)	-CN	5			0.2
Copper	Cu	5	0.10	2)	2
Manganese	Mn	5			
Nickel	Ni	1	0.10	2)	3
Palladium	Pd	5			
Platinum	Pt	5			
Mercury	Hg	5			
Rhodium	Rh	0.2			0.05

Selenium	Se	1			
Tellurium	Te	1			
Thallium	Tl	5			
Vanadium	V	0.2			
Zinc	Zn		2.00	2)	
Tin	Sn	5			

	May be formed in reduced burning	COD	Chemical Oxygen Demand
**	Law applicable in the German state of Baden-Wrttemberg	TSS TA-Luft	Total Suspended Solids Technical Instructions on Air Quality Control
1)	Two hour mixed sample	VwV	Administrative Regulation
2)	Random sample	WHG	Federal Water Act

When waste materials are used as fuel, the above emission limit values must on no account be exceeded, and regular inspection of the charge material, firing system and process, as well as of the waste gases and dusts, is essential (see 3.1).

It is vital that the dust regulations, based on the maximum allowable concentrations in the workplace, are adhered to, particularly in the porcelain and silicate industry. Non-compliance with these regulations leads to diseases with long-term consequential damage. Intensive dust abatement in all plants and in all sections of plants is imperative in this regard also.

The noise problem is underrated in many countries, but constant noise can lead to permanent damage. Here too, therefore, the prescribed noise limits must be adhered to in the workplace and in the surrounding residential areas, and encroachment on residential areas must be prohibited (see 2.2 and 2.5).

Managers of ceramic production plants must be alerted to the specific risks to employees and must be trained in the use of protective measures so that employees are not exposed to health hazards through ignorance (see 3.1). Suitable training must be given and personnel generally made aware of environmental concerns.

In all plants an internal water circuit must be carefully planned. Treated wastewaters which are discharged into receiving bodies of water are subject to minimum requirements which must be met to avoid damage to the ecosystem in areas close to the works.

All the parameters must be regularly checked by internal audits (see 3.1), and works laboratories must be set up to monitor adherence to the specified values.

3.1 Inspection and maintenance of environmental protection installations

A control centre independent of the production process must be established to comply with existing environmental protection regulations. The responsible personnel must be enabled to perform and monitor all inspection functions including measurements relating to environmental protection in the works. They should be available for consultation on investments and take charge of negotiations with environmental protection authorities. Moreover, this department is responsible for ensuring that all environmental protection installations are regularly maintained and upgraded. This internal environmental department is also responsible for staff training.

4. Interaction with other sectors

In the ceramic industry, interaction between different branches of production is

common and is often necessary for a smooth production process. Fine, industrial and utilitarian ceramic works rely on numerous secondary operations, such as extraction plants, fuel stores, workshops and transport systems involving a number of other sectors.

Table 4 **- Environmental impacts of adjacent sectors - fine, industrial and utilitarian ceramics -**

Interacting sectors	**Nature of intensification of impact**	**Environmental briefs**
Extraction/storage of raw materials and fuels	- Landscape impairment - Pollution of bodies of water - Waste storage in former pits	Surface Mining Planning of Locations for Trade and Industry Urban Water Supply Rural Water Supply
Disposal of solid and liquid waste	- Discharge of deposited solids e.g. filter dusts - Pollution of bodies of water	Solid Waste Disposal Disposal of Hazardous Waste

	by wastewaters	
Maintenance of workshops and transport facilities	- Risks of handling water pollutants (e.g. solvents) - Impacts of transport and traffic (noise, link roads)	Mechanical Engineering,Workshops Road Building and Maintenance Planning of Locations for Trade and Industry

All ceramic products must be packed, and the packing materials required for this purpose must be disposed of or recycled after use. Environmental impacts can be avoided in this area by making use of modern processes employed in the packaging industry. Moreover, the ceramic industry is highly transport intensive, since tiles, roof tiles, cleaving tiles and refractory products have high bulk weights and therefore require suitable means of transport.

5. Summary assessment of environmental relevance

The individual process stages in the industrial, utilitarian and fine ceramic industry do not generally give rise to severe environmental burdens.

Table 5 **- Environmental impact of process stages (ceramics)**

Process	Air		Noise	Water1)	Soil	Work- place
	Exhaust gas /flue gas	Dust				
Extraction	1	2	2	3	3	1
Preparation	1	3	3	2	1	2
Moulding	2	2	2	1	1	2
Glazing	3	3	2	3	2	3
Drying	2	1	2	1	2	1
Firing	3	1	3	1	2	1
Sorting	1	1	3	1	1	2
Packing	1	1	1	1	1	1
Internal transport	1	1	1	1	1	2
Processing/	1	2	2	2	2	2

Refining						

Key: 1 very slight; 2 slight; 3 moderate; 4 considerable
1) Depending on composition

Particularly dangerous in the case of free quartz with grain sizes smaller than 5 m

Moreover, numerous measures to protect employees and the environment have been introduced through modernisation of the technologies applied and by installing protective equipment, e.g.:

- Surface mining: pit problems can be overcome by suitable mining planning, water management and recultivation.
- Internal water circuits and downstream stilling basins minimise the wastewater burden.
- Soundproofing of systems and processes prevents long-term hearing impairment.
- Fluorine and sulphur dioxide emissions are reduced to the required levels in the waste gas by controlling the firing processes or by means of downstream separation systems.

- The risk of silicosis is eliminated in relevant plants by technological improvements and dedusting systems, and is monitored by staff conducting routine preventive checks.

The environmental protection installations required in ceramic works may account for as much as 20% of the total investment costs. To achieve the desired results from the equipment in the long term, its efficiency must be guaranteed by proper maintenance. Improvements in the area of personnel and environmental protection can only be achieved by providing proper information and training.

Early involvement of neighbouring population groups in the planning and decision-making processes will enable measures to be devised to deal with any problems arising.

In countries which have no legal guidelines it should be ascertained as early as the planning stage, based on the raw materials to be used and the process technology applied, what environmental protection measures are necessary and appropriate. Environmental protection equipment provided should be of robust design so that the life of this equipment is appropriate to the overall project and so that simple, low-cost maintenance can be guaranteed.

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

48. Glass

Contents - ◄Previous - Next►

Contents

1. Scope

The main raw materials used by the glass industry are sand, lime, dolomite, feldspar, as well as soda, borosilicates and numerous additives which embrace practically the entire periodic system of elements. Its products are a large number of glasses with different properties, many of them further processed after manufacture (Table 1).

Table 1 **- Glass products**

Container glass	**Sheet glass**	**Utility glass and special glass**
- Tall jar - Preserve jar - Medical glass - Packing glass	- Sheet glass (float glass) - Casting glass - Moulding glass - Wire (reinforced) glass	- Optical glasses - Lighting glass - Glass hardware - Laboratory glass - Flasks
Lead crystal and	Mineral fibres	
- Bleaching glass - Goblet glass - Television tubes - Glass fibres for optical transmission	- Glass fibres - Mineral fibres - Borosilicate fibres - Ceramic fibres (high-temperature resistant)	

In the modern glass industry the raw materials are no longer generally extracted by the companies themselves but are purchased in the desired chemical and physical composition, e.g. in terms of granulation, moisture content, impurity (for the environmental relevance of the extraction of raw materials refer to the environmental brief Surface Mining). The substantial differences between the materials to be dosed and mixed necessitate the use of mixing and processing plants where the mixtures are melted in tank furnaces, more rarely in pot furnaces, or special furnaces. Cupola furnaces are still sometimes used for mineral fibres, and electric melting systems are used for manufacturing ceramic fibres. The flue gases formed during melting are nowadays cooled by regenerative or recuperative plants, thereby reducing the specific fuel consumption.

After melting, the glasses are moulded. Most glasses must then be cooled according to the subsequent application, to avoid glass stresses. Glasses are frequently further processed by thermal, chemical and physical post-treatments, such as clamping, pouring, bending, gluing, welding and grinding. Hollow glassware is frequently decorated. Fibres are drawn, centrifuged, blown or extruded after melting, using a variety of technologies.

The capacities of the individual glass-producing companies vary considerably, and it

is often the case that several melting systems with different production programmes are combined in one works. Pot furnaces have a capacity of 3-8 t/day, whilst the tank capacities for special glasses range from 8 to 15 t/day in most cases. In specialist fields, however, the outputs are much higher, e.g. tanks for container glass melt between 180 and 400 t/day, float glass tanks attain melting capacities of between 600 and 1000 t/day.

The melting temperatures of the glass generally range between 1200 and 1500C, the temperature depending for the most part on the mixture and the product to be manufactured. The amount of energy required to melt 1 kg of glass is between 3700 and 6000 kJ. The capacities and energy consumptions indicated above are average values which depend on the design and operating time of the tank, the production programme and the actual tank load. The specific energy consumption should be reduced by the use of waste fragments wherever possible.

2. Environmental impacts and protective measures

2.1 Air

2.2.1 Waste gases/flue gases

In a glass works waste gases are formed during melting of the glass as a result of combustion of the fuels used. In addition to the combustion residues, such as sulphur dioxide (SO_2) and nitrous oxides (NO_x), flue gases also contain compound components such as alkalis (Na, K), chlorides (-Cl), fluorides (-F) and sulphates (-SO_4).

Sulphur dioxide (SO_2)

Sulphur dioxide or SO_x emissions, made up of $SO_2 + SO_3$, lie within the range of 1100 to 3500 mg/Nm^3 of waste gas in the case of regeneratively heated glass tanks within one firing period. Where the chambers are insufficiently scrubbed much higher peak values, as high as 5800 mg/Nm^3 of waste gas, are found at the start of the firing change.

Electrically heated or electrically booster-heated tanks can be operated continuously at a lower SO_x load (< 500 mg/Nm^3). On the other hand, the use of

heavy oil with a very high sulphur content (up to 3.7%) gives rise to extremely high emission values. Natural gas, which does not normally contain any sulphur, does not affect the formation of SO_X. Some of the sulphur emission is also caused by the addition of sulphate to the mixture.

The currently applicable Technical Instructions on Air Quality Control (TA-Luft 1986) indicates a maximum value for sulphur dioxide of 1800 mg/Nm^3 of waste gas, thus in normal glass tanks absorption of the excess sulphur dioxide is required. The sulphur dioxide content can be reduced by feeding magnesium, calcium carbonate and soda into the flue gas. The dusts forming during this process must also be filtered out again.

Nitrous oxides (NO_X)

A further environmental problem in glass manufacture is posed by the NO_X loads occurring, which can range from 400 to 4000 mg/Nm^3 of waste gas. During nitrate refining, i.e. the reduction of the proportion of bubbles or nodules in the glass mass by nitrates, these values are considerably increased. The Nox content depends on the air preheating temperature, the air coefficient (excess air) and the process and

type of tank used. NO_X content can be reduced using catalysts with ammonia (NH_4). This process, which is currently undergoing large-scale trials, promises to reduce NO_X content to below 500 mg/Nm^3 NO_X load.

The NO_X limits applicable in Germany (1991) for the different tanks are summarised in Table 2.

Table 2 **- Nitrous oxide emissions under applicable version of TA-Luft [Technical Instructions on Air Quality Control]**

Plant	**Oil-fired mg/Nm^3**	**Gas-fired mg/Nm^3**
Pot furnaces	1200	1200
Tanks with recuperative heat recovery	1200	1200
Day tanks	1600	1600
Horseshoe flame tanks with regenerative heat recovery	1800	1800

Cross-burner tanks with regenerative heat recovery	3000	3000
Values attainable for electrically heated tanks	500	

The emission values of nitrate-refined tanks must not exceed twice the above-mentioned values.

Fluorine/chlorine

The fluorine contents of the waste gas (calculated as HF) must not exceed certain values since plants and animals can be harmed by fluorine. Fluorides are contained in almost all raw materials used in glass manufacture. Through the addition of waste fragments originally melted with fluorspar to the melting process, the fluorine concentration in the waste gas may exceed 30 mg/Nm^3.

The low fluorine limit value prescribed in Germany under TA-Luft 1986 of < 5 mg/Nm^3 can only be achieved through systematic selection of raw materials or through additive reactions with calcium and alkali compounds.

Chlorine compounds, which are introduced into the mixture primarily through soda or salt-contaminated raw materials, also cause problems. Measurements have indicated gaseous chloride concentrations of between 40 and 120 mg/Nm^3 of waste gas. Problems with gaseous chlorine emissions (HCl) arise mainly in heavy-oil-fired plants. Like sulphur dioxide, chlorides must also be absorbed by calcium or sodium compounds in the mixture.

2.1.2 Dust

One problem area in the glass industry is the dust emission of the glass melting furnaces caused by the high temperatures, and the evaporation of mixture components which sublimate as fine dusts. The dust concentration of different melting tanks without filters is indicated in Table 3.

***Table 3* - Dust concentration in the waste gas of glass tanks - Measured values -**

Glass type	**Firing**	**Dust in the waste gas1) mg/mg^3**
Soda-lime glass	Natural gas	68 - 280

Soda-lime glass	Fuel oil S	103 - 356
Potassium crystal glass	Natural gas/Fuel oil EL	45 - 402
Lead glass	Natural gas/Fuel oil EL	272 - 1000
Borate glass	Natural gas/Fuel oil EL	120 - 975
Borosilicate glass fibres	Natural gas/Fuel oil EL	1425 - 2425

1) Waste gas in the normal condition, 8% oxygen in the waste gas

The values indicated in the table show that glass furnaces without filter systems have high dust concentrations in the waste gas. The prescribed limits of 50 mg/Nm^3 of dust in Germany (TA-Luft 1986) are difficult to achieve without dedusting plants. Electrostatic dust precipitation, fabric dust filters with sorption or wet scrubbing may be used, depending on the type and capacity of the furnace. However, the dedusting systems must also help to reduce fluoride, sulphate and chloride emissions, as well as toxic heavy metals.

Emissions of lead, cadmium, selenium, arsenic, antimony, vanadium and nickel are particularly critical. These environmentally harmful dusts, which are formed primarily during the manufacture of special glasses in the waste gas, can only be

separated by dust filters.

2.2 Noise

The noise generated is particularly significant in the glass industry during melting, moulding and cooling and in the chambers of the compressors, whilst hardly any problematic noise loads are generated in the areas of extraction, processing, packing and finishing.

In the furnaces noise levels of up to 110 dB(A) may be reached during melting and in the feeder. The large fans which produce the quantities of air required and the compressors also generate relatively high levels of noise. However, few workplaces are situated in the vicinity of these noise sources. In modern works these workplaces are provided with static noise protection devices. The control systems of the plants can be soundproofed or can be installed outside the noise zone. Hearing protection must be worn for short-term working in these zones.

An extremely critical area in terms of noise emission, which is also affected by high temperatures and oil vapours, is the container glass moulding area with compressed-air-controlled machines; here the noise load generally exceeds 90

dB(A). In recent years improvements have been made with modified air guides. So far, attempts to enclose the machines for soundproofing purposes have been unsuccessful because of the need for regular oil lubrication of the units and cleaning of the moulds. When the glasses are cooled, noise is generated by fans but can be reduced by suitable designs and enclosures.

To avoid noise nuisance, glass works must be erected at least 500 m away from areas of habitation. The distance from residential areas should be such that no more than 50 to 60 dB(A) is immitted during the day, and no more than 35 - 45 dB(A) during the night.

2.3 Water

The total water consumption per tonne of glass produced varies considerably. Circulating systems should be installed so that only small quantities of additional fresh water are required. The main water-consuming areas of a glass works are:

- **cooling of the compressors required for generating compressed air**
- **cooling of the diesel units sometimes used for power generation**
- **quenching basins for excess glass**

- finishing and refining of glass by grinding, drilling etc.

The wastewater produced in these sectors is cooled and reused, but part is also tapped for other functions, such as:

- moistening the mixture for dust prevention
- cooling of flue gases, particularly in EGR dedusting plants
- moistening of lime products for dry sorption filter plants.

The average water consumption in a glass works should be less than 1 m^3/t of glass produced. The cooling water of the cutting devices and moulding machines, the compressors, any emergency power diesel generators used and also the water from the quenching basins underneath the production machines may be contaminated by oil. This effluent must be cleaned by oil separators. In Germany, if water is discharged it must meet the minimum requirements regarding discharge of effluent into watercourses (direct dischargers). By virtue of these regulations no more than 0.5 mg/Nm^3 of depositable substances may reach the effluent in glass production.

Special disposal arrangements are required for the sewage produced (see the environmental brief Wastewater Disposal).

2.4 Soils

In the area surrounding modern glass works which meet the existing environmental regulations regarding waste gas and dust, are equipped with the necessary cleaning systems and have a suitable internal wastewater circuit and water separator, there is unlikely to be any contamination of the soil or consequent damage to plants or animals.

2.5 Workplace

Employees of glass works may be endangered or oppressed particularly by noise and in certain workplaces by heat. Hardly any dust problems arise in well-maintained glass works, but in special cases, e.g. in the manufacture of special glasses, toxic dusts may pose a health hazard.

In principle no workplace within a plant should be exposed to a continuous noise level in excess of 85 dB(A); at this level hearing protection should be provided, and from 90 dB(A) protection must be worn in all cases. Hearing protection is compulsory in noise-intensive process areas, even when employees remain there only for a short time.

So far it has not been possible, for technical reasons, to enclose glass moulding machines, particularly the noisy container glass machines, or to automate them completely, so that employees must wear hearing protection in these areas. Noise from burner systems, fans and compressors can easily be avoided; firstly there are hardly any workplaces in the vicinity of these machines, and secondly the control units of the machines can be screened against dust, heat and noise. When carrying out maintenance and repair work, employees must wear the prescribed hearing protection and, if necessary, protective clothing.

In the event of stoppage or unexpected breakdown of tanks or faults in the preheating system very high temperatures may occur, since some tanks are operated at temperatures in excess of 1500C. Work in such emergency situations must be carried out under supervision, and protective devices to facilitate the work, such as thermal protective suits, must be available in all works in case of emergency. Contingency plans must be drawn up and regular drills carried out to ensure rapid, targeted intervention in emergency situations.

According to recent studies, glass and mineral fibres are suspected of having carcinogenic effects. Regular medical examinations should therefore be carried out in glass works to identify any problems arising at an early stage and forestall

adverse consequences.

2.6 Ecosystems

Glass works process 70 - 80% natural raw materials (sand, feldspar, dolomite, lime), but these are not generally extracted in the vicinity of the works. About 75% of the natural raw material is quartz sand which nowadays is rarely extracted by the glass works themselves. The soda required is manufactured in Germany synthetically from salt (NaCl) and carbon dioxide, the latter being extracted from limestone. Soda may also be extracted from natural deposits occurring mainly in the USA. Certain of the other raw materials are synthetic or cleaned raw materials such as sodium and boron compounds.

Approximately 1.2 - 1.3 tonnes of raw materials are required to melt one tonne of glass, but the area required for extracting the glass raw materials cannot be determined accurately because the deposits in question are not used exclusively for the glass industry and the extraction levels vary considerably.

If a works carries out its own extraction, the environmental protection aspects must be considered as early as the extraction planning phase, particularly as regards

water management and the constant need for recultivation. The extraction and recultivation costs must be added to the raw material costs (see the environmental brief Surface Mining).

When selecting the site of a glass production centre, the environmental factors must also be taken into account. In the case of sites in areas which have so far been used for agricultural purposes alternative sources of income must be examined, particularly for affected women. Besides complying with the applicable regulations regarding waste gas, dust, noise and water, the subsoil conditions, landscaping and infrastructure must also be examined. The infrastructure includes, among other things, recruitment and housing of employees, traffic and transport systems and the existing and planned industrialisation of the area.

Since the environmental impacts are not limited to the works area, the population groups concerned, particularly women and children, should be provided with access to medical care.

The addition of a recycling system for waste glass may on the one hand reduce the energy requirement for glass manufacture and on the other hand substantially relieve pressure on refuse tips. In a similar vein, disposable packaging systems

should be replaced by reusable packaging systems.

3. Notes on the analysis and evaluation of environmental impacts

The limits - based on TA-Luft (Technical Instructions on Air Quality Control) and TA-Lrm (Technical Instructions on Noise Abatement) and other regulations - summarised in Table 4 for waste gas, dust and noise are now applicable in Germany and are being adopted in similar form by most European countries. The minimum requirements in Germany regarding treated wastewater discharged into receiving bodies of water are also indicated.

Table 4 **- Limitation of hazardous substances under TA-Luft (Technical Instructions on Air Quality Control) and the 17th Administrative Regulation (VwV) according to 7a of the Federal Water Act (WHG)**

	Air		**Water**	
Glass industry	**mg/Nm^3**	**Direct discharger**	**Sample type**	**Indirect**

			g/m^3		**discharger$^{3)}$**
Dust Sulphur dioxide as SO_2 Glass melting furnaces Pot furnaces and day tanks NOx nitrous oxide as NO_2 Fluorides Chlorine Filterable solids Total suspended solids Chemical oxygen demand Antimony	SO_2 NO_x F Cl TSS COD Sb As Pb Cd Cr Co -CN	50 1800 1100 400-3500 5 30 5 1 5 0.20 5 1 5	100 0.50 80 0.50 0.07 0.10 0.10 0.10	1) 2) 2) 2) 2) 2) 2)	**g/m^3** 50 1 1 2 0.50 2 0.20 2

Arsenic	Cu	5			
Lead	Mn	5	0.10	2)	3
Cadmium	Ni	1			
Chromium	Pd	5			
Cobalt	Pt	5			
CyanideS2)	Hg	5			0.05
Copper	Rh	0.20			
Manganese	Se	1			
Nickel	Te	1			
Palladium	Tl	5			
Platinum	V	0.20	2.00	2)	
Mercury	Zn				
Rhodium	Sn	5			
Selenium					
Tellurium					
Thallium					
Vanadium					
Zinc					
Tin					

*	May be formed in reduced burning	COD	Chemical Oxygen Demand
**	Law applicable in the German state of Baden-Wrttemberg	TSS TA-Luft	Total Suspended Solids Technical Instructions on Air Quality Control
1)	Two hour mixed sample	VwV	Administrative Regulation
2)	Random sample	WHG	Federal Water Act

Glass works, which are generally large-scale plants, produce considerable emissions. In principle a maximum of 1800 mg SO_2Nm^3 should be established as the mean guideline value for avoiding serious environmental pollution. The NOx emissions must not exceed the currently applicable values, and nitrate refining should be dispensed with because of the high NO_x levels generated.

No separate wet or dry sorption plants are required to comply with these relatively high mean values. Accurate control of the tank heating is vital in order to attain the required values.

Fluorine and chlorine emissions which may give rise to direct damage must be kept as low as possible. The values indicated above can be achieved by suitable selection

of raw materials and fuels and systematic monitoring of burner operation. A further benefit is that energy consumption can be further reduced by conforming to these guideline values, resulting in greater economy.

The dust emission from glass furnaces should not exceed 50 mg/Nm^3. A dedusting plant should always be installed in order to comply with this limit.

It is vital to adhere to the emission limits for toxic dusts (heavy metals) such as cadmium, lead, fluorine, selenium and arsenic; the maximum values specified in TA-Luft must not be exceeded.

For individual substances, the Compendium of Environmental Standards contains notes on evaluating environmental relevance.

It is absolutely essential to comply with the regulations on permissible noise levels, since failure to prevent or protect against noise can result in permanent injury of employees.

To avoid environmental pollution, the limits laid down for direct water dischargers must be observed, particularly regarding heavy metal concentrations in the effluent.

If no national regulations exist, values in line with German or European standards should be established for the erection of new glass works, particularly in areas already suffering from serious environmental pollution. Special regulations must be introduced for plants already in operation. The parameters defined for the principal hazardous substances must in future be regularly monitored and disclosed by the glass works, so that appropriate steps can be taken immediately in the event of nonconformance (see 3.1).

For all practical purposes it may be assumed that in order to comply with the limits indicated all alkali borosilicate, borate, lead and most special glass furnaces must be equipped with dedusting systems. Allowance must be made for these dedusting and sorption systems as early as the planning phase.

In countries with low-cost electricity it is possible to construct glass furnaces of special design which produce far lower emissions and do not require expensive environmental protection equipment. The energy requirement per kg of glass can also be reduced by introducing such melting methods.

3.1 Inspection and maintenance of environmental protection installations

A control centre independent of the production process must be established to comply with existing environmental protection regulations. The responsible personnel must be enabled to perform and monitor all inspection functions including measurements relating to environmental protection in the works. They should be available for consultation on investments and take charge of negotiations with environmental protection authorities. Moreover, this department is responsible for ensuring that all environmental protection installations are regularly maintained and upgraded. This internal environmental department is also responsible for staff training.

4. Interaction with other sectors

Glass works which rely on numerous secondary operations, such as workshops, compressed air generation, fuel stores, galvanisation shops, refining shops, transport and packing departments etc. are also affected by regulations applicable in other sectors.

Because of the relatively high transport costs, container glass factories must be

located near their main customers. Modern sheet glass works, on the other hand, can only operate economically with capacities upwards of 600 t/day, thus they supply their products to more distant sales areas and are reliant on good transport facilities.

***Table 5* - Environmental impacts of adjacent sectors - Glass -**

Interacting sectors	**Nature of intensification of impact**	**Environmental briefs**
Extraction/storage of raw materials and fuels	-Landscape impairment - Pollution of bodies of water - Waste storage in former pits	Planning of Locations for Trade and Industry Urban Water Supply Rural Water Supply
Disposal of solid and liquid waste	- Discharge of deposited solids e.g. filter dusts - Pollution of bodies of water by wastewaters	Solid Waste Disposal Disposal of Hazardous Waste
Maintenance of	- Risks of handling water	Mechanical Engineering,

workshops and transport facilities	pollutants (e.g. solvents) - Impacts of transport and traffic (noise, link roads)	Workshops Road Building and Maintenance Planning of Locations for Trade and Industry

5. Summary assessment of environmental relevance

The effects of glass works on the environment and workplace are caused by noise, dust, effluent and flue gases.

***Table 6* - Environmental impact of process stages (glass)**

Process	Air		Noise	Water	Soil	Work-place
	Waste gas/ Flue gas	Dust1)				
Dressing	1	2	2	1	2	2

Melting	3	3	3	3	3	3
Moulding	2	1	4	2	3	4
Cooling	2	1	3	1	2	2
Sorting	1	1	2	1	1	1
Packing	1	1	2	1	1	1
Machining/Refining	1	2	2	3	1	2

Key: 1 very slight; 2 slight; 3 moderate; 4 considerable

In some cases technological and processing developments and improvements have already been implemented, e.g.:

- **Arsenic and tellurium are now only used as refining agents in exceptional cases.**
- **Fluorspar is no longer used as a flux.**
- **The specific outputs of the tanks have been increased with a simultaneous reduction in energy consumption.**
- **Wastewater circuits have been introduced.**
- **Numerous noise protection devices have been installed.**
- **Wet, electric and dry sorption plants have been installed for dust**

extraction.

- Tank designs and fire management systems have been improved.

Many of the processes so far tested in individual cases are capable of further technical improvement and more economic design, paying particular attention to environmental regulations. The expected costs of environmental protection devices and measures may be as much as 20% of the total investment costs of a glass works.

Proper maintenance is essential to environmentally acceptable operation of the plants. Suitable training must be given and personnel generally made aware of environmental concerns.

Early involvement of neighbouring population groups in the planning and decision-making processes will enable measures to be devised to deal with any problems arising.

In countries which have no legal guidelines it should be ascertained as early as the planning stage, based on the raw materials to be used and the process technology applied, what environmental protection measures are necessary and appropriate. Environmental protection equipment provided should be of robust design so that

the life of this equipment is appropriate to the overall project and so that simple, low-cost maintenance can be guaranteed.

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Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

49. Iron and steel

Contents - ◀Previous - Next▶

Contents

1. Scope

This environmental brief covers iron and steel production and processing with the following activities:

- sinter, pellet and sponge-iron production
- pig iron, cast iron and crude steel production (including continuous or strand casting)
- steel forming (hot and cold)

- foundry and forging operations.

The above activities are carried out in an integrated ironworks or sometimes in separate locations.

After delivery and pretreatment of the ore in the ore preparation, sintering and where applicable pelletising plant, pig iron is smelted in the blast furnace with the addition of coke and admixtures; coke supplies the energy and reduces the ore to pig iron. In the converting mill the molten pig iron is refined to form crude steel by top blowing or purging with oxygen and the addition of scrap. Crude steel is also produced from scrap in electric furnaces, sometimes with the addition of pig iron, ore and lime. The crude steel is either continuously cast as blanks or, after casting as slab ingots or blocks in permanent moulds, rolled in the hot rolling mill to form sheets, billets or profiles. Further processing takes place in the cold rolling mills and forges. Continuous casting which already represents 90% of German and 60% of worldwide steel production improves crude steel utilisation by some 10%, saves energy by rolling operations and reduces the production scrap yield in steel and rolling mills per tonne of finished steel by more than 50%.

The direct-reduction process represents an alternative to traditional steel

production. With the addition of reduction gas, e.g. from natural gas or coal, sponge iron is produced as a solid, porous product from which crude steel is then refined in the electric furnace, often with the addition of scrap. 90% of sponge iron is produced by the gas-reduction process.

Cast iron smelting takes place in the cupola furnace, with increasing use of induction furnaces.

Moulds and cores are required for the shaped casting of cast iron; these are mostly of sand but frequently contain an organic binding agent.

The following are classified as major units:

sintering plants 20,000 t/day
blast furnaces 12,500 t/day
steel converters 400 t holding capacity
electric furnaces (arc) 250 t holding capacity
cupola furnaces 70 t/h
induction furnaces 30 t/h

In many countries steel is extensively produced from scrap in electric furnaces.

Since iron and steel production is predominantly based on pyrometallurgical processes, air pollution is a primary consideration. In addition to a multitude of gaseous air impurities, dusts play a special role, not only because they occur in large quantities but also due to the fact that the dusts contain some hazardous substances affecting both man and the environment, e.g. heavy metals. Due to the use of coolant water and wet separation methods, problems of maintaining water purity also occur. Continuous casting plants require high specific water quantities from which the wastewater is considerably contaminated with oil. Casting without spray-water cooling relieves the load on water resources.

Metallurgical processes also produce slags which should be recycled wherever possible. Where no effective recycling and final dumping facilities exist, dusts and sludges separated from the waste gas cleaning systems represent potential pollutants of the ground and water environments.

In blast furnace plants and converting mills, also in rolling mills and forging works, noise and vibration protection is of fundamental importance. Foundries produce large amounts of waste from used sand, broken cores and cupola slag.

For reasons of ecology and economy, work is taking place worldwide on process methods which permit the use of coal instead of coke and the extensive use of lump ore instead of sinter or pellets. This would enable coking and sintering plants to be dispensed with as emission sources in a metallurgical plant.

Other developments concern the casting of rolling feed stock in approximately final dimension form. Shortening the process chain permits reductions in energy requirements, residual substances, waste and emissions.

2. Environmental impacts and protective measures

2.1 Sintering / pelletising plants

Sintering plants form lumps of fine ore prior to introduction into the blast furnace and recycling of ferriferous residues (waste materials). Sintering is the traditional method of treating residual and waste materials from the smelting plant. Factors determining the limits include the zinc concentration, because zinc in the sinter contributes in the blast furnace to the formation of scaffolding with impaired gas

distribution.

Sintering plants produce the following emissions:

Waste gases and dust containing components with potential environmental relevance:

SO_2, NO_x, CO_2, HF, HCl, As, Pb, Cd, Cu, Hg, Tl, Zn

Of dust components, the heavy metals lead, cadmium, mercury, arsenic and thallium have the greatest environmental relevance where these are present in the charge materials. The relevance of anthropogenic heavy metal emissions is based less on their overall emission rate than in high localised mass flow densities or concentrations. The iron and steel industries are among those industries in whose vicinity the highest immission rates of heavy metals occur in the air and ground.

Dust is separated and returned to the sinter process in gas cleaning systems, normally electrostatic precipitators. In continuous operation the dust content of clean gas is between 75 and 100 mg/m^3. Heavy metal, e.g. lead, enrichment in the sinter plant dust is possible with continuous recycling. Dust with heavy

concentrations of lead and zinc should be conducted to a zinc and lead recovery system. In the case of stoppages of the sintering belt due to faults, care must be taken to ensure that the gas cleaning system continues to operate at maximum possible separation capacity. In addition to sintering belt dedusting, modern sintering plants also have room dedusting whereby dust-laden waste air from transfer stations, chutes, crushers etc. is cleaned by a hot sieve system.

Depending on the composition of charge materials, inorganic gaseous fluoride and chloride compounds as well as sulphur dioxide and nitrous oxides are emitted. Sulphur dioxide emission can be significantly reduced by using coke with a low sulphur content. The emission of gaseous pollutants can also be reduced by increased lime dosing. This results in problem substances being transferred to the separated dust. Where regional conditions and process engineering do not permit these measures, wet-process desulphurisation systems offer a means of reduction; in this case some problem substances are transferred to the wastewater. On account of the large gas volumes - up to 10 E 6 m^3/h - only partial waste gas desulphurisation can take place. For this reason preference should be given to primary measures. Concentrations in cleaned waste gas are around 500 mg/m^3 sulphur dioxide.

With respect to noise impact, a distinction is made between the noise immissions of operations to the neighbourhood and the effect on the staff at their work-places. Principal noise sources of the sintering plant include the large fans for drawing air through the sinter cakes, cooling the sinter and dedusting. Crushing and screening stations should be housed in solidly constructed buildings whose walls restrict the propagation of sound. Possible noise reduction measures are silencers in the air supply and discharge pipelines, also the encapsulation of individual units. The acoustic power immission level is used to evaluate the noise radiated to the open air by the plant. The acoustic power level of a noise source is a distance-dependent parameter; for sintering plants without silencers on supply and discharge air pipelines it can be as high as 133 dB(A) and for those with silencers 124 dB(A). With very good acoustic planning and execution an immission level of around 40 dB(A) can be achieved at a distance of 1,000 m from the individual noise sources. If this target cannot be achieved, protection of the residential area adjacent to the sintering plant is only possible by noise protection measures on the propagation path, e.g. a noise abatement wall. Measures for optimising noise protection are to be considered in parallel with the planning of the production unit.

By encapsulation and the separate installation of principal noise sources it is also possible to protect the work places. The typical noise level in the sintering hall is

between 83 and 90 dB(A); attention must be paid to the use of personal noise protection because long-term exposure to an acoustic power level in excess of 85 dB(A) results in serious hearing impairment. The wearing of safety helmets and shoes also helps reduce industrial accidents. Staff in work-places particularly exposed to dust, gases, noise and heat are to have regular preventive medical examinations by works doctors.

In pelletising plants, fine ores are mixed with additives and water to form green pellets which are burned in pellet incinerators on travelling grates. The dust-laden waste gases are cleaned in dedusting plants, usually electrostatic precipitators. The filter dust is re-used. Pelletising plants are associated with lower dust and gas emissions than sintering plants. In contrast to sintering, pelletising is mainly performed at the ore mine.

2.2 Blast furnaces

The blast furnace is a countercurrent reactor loaded or charged from the top with layers of feed and coke, the molten pig iron and slag being drawn off from below. Hot air is injected in the opposite direction from the bottom of the furnace. Residual materials (waste) such as oily metal chips and oily rolling scale can be

introduced after sintering.

The principal emissions, residues and waste materials are:

- **top gas, with the following potentially environmentally relevant components: CO, CO_2, SO_2, NO_x, H_2S, HCN, CH_4, As, Cd, Hg, Pb, Ti, Zn**
- **top gas dust (dry) from the gas cleaning plant with high iron contents (35 - 50%)**
- **slag with the following major components : SiO_2, Al_2O_3, CaO, MgO**
- **sludge from the waste gas cleaning system**
- **wastewater from the waste gas cleaning system, with the pollutants: cyanides, phenols, ammonia**
- **dust from the casting house dedusting system.**

The waste gases from the blast furnace are pretreated in mass force separators (dust catchers or cyclones) and, in a second stage, finally cleaned with a high pressure scrubber or wet electrostatic precipitators. Clean gas dust concentrations from 1 to 10 mg/m^3 are achieved.

Other dust emissions in the blast furnace area, particular from the burdening process, pig iron desulphurisation and the casting house must also be identified and cleaned.

Dust formation ("brown fume") in the casting house affects not only the neighbourhood but also, to a considerable extent, the workplaces. Efficient casting house dedusting systems which intercept process waste gases and peripheral emissions at the taphole, runners and cut-off points and separate dusts in horizontal electrostatic precipitators can achieve clean gas dust concentrations significantly under 50 mg/m^3 (best values 7 and 12 mg/m^3 and dust emission factors between 0.020 and 0.028 kg/t pig iron in blast furnace plants with a capacity of 4,000 to 6,000 t/day). As a replacement for the standard collection and cleaning methods, trials are currently in progress with the suppression of "brown fume" through inertisation with nitrogen.

In the dedusting of pig iron desulphurisation, clean gas dust concentrations of 50 mg/m^3 are adhered to in both calcium carbide and soda desulphurisation, using radial flow scrubbers or electrostatic precipitators.

The top gas contains between 10 and 30, though possibly as much as 60 g/m^3 dust with 35 to 50% iron, i.e. 30 to 80 kg/t pig iron, in older plants 50 to 130 kg/t pig iron. The dust is separated in the dry state in mostly multistage separators, from where it goes to the sintering plant and from there back to the blast furnace.

In view of the zinc and lead content and other factors, the top gas scrubbing water sludge must be disposed of by dumping, unless there is a special hydro-cyclone separation system. With higher concentrations, it should be transferred to a non-ferrous metal works. Recycling in this way would leave the blast furnace process practically free of residues. Dumping involves the risk of leaching and hence penetration of the soil and groundwater by compounds of zinc, lead and other heavy metals. The dump must be permanently and verifiably sealed and the seepage water must be collected and chemically processed. The special requirements imposed on such a dump must be laid down in the project planning stage.

Slag produced by the blast furnace process accounts for roughly 50% of the overall waste materials from pig iron and steel production. This slag is mostly used in road-building. Part of the molten slag is granulated by quenching in water. This so-called slag sand is also used in road-building. Part is used to produce iron slag Portland

cement and blast furnace cement. Quenching and granulating releases carbon monoxide and hydrogen sulphide. The wastewater has an alkaline reaction and contains small quantities of sulphide.

Slag heaps sometimes produce seepage water with high levels of dissolved sulphides and strong alkaline reaction, posing a hazard for the groundwater. Slag heaps must be sealed and any seepage water must be treated.

Wastewater is generated by top gas scrubbing and simultaneous wet dedusting. The wastewater is normally clarified in settling tanks and, where necessary, gravel bed filters and recirculated. The wastewater contains suspended matter (dust) and sulphides, cyanides, phenols, ammonia and other substances in dissolved form. The last three substances must be removed from the wastewater using appropriate physical and chemical treatment processes.

The top gas can be used as a fuel for heating purposes within the works, in view of its high carbon monoxide content due to the reducing atmosphere in the blast furnace, though this will inevitably result in the formation of carbon dioxide, with its climatic implications.

Excessive levels of sulphur dioxide and nitrous oxide gases can be reduced by flue gas desulphurisation and denitrification.

Carbon monoxide concentrations in the workplace pose a particular problem. Where top gas pipes are not perfectly leakproof there is a danger of poisoning with possible fatal consequences for workers present at the furnace throat. Close attention must also be paid to CO concentrations by carrying out measurements and ensuring that protective breathing equipment is worn during repair and maintenance work on shut-down blast furnaces or gas cleaning systems.

Protective equipment for blast furnace workers includes fireproof clothing, breathing equipment and ear protectors, depending on where they are working; protective helmets and safety footwear must be worn in all areas.

Noise in blast furnace plants comes mainly from the combustion air fans and the charging process; also there is the noise generated upon changeover from blast to heating operation. Suitable abatement measures include silencers, enclosure of the furnace throat or encapsulation of all valves and shields. The noise level from the blast furnace plant is in the range of 110 to 125 dB(A); the level of background noise in the immediate vicinity may be 75 to 80 dB(A). Possible noise reduction measures

should be selected as early as the blast furnace planning phase. Their effect can be determined by advance calculation, taking care to ascertain the significance of the emission sources (plant sections and operating processes). One should preferably begin by damping or eliminating occurrences and noise sources which arise only periodically.

2.3 Direct-reduction plants

Direct reduction plants function according to a variety of methods, e.g. with shaft furnaces or rotary tube furnaces which are similar to blast furnaces. In the former, the top gas is scrubbed and then enriched with natural gas and used for heating; in the latter, the gas is not used unless steel and rolling mills are available for this purpose. If this is the case, the gas should be burnt provided the CO content is sufficiently high. The waste gas flow is cleaned by mass force separators (dust chambers) for preliminary separation and then by fabric filters. Sulphur dioxide emissions may occur in the solids reduction process, depending on the sulphur content of the coal used.

2.4 Crude steel production

Excessive carbon content impeding further processing of the pig iron and substances influencing the quality of crude steel, such as silicon, phosphorus or sulphur, are either expelled in gaseous form or slagged during the steel production. The following emissions occur in the steel works:

- **waste gases and dust containing components with potential environmental relevance: CO, NO_x, SO_2, F, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Si, Tl, V, Zn ammonia, phenol, hydrogen sulphide and cyanide compounds may occur, depending on the process.**
- **dust from waste gas cleaning**
- **slag**

In the steel works dust is formed mainly due to the top-blowing or through-blowing with oxygen necessary for oxidation. The solids content of the waste gases from the oxygen converter is between 5 and 50 g/m^3. They contain finely dispersed evaporation products of iron oxides and primary anoxide ("brown fume"); also sulphur and phosphorous compounds, fluorine compounds and, where fluxing agent is used, silicon tetrafluoride.

Specific dust masses are approximately as follows:

- electric furnace: 2 - 5 kg dust per tonne crude steel
- bottom blowing converter oxygen bottom metallurgy (OBM) 5 - 10 kg dust per tonne crude steel
- top blowing converter (LD and LDAC process) 15 - 20 kg dust per tonne crude steel

Gases occurring in addition to carbon monoxide include inorganic fluorine compounds with the addition of fluorspar, also small quantities of sulphur dioxide and nitrous oxides, nitrous oxide formation being significantly higher in electric furnaces than in the blowing converter.

A technical solution exists for the collection and cleaning of the process gases from the converter. A fixed or lowerable hood over the converter prevents the intake of large quantities of infiltrated air or the escape of converter gases. The gas is subsequently dedusted by a wet or dry process. Wet dedusting takes place in a two-stage operation by a combined wet scrubber and wet electrostatic precipitator. For dry dedusting, dry electrostatic precipitators are used, designed to resist internal pressures up to 2 bar (due to risk of deflagration). The clean gas concentrations are under 50 mg/m^3 dust and under 500 mg/m^3 sulphur dioxide. A value of under 400

mg/m^3 nitrous oxide cannot be continuously maintained. Maintenance of the separation equipment is important in order to achieve an adequate continuous level of separation. Dry dedusting is advantageous as the yielded dust can be returned to the converter after hot briquetting.

Transfer, charging and mixing processes produce random dust emissions which may pose a considerable nuisance for the neighbourhood. Clean gas contents of 10 mg/m^3 can be maintained by a waste gas collection system with a collection rate of 90% and a downstream separator using fabric filters or horizontal electrostatic precipitators.

Proposals for the use of a process-dependent control and instrumentation system for reducing specific waste gas quantities must be examined with respect to system requirements such as robustness, error detection ability and ease of maintenance.

Since waste gas collection is difficult with Siemens-Martin furnaces while the furnace is in operation, the solution is to convert to electric furnaces. In addition to lead and zinc, chromium, nickel and vanadium occur in the dust if electric furnaces are used to produce fine steels. Certain chromium compounds in the form of

breathable dusts have proved to be carcinogenic.

A full doghouse enclosure is necessary to achieve 95% collection of the waste gases occurring with electric furnaces during charging, smelting and casting. Fabric filters permitting clean gas dust concentrations of under 20 mg/m^3 are used for dust separation.

When the converter is in operation, large amounts of carbon monoxide are produced which should be transferred for controlled burning in a torch or in a boiler with energy conversion, so as to avoid excessive air burdens (immissions). A potential source of polyhalogenated dibenzodioxin and furan emissions (though not currently thought to pose a major risk) is the recycling of iron scrap in electric steelmaking plants. Large quantities of iron scrap contaminated with halogen compounds and the operating conditions give rise to the formation of these substances. Initial random sample checks yielded emission concentrations of the order of a few nanograms. A comprehensive measuring programme is being prepared. Careful selection and preliminary sorting of iron scrap is currently a practicable way of minimising carcinogenic emissions. Processes for separating health-endangering dioxins and furans are currently being developed. Current trials of activated charcoal adsorption filters and their separation capabilities are being

followed with close interest.

The wastewater from wet dedusting is clarified in a hydrocyclone or settling tank and recirculated. The separated sludge is dewatered by a vacuum drum filter and returned to the blast furnace via the sintering plant. Attention must be paid to the zinc content of the sludge upon recycling. Slag produced in steel works is used in road construction or processed into fertilisers.

Loud noise is generated in converting steel works by high-powered fans and dedusting systems and in electric furnaces by the arcing and transformer. Noise levels in electric steelmaking plants without noise reduction measures is between 117 and 132 dB(A), and around 100 dB(A) with noise reduction.

Noise reduction measures can include:

- **arc soundproofing**
- **smaller apertures in the furnace shell**
- **encapsulation of the furnace**
- **acoustic separation of the furnace bay from adjacent bays**
- **increasing the soundproofing of bay walls**

- silencers on air intakes and outlets
- slow-running cooling air fans
- enclosure of individual systems
- avoiding free-fall of scrap upon loading and charging.

Very high peak noise levels can occur during smelting, especially with wet scrap. Highly automated modern plants have control rooms which provide effective protection against noise at the workplace. The protective measures mentioned under 2.2 also apply to workplaces in steelworks.

2.5 Steel forming

The following emissions and residues occur with forming (shaping) of crude steel into rolled steel:

- oily rolling scale
- waste gases from the furnace
- oily wastewater
- wastewater from the waste gas cleaning

During the production of steel plate, the following are produced:

- **oily wastewater**
- **waste air from the pickling baths**
- **spent pickling solutions**
- **sulphuric and hydrochloric acid**
- **or nitric and hydrofluoric acids**
- **mixtures**

The most prolific residue produced in hot rolling mills is rolling scale. The specific mass is 20 to 70 kg/t finished steel. Scale comprises mainly iron oxides (70 - 75) and can therefore be utilised in the blast furnace. Finer components must first be sintered or pelletised. Oily scale with a small percentage of oil from the machinery lubricants can be freed of oil by combustion or by alkaline wet scrubbing. To avoid polluting the subsoil with oil, oily scale should not be dumped.

Wastewater is produced in the hot rolling mill by

- **transport of the scale to the wastewater treatment system**
- **alkaline washing of the oily scale.**

The scale-water mixture is separated in settling tanks and gravel filters (sometimes with the addition of flocculation agents). Floating rolling oil and grease is skimmed off and the settled or filtered scale is dewatered and transferred to the sintering plant. The clarified wastewater is recirculated.

The alkaline scrubbing water from the scale scrubber contains an oil emulsion which must be broken down with chemicals. The water contains oil and chemical residues. It should be transferred to a biological filter plant. The recovered oil can be processed and in certain cases re-utilised in the rolling mill.

In the cold rolling mill the steel plate is descaled in a pickling bath before further processing. Hence, no solid waste (scale) is produced in the actual cold rolling process.

With cold rolling, wastewater occurs due to contamination of water with rolling oils (mineral oils, palm oil) and from the pickling. The rolled down plates are once more pickled with acid and electrolytically degreased prior to tinning or galvanising.

Wastewater treatment requirements in rolling mills depend on the type and extent of recycling and the quality of the receiving body of water. Regular monitoring of wastewater values is necessary.

The oil-water emulsions produced by the cold rolling process must be chemically treated (flocculation with ferrous salt and lime). The oily sludge must be incinerated and the ashes transferred to the sintering plant. Oil separated from the emulsion can be used for secondary lubrication purposes.

To protect soil and groundwater from unwanted discharges, a waste disposal and re-utilisation record should always be kept for emulsions, mixtures of mineral oil products and mineral oil sludges.

Spent steel pickling agents contain mainly ferrous salts. These can be separated and sold (for production of pigments, precipitation agents for clarification processes, sulphuric acid). The remaining pickling agent must be neutralised with lime milk. The resulting hydroxide sludges are placed in drying beds or preferably dewatered with filter presses. Before dumping, the leachability and stability of these residues must be checked to ensure they are suitable for final dumping. If the solids content exceeds 40%, the residues should be taken to the sintering plant.

The acid pickling water must be neutralised and the coagulated hydroxide sludges separated in clarifying tanks. The clarified wastewater can be re-used (must be neutralised with acid); sludges must be placed in a suitable, sealed dump.

Special hoods are used to eliminate oil mist in rolling mills; it is separated by a mechanical preliminary separator combined with a downstream electrostatic precipitator.

The effective noise level generated by hot and cold rolling mills is 95 - 110 dB(A). In a rolling mill the noise level, e.g. 5 metres from the open bar steel train, is 106 dB(A) and in a pipe steel rolling mill, near the tube straightening machine, as much as 124 dB(A).

To protect workplaces from noise, the plant is extensively automated and provided with appropriate control rooms. These can be well insulated against noise. Ear protection should be worn at workplaces with high levels of noise.

2.6 Foundry and forging operations

Smelting takes place in cupola furnaces (shaft furnaces) and electric melting furnaces. Gaseous emissions from smelting are: carbon monoxide, sulphur dioxide,

fluorine compounds and nitrous oxides; those from casting are: phenol (briefly), ammonia, amines, cyanide compounds and aromatic hydrocarbons (traces).

Dust occurs in foundries during e.g. preparation of the moulding sand and core sand, manufacture of sand moulds and cores, in casting, cooling of castings, knocking out moulds and with the surface treatment of parts of moulds, known as fettling. Fabric filters have proved effective for reducing dust emissions. These have permitted the achievement of concentrations of under 10 mg/m^3 in the clean gas from sand preparation dedusting systems. Optimum fine dust separation with fabric filters can help reduce toxic emissions, e.g. nickel, during fettling.

Dust occurring in cupola furnaces during smelting is intercepted by wet type dedusters or filtering separators. With cold blast cupola furnaces with smelting capacities below 10 t/h, wet dedusters are increasingly being replaced by fabric filters with preliminary separators. Clean gas dust concentrations of under 20 mg/m^3 are being adhered to. Fluorine emissions can also be reduced by dry absorption using hydrated lime.

It is essential to intercept emissions in all operating phases, including blowing and

melting-down.

With hot blast cupola furnaces with smelting capacities exceeding 10 t/h, operators have managed to obtain clean gas dust concentrations of 20 mg/m^3, with blowing and melting-down as well, using optimised wet type dedusters in combination with primary measures on the cupola furnace. An enclosed forehearth feed bay also contributes to low-emission operation.

The use of induction crucible furnaces is increasing; with these, emissions from the crucible opening are intercepted by an extraction system.

When using electric furnaces, which produce significantly lower dust emissions than cupola furnaces, values of 20 mg/m^3 are possible using filtering separators. Additional emissions of hydrochloric acids, soot and traces of organic compounds (possibly dioxins) occur when smelting large amounts of scrap mixed with oil, paints and plastics. A high-performance wet scrubber must be used under these operating conditions.

Highly odorous substances such as formaldehyde, phenols and ammonia occur in foundries for small castings for which moulds are produced according to the cold-

box, hot-box or Croning process. In addition to the odour nuisance, these substances are also health hazards. As formaldehyde and high ammonia concentrations are suspected carcinogens, steps must be taken to reduce these. Emissions can be reduced by a counter-current scrubber with a phosphoric acid solution. The scrubbing fluid is recirculated and continuously treated.

Waste gases with inorganic compounds occur during core production, including core sand mixing. The waste gases must be cleaned with a wet scrubber and in particular the amount of amines in the waste gas must be under 5 mg/m^3.

The sludge-water mixture resulting from wet dedusting, which may contain substances hazardous to health and the environment such as cadmium, lead and zinc, is neutralised. The precipitated solids are separated from the water by sedimentation. The scrubbing water is recirculated. Before dumping the sediment, which may contain phenols from the moulding sand binders, it must be tested for leachability and treated if necessary. In a suitably modified process, part of the wastewater flow can be evaporated and the circuit largely, closed, thereby considerably reducing the scrubbing water requirement.

The moulds are made of moulding sands with approx. 4 to 10% binder (clays,

cement, organic materials, hardenable plastics, soda, water glass etc.). They are usually used once and then broken up. The used sands can be treated and re-used as components in clay-bonded mould production.

The ambient noise levels in foundries can reach 120 dB(A). Noise sources include loading operations, mixing, dedusting systems, fettling bays, sand preparation, conveyors and fans. Noise reduction measures include enclosed hall designs, installation of fans in enclosed rooms and silencers on air intakes and outlets. Machine soundproofing measures are especially necessary in the moulding, core and fettling shops. Measurements made over an 8 hour shift have yielded workplace noise levels of 106 dB(A) in the moulding shop, 99 dB(A) in the core shop and 103 dB(A) in the fettling shop. Principal noise sources affecting workplaces are: jolt moulding machines, vibratory grates, swing conveyors, fettling machines, impact pneumatic tools, grinders, fans, compressors and conveyors.

Appropriate noise protection measures in the workplace include encapsulation of noisy machines, separation of noisy machines from other parts of the shop and avoidance of manually operated machines. Personal ear protection must of course be worn. Monitoring is imperative.

Waste gases are expelled from the furnace in forges. Emissions can be controlled by using gas as a fuel. A forge must be regarded as an industrial installation as regards production of wastewater and waste materials.

The ambient noise level in a forging shop with e.g. 6 hammers (impact energy 0.6 to 1.3 Mpm) is 112 dB(A). The background noise level due to heating furnaces, fans etc. is already 90 to 100 dB(A); to this must be added the pulsating noise of the forging machinery. Forging hammers are louder than mechanical and hydraulic presses. It is important to maintain a safe distance between the forge and purely residential areas. This distance must be calculated and allowed for in the planning where a reasonable noise level cannot be achieved in the near vicinity through noise reduction measures in the works. The maximum noise level in the workplace of a drop hammer (1,500 kg tup weight) is 120 dB(A). That of an electric forging hammer in the workplace (tup weight 275 kg) is 97 dB(A). The interior noise level in forging shops is normally above 90 dB(A).

Possible noise reduction measures include reducing structure-borne noise by modifying the forging force curve, reducing the propagation of the structure-borne noise, encapsulating work room openings, reducing the noise from pneumatic control systems, placing silencers on air relief pipelines and using multiple tube

nozzles for descaling. The wearing of personal ear defenders should be obligatory and should be monitored.

Besides noise, forging also produces vibrations. Measures to reduce vibration include the definition, at the planning stage, of suitable foundation designs, with appropriate vibration insulation at the time of installation. Vibrations in the neighbourhood must be below the threshold of perceptibility.

Contents - **Previous** - **Next**