GERMAN CLEAN AIR POLICY (FRG)

- realisations by thermal power stations and problems caused by the operation of these systems

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SUMMARY:
The history of the clean air policy is mentioned. During the years 1985 to 1988 more than 40 000 MW are retrofitted with FGD systems. Wet limestone scrubbers producing gypsum, are the most common systems for the FGD.
For most of the coal fired power stations there $DeNO_x$-plants, mostly SCR-systems, had been retrofitted from 1986-1990.
Problems by operating, maintenance, handling of residual products, will be explained as example at Badenwerk Rheinhafen Power Station Unit No. 7.

CHAPTER 1 - ELECTRICITY PRODUCTION IN THE FEDERAL REPUBLIC OF GERMANY

During the Fifties, after the second world war, coal and hydraulic power were the dominant energies for electricity production in our country.

Hydraulic power stations are situated along large river systems e.g. Rhine or Danube, or situated as pumping storage plants in the southern parts (the Alps or the Black Forest) of our country.

Most of the coal fired power stations are situated at the "Ruhr Area", some others at coastal areas or in Southern Germany near by rivers (served by barges).

The coal energy at this time for power stations was domestic coal, or imported coal mostly from UK or USA.

In the early Sixties the transition from coal to oil - heavy fuel oil for power stations - bought Western Europe to a coal crisis. Suddenly there was a surplus of coal, and many countries supported the use of (domestic) coal by subsidiaries.

During the Sixties many oil fired power station were built, even gas fired stations.

The end of the Sixties and the beginning Seventies brought the construction and the erection of the first commercial working nuclear power units. These nuclear power stations were of BWR or PWR design.

Today the power station (public service only 1988) consists of:

abt 22 500 MW nuclear
abt 11 500 MW lignite fired
abt 26 400 MW hard coal
abt 12 600 MW oil fired
abt 8 700 MW nat. gas
abt 2 500 MW hydraulic
abt 3 800 MW pumping storage power stations

totally abt 88 000 MW (fig 1)

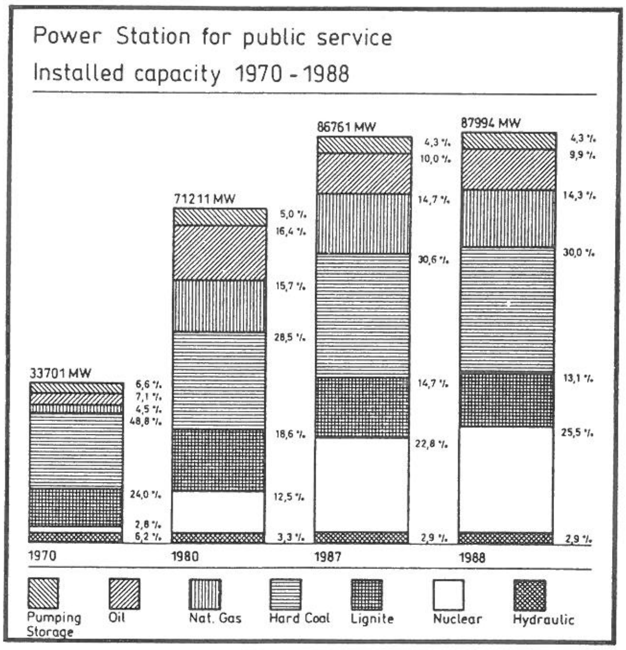


Figure 1

The electricity production in 1988 came from

39,3% nuclear (base load)
20,3% lignite (base load)
27,9% hard coal (interm. load)
1,8% oil (peak load)
4,8% nat. gas (peak load)
5,0% hydraulic (peak and base load)
1,6% others (garbage, etc.)

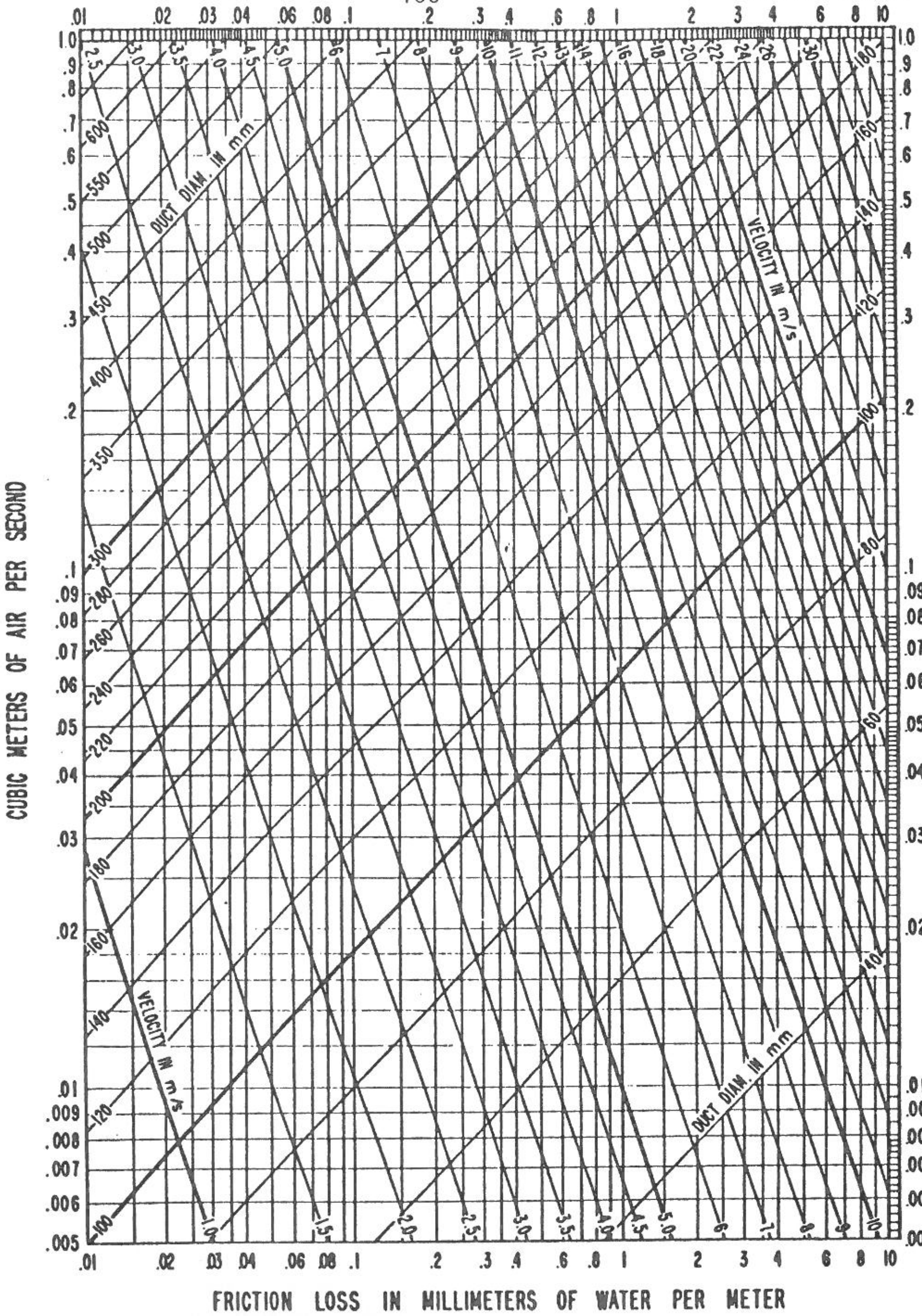
The total electricity production (utilities) in 1988 was about 367 TWh (fig 2), including industrial producers the electricity production grows up to 431 TWh.

The electricity grid of the Federal Republic is part of the Western Europe Connection (UCPTE) with a (1988) capacity of about 370 000 MW.

TECHNICAL NOTES

No 3: Duct friction loss at 100 kPa and 21°C.
When air volume is measured at local pressure, the friction loss may be multiplied by the ratio $\left(\frac{\text{local pressure in kPa}}{100}\right)$.

Source: ACGIH: Industrial Ventilation, 17th ed.



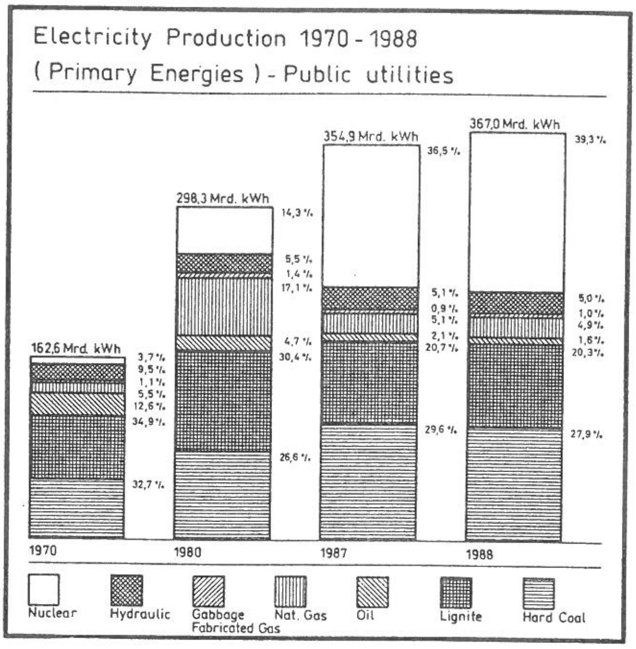


Figure 2

In the Federal Republic, most of the coal firing p. st. work on intermediate load, due to the use of domestic coal. (domestic coal, coming from underground mines costs about 3 times as much as South African coal cif FRG. In 1980 there was signed a - state supported - contract between mines and utilities, to buy a quantity of 40 million tons domestic coal each year. This contract goes up to 1995.

CHAPTER 2 - LEGISLATION ON ENVIRONMENTAL PROTECTION, REFERRING TO THE OPERATION OF FOSSIL FIRED POWER STATIONS

In the Fifties there started already a limitation on dust emissions from coal fired power stations. During the Sixties, by the transition from coal to oil there was a new limitation on the sulphur content of fuel oil (max 2%).

In 1964 the first clean air act named TA-Luft (technical ordinance "air") gave limitations for the dust emission to less than 300 mg/m^3 for new power stations and a figure 2,5 times higher for existing power stations (max dust emission 750 mg/m^3).

Further there was a demand for the installation of flue gas desulphurisation plants (FGD) for all new coal fired power stations. In addition to the FGD-plants we had in our country a transition from wet bottom boilers with the high nitrogen-oxide production, to the dry bottom boilers with a lower NO_xproduction (from 3 000 - 2 000 mg, m^3 to less than 1 200 mg/m^3).

In the Seventies only very few new coal fired power stations were commissioned, so the clean air act 1974 was not too helpful for the reduction of sulphur dioxide from power stations.

Yet this decade was the time for developing commercial FGD-Systems in our country.

In 1983 the third clean air act - named Grossfeuerungs-Anlagen-Verordnung (Ordinance on large power plants) arrived. The GFAVO gave legal limitations for all power stations-existing and under construction due to dust, SO_2 and NO_x.

The stated figures for the emission of power stations with more than 300 MW thermal rating (abt 100 MW electric output) are for dust:

new power stations	50 mg/m^3
existing power stations	125 mg/m^3

(Existing power stations must fulfil these limitations until 1 June 1988).

Sulphur dioxide

Retrofit to all power stations fired by coal, lignite or fuel oil with flue gas desulphurisation plants (FGD).

Limitation of the emission range to 15% of the calculated SO_2 content in the flue gas after boiler. Limitations absolutely to max. 400 mg/m^3 in the flue gas at stack.

The decision to retrofit or not had to be made by 1 July 1984. By decision not to retrofit the power station would have to be shut down before 1 April 1993 with a maximum use of 30 000 hours (full load) in these ten years.

By decision to retrofit a power station, the FGD plant had to be commissioned and in commercial operation at 1 July 1988.

Nitrogen oxide.

The third clean air act stated for NO_x different figures:

coal fired boilers with:

wet bottom boilers	1 800 mg/m^3
dry bottom boilers	900 mg/m^3
oil fired boilers	450 mg/m^3
gas fired boilers	350 mg/m^3

These figures were cancelled in 1984 due to a decision by the ministers on environmental affairs of the "Länder". A new limitation was given down to 200 mg/m^3 NO_x.

Since end of 1989 nearly all coal fired power stations are retrofitted with catalysts as $DeNO_x$ systems.

CHAPTER 3 - REALIZING OF $DeSO_x$ AND $DeNO_x$

Desulphurisation ($DeSO_x$)

Under the obligations of the third clean air act (GFAVO) there are about

- 30 000 MW (electric) coal fired power stations
- 10 000 MW (electric) lignite fired power stations

In 1983 there are FGD's in operation for about 10 000 MW. At this time at lignite fired stations only test plants worked. The used system there was dry additive by injection of lime into the furnace.

The short time for retrofitting FGD's required the installation of proven FGD's with a high efficiency.

Proven in 1984 were FGD's of the wet line or limestone type.

The investigations during the Seventies developed gypsum as a final product instead of the sludge of the former times.

The interest on gypsum in our country belongs to the environment protection legislation, to recycle as much as possible all waste products.

Figure 3 shows the installations of todays FGD-plants. Nearly 90% of the FGD's are of the wet limestone type. Limestone is about 5 times less expensive than lime, so most of the former lime type FGD's have been changed to limestone.

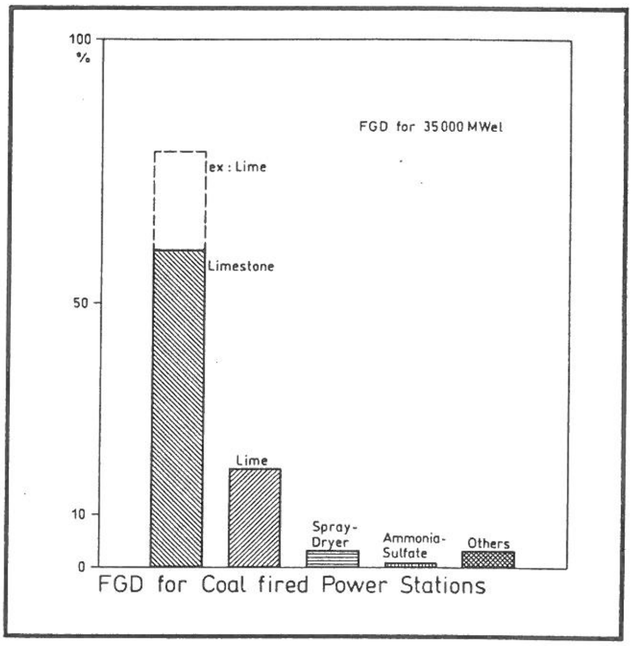


Figure 3

3.1 Basic principles of FGD's with limestone

The principle of the wet-limestone-systems are SO_2 + $CaCO_3$ = $CaSO_3$ + CO_2, best efficiency at a operating temperature of abt. 50°C and an acidity of pH 5,8 - 6,3.

The first step gives sludge as a final product. The second step changes the useless sludge to useful gypsum $CaSO_3 + O_2 + 2H_2O = CaSO_4 . 2H_2O$.

This reaction works at 50°C and pH 3,5 - 4,3 in the most optimal manner.

3.2 Realization of full scale equipments

Technological equipment always is a equilibrium between science and simplicity in accordance with the demand of a good, and simple operation and maintenance.

So we can see the main principles for realization of the FGD plants (fig. 4)

Principle A: To avoid sedimentation in the absorber tank, there are chosen absorber tanks without fill, only spray - (nozzles and drift eliminators (demisters) are inside of the tank). The active parts work at an acidity of pH 4,5 - 5,5 instead of pH 5,8 or more. At the bottom part the $CaSO_3$ will be oxidized up to $CaSO_4 . 2H_2O$. Sometimes a special "oxidator tank" is used. This principle is called as "single loop system".

Principle B: Optimal operating conditions due to acidity.

This principle leads to a double loop system, two loops in one tank. This system needs more installations inside of the tank. The most significant installation is a basin, to collect the dispersion of the upper loop, and divide the pH's of both loops. So the lower loop can work at a optimal pH of 3,8 - 4,3 and acts as a pre-cleaning area. The benefits of this design are smaller dimensions of the tanks by an increase of scrubbing efficiency in comparison to the single loop system.

Both systems are installed in our country and have good operating results. The next step, after flue gas cleaning, is the fabrication of a useful residual product - gypsum!

In the quencher swump there is a slurry of about 80% water and only 20% solid particles (gypsum). A drainage system must separate the liquid from the solid particles. This is possible either by centrifuges, which win all solids at once, or by use of hydrocyclones. Hydrocyclones separate the solids due to their crystal size. As centrifuge separate all solids at once, there must be guaranteed that there is no $CaSO_3$ in the dispersion, but only gypsum. The humidity at the discharge of a centrifuge is less than 5%. Hydrocyclones cannot separate liquid and solids totally, but they can screen the sizes of the solid particles. So the large size of the gypsum crystals can be divided from the small sized calcium sulfite crystals. Passing the hydrocyclones the liquid content will be increased up to 50% and 50% gypsum. The sulphite content there is reduced down to zero, the sulphite flows back to the quencher.

Further on the gypsum will be dehumidified to a moisture content of less than 10%.

The final production of a useful gypsum for building purposes can be as follows:

1. Direct use of the gypsum with 5-10% moisture at the gypsum mill, by calcinating the $CaSO_4 . 2H_2O$ to semi-hydrate gypsum ($CaSO_4 . 1/2\ H_2O$).

3.3.1 Primary methods -low NO_x-burners:

These measures reduce the production of NO_x coming from fuel and high temperatures. The leading boiler manufacturers developed 'Low NO_x-burners', to reduce the temperature in the furnace. With this design the NO_x emission has been reduced from abt. 1 400 mg/m³ to abt. 650 mg/m³ (dry bottom boilers).

3.3.2 Secondary methods:

Additional systems for denitrification are named 'secondary methods'. These are the only systems which allow a NO_x emission of less than 200 mg/m³ at the stack by using coal.

Simultaneous systems ($DeNO_x$ and $DeSO_x$) had been tested at 2 large power stations in Germany, but unfortunately there was no sufficient success by operating this systems. So nearly all coal fired stations are equipped with a catalyst and work by the system of Selective Catalytic Reduction (SCR).

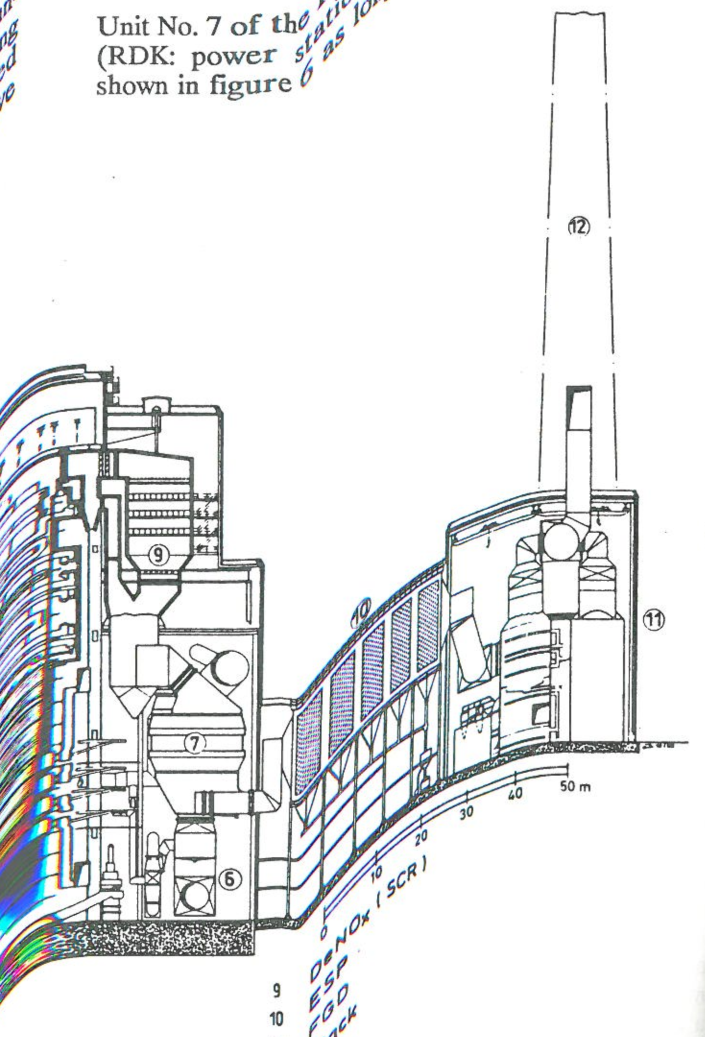
High dust and low dust systems, both are installed. The high dust system has been installed more or less at modern, dry bottom boilers. The elder boilers and the wet bottom boilers are equipped with the low dust system. Ammonia (NH_3) will be added for reduction of the NO to N_2 and water. Working temperature of the catalysts is 300°C - 380°C. In this regard low dust systems - situated after the FGD installations - must be reheated up to the operating temperature.

CHAPTER 4 - THE FLUE GAS CLEANING SYSTEMS AT THE KARLSRUHE

- Rheinhafen Power Station Unit No. 7

Installations, Experiences.

Unit No. 7 of the Rheinhafen-Dampfkraftwerk-Karlsruhe (RDK: power station at Karlsruhe Rhine harbour) is shown in figure 6 as longitudinal section.



9 DeNOx (SCR)
10 ESP
11 FGD
12 Stack

and34 - 38%
6 - 11%

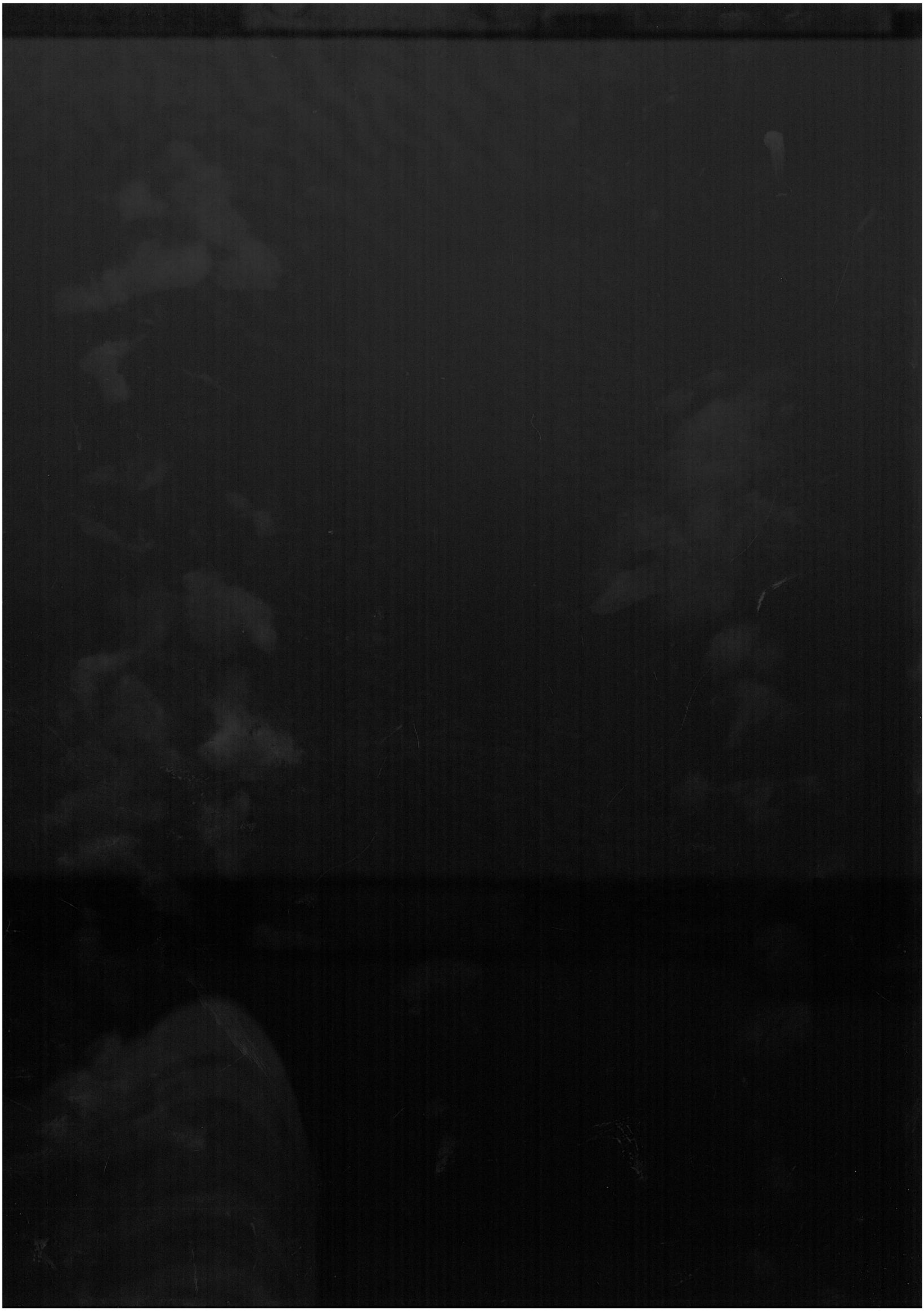
6

6 - 8%

6 - 10%

Volatile content 13%
ash

moisture 8 - 10%



The operation of the SCR-Denox system is in deviation to the FGD nearly without problems. The installations work very well, due to the physical conditions of the high pressure of liquified ammonia.

The manpower we need, to operate all environmental protection installations is as follows:

1	operator	(5 shifts)
1	circulation man FGD	(5 shifts)
1	circulation man ESP and $DeNO_x$	(5 shifts)
1	circulation man for the sewage plant	(5 shifts)
1	man for ash gypsum and limestone handling	(3 man)

In 1989 we produced at an input of 860 000 t coal

2,4 TWh electricity
70 000 t ash
40 000 t gypsum, for this we used abt 25 000 t of limestone

CHAPTER 5 - USE OF RESIDUAL PRODUCTS, COMING FROM COAL FIRED POWER STATIONS

As mentioned above, we have legal obligations in our country to recycle residual products as much as possible. Today we can say that the "classic product" fly ash is used to more than 85% for building purposes, either directly as an addition to concrete, or to cement. More than 5 million tons/a will be used.

This was also the reason to develop wet scrubbers to produce gypsum instead of sludge. The chose of wet, limestone type scrubbers brought a quantity of about 3 million tons/year of gypsum to the market. The domestic market for gypsum is not more than 5 million tons/year. Nevertheless the additional quantity of fabricated gypsum could be sold.

To sell these products, some utilities founded their own marketing companies for the distribution of the residual products.

As a conclusion we can say: The environmental protection installations work very well, but they need a lot of work for working very well, and sometimes we have to remember that we produce electricity too!

ERRATA: AIR QUALITY STANDARDS FOR THE CHEMICAL INDUSTRY (VOL 8 NO 2) TABLES 5 AND 6

Table 5

SUMMARY OF AIR QUALITY GUIDELINES, DEVELOPED BY THE WHO REGIONAL OFFICE FOR EUROPE

1. **Air quality guideline values for individual substances**

Substance	Guided value: Time-weighted average concentration (per m^3)	Averaging time
Cadmium	1-5 ng (rural areas)	1 year
	10-20 ng (urban areas)	1 year
Carbon disulfide	100 µg	24 hours
Carbon monoxide	100 mg	15 minutes
	60 mg	30 minutes
	30 mg	1 hour
	10 mg	8 hours
1,2-Dichloroethane	0,7 mg	24 hours
Dichloroethane (methylene chloride)	3 mg	24 hours
Formaldehyde	100 mg	30 minutes
Hydrogen sulfide	150 µg	24 hours
Lead	0,5-1.0 µg	1 year
Manganese	1 µg	1 year
Mercury	1 µg (indoor air)	1 year
Nitrogen dioxide	400 µg	1 hour
	150 µg	24 hours
Ozone	150-200 µg	1 hour
	100-120 µg	8 hours
Styrene	800 µg	24 hours
Sulfur dioxide	500 µg	10 minutes
	350 µg	1 hour
Tetrachloroethene	5 mg	24 hours
Toluene	8 mg	24 hours
Trichloroethene	1 mg	24 hours
Vanadium	1 µg	24 hours

2. **Guideline values for combined exposure to sulfur dioxide and particulate matter**

Average	Reflectance assessment: SO_2 (µg/m^3)	Reflectance assessment: Black smoke (µg/m^3)	Gravimetric assessment: Total suspend particles (TSP) (µg/m^3)	Gravimetric assessment: Thoracic particles (TP) (µg/m^3)
Short term 24 hours	125	125	120	70
Long term 1 year	50	50	-	-

3. **Guideline values based on sensory effects or annoyance reactions**

Substance	Detection	Recognition	Guideline	Averaging
Carbon disulide in viscose emissions			20 µg	30
Hydrogen sulfide	0.2-2.0 µg	0.6-6.0 µg	7 µg	30
Styrene	70 µg	210-280 µg	70 µg	30
Tetrachloroethene	8 mg	24-32 mg	8 mg	30
Toluene	1 mg	10 mg	1 mg	30

Table 6

ALLOWABLE CONCENTRATION FOR THE MORE COMMON POLLUTANTS: SOUTH AFRICAN LIMITS

POLLUTANT	CONCENTRATION IN PPM				
	INSTANT PEAKS	1-HOUR AVERAGE	24-HOUR AVERAGE	1 MONTH AVERAGE	ANNUAL AVERAGE
SULPHUR-DIOXIDE	0,6	0,3	0,10	0,05	0,03
OZONE	0,25	0,12	0,05	0,03	0,01
NOX	1,4	0,8	0,4	0,3	0,2
NO2	0,5	0,2	0,1	0,08	0,05
NO	0,9	0,6	0,3	0,2	0,15
NON-METHANE HYDROCARBON	0,70	0,40	0,20	0,15	0,06

TOTAL SUSPENDED SOLIDS (HI-VOL):

a) 24-HOUR AVER: 350 MICROGRM/CUB METRE
b) ANNUAL AVER: 150 MICROGRM/CUB METRE

SMOKE (from CSIR Soiling Index):

a) 24-HOUR AVER: 250 MICROGRM/CUB METRE
b) ANNUAL AVER : 100 MICROGRM/CUB METRE
(Microgrm/cub metre = 5 times Soiling Index)

DUST FALL-OUT (DEPOSITION):

a) SLIGHT : less then 0.25 GM/SQR METRE/DAY
b) MODERATE : 0,25 TO 0,5 GM/SQR METRE/DAY
c) HEAVY : 0.50 TO 1,2 GM/SQR METRE/DAY
d) VERY HEAVY : more than 1,2 GM/SQR METRE/DAY

ODOUR THRESHOLD LIMIT FOR HYDROGEN SUPHIDE: 0,003PPM
MAXIMUM AMBIENT LEAD CONCENTRATION : 2,5 MICROGRM/CUB METRE (MONTHLY AVERAGE)