

# THE TREATMENT OF THE AIR POLLUTION PROBLEM WITHIN THE CHEMICAL INDUSTRY OF WEST GERMANY

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## ABSTRACT

1. Legislation and consequences. Federal Law for Preservation of Clean Air 1959, Technical Instructions 1964, Provisional Law 1965, Law for Protection from Ground Pollution; Smog Warning System. Monetary consequences.

2. Principal problems in the chemical industry.

Characterization: manifold, non-uniform production; alterable products; modification of processes; temporary and quantitative fluctuations. Main pollutants, meteorological influences. General causes of emission leakages, div. basic operations. Problems of waste gas purification: large amounts of air, low concentrations of impurities, limits of treatment by catalytic and adsorption processes; problems arising from waste incineration, flares and filters.

3. Examples for the abatement of air pollution. By modification of the production process: manufacture of sulphuric acid, of nitric acid, of calcium-carbide, chlorination by means of waste gas. By purification of waste gases, originating from the production of electrodes, rayon, nitric acid, naphthol, phosphoric acid, dyestuffs; deodorisation.

4. Control of the emissions and the atmosphere. Special departments in the factories. Control of individual plants. Extramural control. Control of the purification equipments. Development of analytical methods. Research work on plant damages from waste gases. Reports to operators and to the management. Exchange of experiences between firms. Collaboration with the authorities.

5. Philosophy of clean air work under the view of the chemist: promotion of international exchange of practical experience, international standardisation of analytical methods. Use of the best practicable means for the attainment of clean air, but no irrational and one-sided perfectionism.

## GENERAL CONDITIONS WHICH ARE OF SIGNIFICANCE IN THE TREATMENT OF THE AIR POLLUTION PROBLEM IN THE CHEMICAL INDUSTRY

The chemical production processes and the associated emission phenomena are essentially the same or very similar in all countries. Differences in the treatment of the emission problem arise from the size of these industries, from local conditions and from the legislation in the particular countries.

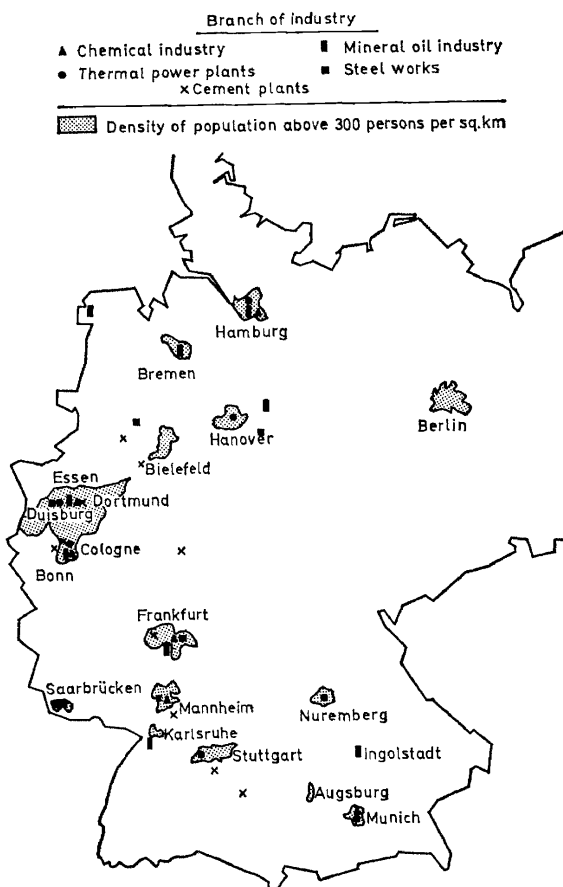
This paper is a report on the situation within the chemical industry in the Federal Republic of Germany.

### The significance of the West German chemical industry

The net turnover of the total West German industry in 1968 was 405.6 milliard DM, that of the chemical industry 41.8 milliard DM or 10.3%. The average annual rate of growth since 1953 has been 9.8%. The proportion of the total turnover made up by export of products was approximately 36% in 1968.

### Local conditions

The larger chemical factories are situated in the areas of industrial concentration where the atmosphere is already burdened by the emissions of other industries, by the concentration of residential areas and by an intensified traffic density (*Figure 1*). Twenty-three per cent of the chemical



*Figure 1.* Concentration areas of industry and population

production is located in the Frankfurt-Main, Wiesbaden, Mainz, Darmstadt area—17% in Mannheim/Ludwigshafen, 16% in Leverkusen and 19% in the Ruhr region.

### Legislation

The West German chemical industry has taken many steps on its own initiative to decrease its emissions. On the other hand, in the course of the last 10 years clean air legislation has been enacted which has spurred on the chemical industry in particular to increased effort in this sphere. This legislation will therefore be briefly mentioned here.

Until the year 1959, the legislation for the approval of the erection and operation of industrial enterprises was based on the 1869 Trade and Industrial Code. Industrial growth after World War II and the associated phenomenon of an increased pollution of the air led in December 1959 to the Federal Government's Clean Air Act. It is a 'skeleton' law to be supplemented by legislation in the individual provinces. The law lays down that industrial installations, the operation of which contributes to a considerable degree to air pollution, are subject to a special authorization procedure. The enterprises concerned are listed in an ordinance of the year 1960. They include the most important concerns in the chemical industry. To help the Industrial Supervisory Authorities in the practical implementation of the authorization and supervision procedures, the Federal Ministry of Health in 1964 published the Technical Codes for the Maintenance of Clean Air. These apply not only to new plants seeking authorization but also to those already in operation. This is to say, retrospective ordinances can be enacted also for those plants. Authorizations are only granted "when the plants are equipped with installations for limiting and dispersing dusty and gaseous emissions which are in conformity with current technology," and "if the emission limit values are not exceeded within the effective range of the plant during its operation." Similar limit values are laid down for dusts and for some gases. In addition, requirements are laid down for determining the basic levels of contamination of rural areas by sulphur dioxide. In any event, practice has shown that the Technical Code must be supplemented and improved.

The North Rhine-Westphalia Province, as the area of largest industrial concentration, has passed a special Immission Protection Law and, in addition, in 1963 introduced a smog warning system based on sulphur dioxide. Further in 1965, the Federal Government passed the "Law concerning preventive measures for the maintenance of clean air." This allows the supervision of the general status of air pollution by means of official measurements.

These drastic legislative measures are limited by the technological and economic limitations. For their practical implementation, thus, a knowledge is required of the individual production processes where they are to be applied. In co-operation with the authorities, the Commission for the Maintenance of Clean Air in the Society of German Engineers (VDI) have published a guide (VDI Directives) which provides technical and scientific descriptions of production processes and the associated emission

and immission problems, also ways of combatting these and figures on the permissible emissions and immissions.

It is clear that these comprehensive and more stringent laws for maintaining clean air have often posed difficult and costly problems for the chemical industry of Western Germany.

### GENERAL SURVEY OF EMISSION CONDITIONS IN THE CHEMICAL INDUSTRY

Permit me to characterize more closely the general conditions as regards emissions in the chemical industry. In chemical factories which carry on essentially one specific type of production only, e.g. super phosphatefactories, viscose factories, the emission pattern in normal operation is constant and the emissions contain only few substances. In other chemical factories, tens of thousands of products are created: heavy chemicals, fertilisers, dyes, plastics, pharmaceuticals, textile auxiliaries, pesticides, solvents and intermediate products.

The most important emissions which may occur (i.e. dusts from salts, dyes, plastics, iron oxide, fly ash from the factory's own power stations; vapours and fogs from hydrochloric acid, nitric acid, sulphur trioxide, phosphorus pentoxide, phosphorus halogenides; gases like ammonia, sulphur dioxide, nitrogen monoxide; chlorine and hydrogen sulphide) do not in general occur in larger quantities since they are automatically kept in closed apparatus because of their high toxicity.

It is not possible to list the numerous emissions caused by organic chemical production.

The causes of emissions are incomplete reactions, yield of by-products, e.g. fluoric acid from crude phosphates; losses of materials, e.g. carbon disulphide in viscose manufacture.

The emission situation is also influenced by the following factors: many production processes are discontinuous or fluctuate quantitatively; changes in production processes are not rare in the chemical industry; changes in emissions—both positively and negatively—may also be associated with all these factors. Besides this, there may be secondary reactions within the confines of a plant between the waste gases released into the atmosphere—but also with the waste gases of other neighbouring plants. Finally, emission conditions are also influenced by the immediate environment and the more peripheral environment of the factories and the associated daily and seasonal meteorological conditions. Photochemical reactions do not play a decisive role in the atmospheric conditions prevailing in West Germany. By contrast frequent inversion weather conditions occur in some regions which have adverse effects.

Practice shows that there are also emission sources which do not derive directly from chemical reactions: drying processes, filling and emptying operations with portable containers and equipment, leaks in pumps. Often emissions develop also externally to the works when effluents mix in drains and reactions occur between the materials in them, giving rise to gases. The occurrence of chlorine is well-known when hypochlorite lyes, for example, from an air exhaust dechlorination installation comes into contact with acidic water. Equally refuse incinerators can be a source of emission.

The emission conditions in the chemical industry which are described above in their essentials underline the assertion that a generally applicable solution cannot be provided for the problems of maintaining clean air in this industry. Even the application of a measure successful in one instance to another similar case may fail. In most cases, it is preferable to handle emission problems individually. In this paper, too, a selection of some significant examples must be made for the steps which the West German chemical industry is applying to improve its emission conditions.

## MEASURES TO DECREASE EMISSIONS

The following approach to the decrease of emissions accompanying the production processes should be adopted:

- I. Direct: (a) as a result of change in the production process  
               (b) through purification measures on the process exhaust gases
- II. Indirect: through continuous inspection of the atmosphere and the factories through special departments for the maintenance of clean air.

### I. Examples of the direct approach

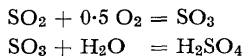
#### (a) *Change in the production process*

After the Second World War technical innovations in various large production sectors of the West German chemical industry were proposed which at the same time were intended to diminish large emissions.

(i) *The decrease in sulphur dioxide emission*—Sulphur dioxide emissions are not a specific problem of the chemical industry. However, it may occur in a more marked form locally in sulphuric acid factories, ore roasting and sintering plants, etc.

A well-known example of a change in process which results in considerable reduction of  $\text{SO}_2$ , is the two-stage contact process—the 'double contact process' of the Farbenfabriken Bayer at Leverkusen—in the production of sulphuric acid.

The principle of the process may be briefly recapitulated: to manufacture sulphuric acid, sulphur dioxide is oxidized by air with a catalyst to sulphur trioxide and this is converted to acid with water.



In the conventional technique these reactions are carried out in one stage. By this means, conversions of  $\text{SO}_2$  of almost 97.5% are achieved and an output of approximately 17 kg  $\text{SO}_2$  per ton of acid is expected to be produced. In the double contact process, in the first stage only 90% of the  $\text{SO}_2$  is converted—by temperature control—and the  $\text{SO}_3$  produced is absorbed from the reaction mixture prior to a second contact stage. In the second stage the reaction, in accordance with the law of mass action, approaches the theoretical equilibrium (*Figure 2*). Conversions of 99.5–99.7% are achieved and the output is only 2–3 kg  $\text{SO}_2$  per ton of acid produced.

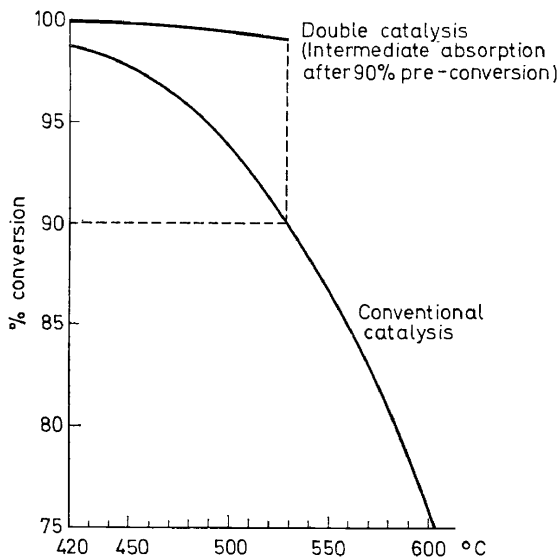


Figure 2. Principle of the Bayer Double Contact Process

In 1967, 3.43 million tons of sulphuric acid (100%) were produced in the Federal Republic. New sulphuric acid factories are built only as double contact plants. In February, 1969, there were 40 plants of this kind in operation all over the world, with a capacity of 5 million tons per year. In the Federal Republic, there are 20 plants with a capacity of approximately 3 million tons per year.

The share of the chemical industry in the total sulphur dioxide emission throughout the territory of the Federal Republic which in 1965 was established at 5.4 million tons, was 1.5–2%. It is estimated that the production of sulphuric acid up to the year 1970 compared to that of 1964 will have increased by approximately 50%. In terms of the conventional processes, an increase of  $\text{SO}_2$  emission of about 30,000 tons per year will result from these sources. Through the double contact process it will be reduced by between a fifth and a sixth of the total.

(ii) *Decrease in nitrogen monoxide emissions through change in method of operation*—A considerable proportion of the pollution of the air by nitrogen monoxide arises from combustion processes—especially from the exhausts of motor vehicles. In this respect, we are dealing with a world problem.

Large local industrial emission sources are the nitric acid factories. At present, a round 3 million tons of nitric acid (considered as 100%) is produced annually in Western Germany in 12 plants which are spaced far apart through the territory of the Federal Republic (Figure 3). About 80% is produced as acids of average concentration (56–63%) which are employed in nitrogenous fertilisers. All factories use the process of the catalytic oxidation of ammonia with air and the associated absorption of nitrogen monoxide in water with formation of nitric acid.



Figure 3. Distribution of nitric acid plants over the area of the Federal Republic (April 1958)

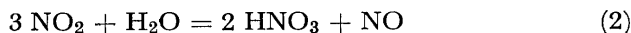
Key for the numbers in Fig. 3

- No. 1: Badische Anilin- & Sodafabrik AG Ludwigshafen/Rh  
 2: Sueddeutsche Kalkstickstoffwerke Trostberg  
 3: Farbwerke Hoechst AG Frankfurt-M/Hoechst  
 4: Chemische Fabrik Koeln-Kalk  
 5: Guano-Werke Krefeld  
 6: Ruhrchemie AG Oberhausen-Alten  
 7: Scholven-Chemie Gelsenkirchen-Buer  
 8: Stickstoffwerke Hibernia Herne  
 9: Gewerkschaft Viktor Castrop-Rauxel  
 10: Ruhr-Chemie AG Werk Embsen  
 11: Ruhr-Chemie AG Werk Langelsheim

The well-known emission phenomenon of these factories to which the public object especially on account of their appearance are the brown flue gases. The cause of these emissions may be briefly reviewed: the nitrogen monoxide originally produced through the oxidation of ammonia oxidizes again—since there is excess air—after cooling:



and reacts with water to form nitric acid



The entire process is carried out in successive absorption plants. The reconstituted NO in terms of reaction (2) is constantly being again oxidized to NO<sub>2</sub> which forms acid.

Yet its concentration is continually decreasing and both the velocity of reactions and that of absorption finally become so low that it is no longer economic to reclaim nitric acid from these residual gases. The investigations carried out in a large absorption plant have shown that if the volume of a conventional absorption plant with six towers is equated to one and a gas with 10 vol % NO to 90% is oxidized there, the 100-fold of the initial volume is required to oxidize the remaining 1 vol % to an equal amount. The residual content of nitrogen monoxides in the exhaust gases thus is inevitably bound up with the manufacturing processes.

In older plants, operating under normal pressure, the nitrogen monoxide content of the exhaust gases—calculated as NO—is some 4 g/m<sup>3</sup>. Measurements, which have been carried out by the authorities, in the vicinity of two large nitric acid factories over a long period, have shown that nitrogen monoxide concentration near the ground created by these emissions is considerably below the limiting value of 1 mg NO<sub>2</sub>/m<sup>3</sup> prescribed by the Technical Code. Despite these encouraging results the authorities are demanding a further reduction of the emission.

It has in the meantime been considerably reduced through the application of increased pressure. The pressure process is practised in two-fold fashion in Western Germany: either oxidization takes place under normal pressure and the absorption plant is merely fixed at below 2–3 at. or the oxidization and the absorption are carried out at below 7–8 at. In the latter process, which is conducted at 4 places, the energy utilization of the gas plays a decisive role.

With the pressure process, residual contents of exhaust gas of less than 1.5 gNO/m<sup>3</sup> are achieved. These gases, too, are still brownish. A technique has been developed for the decolouring of the exhaust gas by catalytic reduction of the nitrogen monoxide. But the auxiliary gases needed for this are too expensive, so that the process has not yet been used. The improvement of the emission conditions in nitric acid production is the object of further technical and economic studies.

(iii) *Decrease in the dust emission through change in the design of the apparatus*—A chemical industrial process where the emission of dust leads to a local nuisance is the manufacture of calcium carbide in the electric furnace. In 1965, the production of carbide in the Federal Republic was 1,039,000 tons per year and, in 1968, it was 950,000 tons per year. It is thus a rather retrograde trend as an increasing proportion of acetylene is produced by petrochemical methods. Thus, the total production of acetylene in 1966 was 273,000 tons per year of which 80,000 tons was produced from carbide and 193,000 tons by means of pyrolysis. Today, about 37% of the carbide production is used for the manufacture of calcium cyanamide. In the Federal Republic, 18 carbide furnaces are in operation with a current consumption ranging from 3.5 MW to 55 MW.

The emission problem here is dust discharge. The carbon monoxide generated in accordance with the reaction

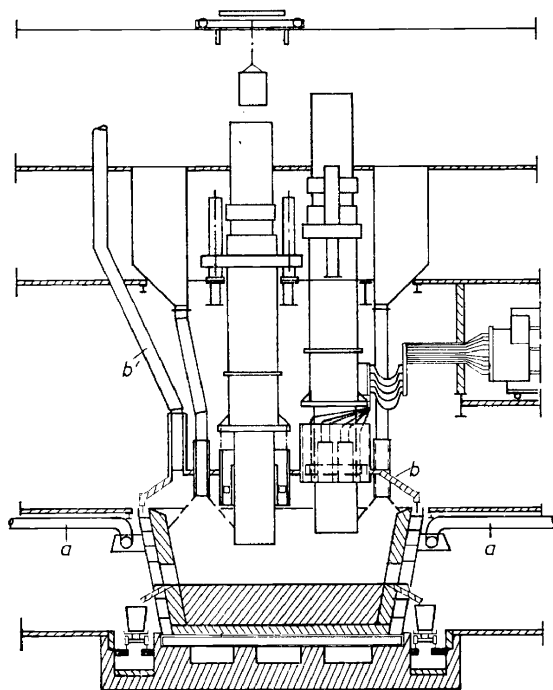




burns away with the conventional furnace construction. However, the furnace charge—the mixture of lime and carbon—develops considerable quantities of dust through abrasion, through vaporization and through chemical reduction processes. Thus, the exhaust gas of the conventional 'open furnace' may contain 0.25–2.5 g/m<sup>3</sup> of dust, which consists basically of the oxides of calcium, magnesium and potassium. The daily dust discharge may amount to several tons. This dust is of very fine particle size and presents one of the most difficult problems of dust separation.

The technical development which eventually led to completely dust-free operation has proceeded from the open furnace, through the semi-closed, to the closed carbide furnace. In the open furnace, the exhaust gas is not captured. With the semi-closed furnace it is partly captured. With both types de-dusting measures are adopted with partial effect. With the closed furnace (*Figure 4*) no exhaust gas emerges. The carbon monoxide is purified in a de-dusting plant and reclaimed. There is no dust emission problem.

The technical development work on the construction of this type of furnace has taken 25 years. At the present time, there are 9 open furnaces, 4 semi-closed and 5 fully closed furnaces. New plants are built in the closed type of design.



*Figure 4.* Fully closed carbide furnace (a = exhausts for dust and waste gas; b = feed pipes for charge)

(b) *Purification measures on the process exhaust gases*

A change in production processes with simultaneous improvement in the emission conditions, as illustrated above, cannot be generally demanded. It

involves lengthy development work and research both in the chemical and engineering field. Quality and cost of the products manufactured by modified methods can not be allowed to drop. This is the way the purification of the waste gases must be carried out in the majority of cases.

In a large chemical factory, 535 installations with varying types of operation daily purify 69 million cubic meters of exhaust air. Some 90% of the exhaust gases are purified of inorganic and organic dusts by means of centrifugal separators, gauze filters, electrostatic separators, gravel bed separators and wet separators. Scrubbing towers and Venturi scrubbers are employed for inorganic and organic vapours and gases. Volatile hydrocarbon compounds are burnt in flares.

The treatment of exhaust air takes place partly in the production equipment as such, partly in the central installation. Thus the usual outlets in organic operations which pass over the roof are combined in a central duct and led into a central purification installation.

To separate particularly resistant aerosols and salt dusts, the Petersen-type pressure drop separator is being introduced on an increasing scale (*Figure 5*). The principle of this system consists in the division of the exhaust gas current into several individual currents which pass at high speed through a system of specially shaped ring slots in which they are sharply deflected. The particles present in the exhaust gas in this way attain an extremely high centrifugal acceleration—up to 100,000 times the gravitational acceleration—and in this manner they are separated and removed by means of

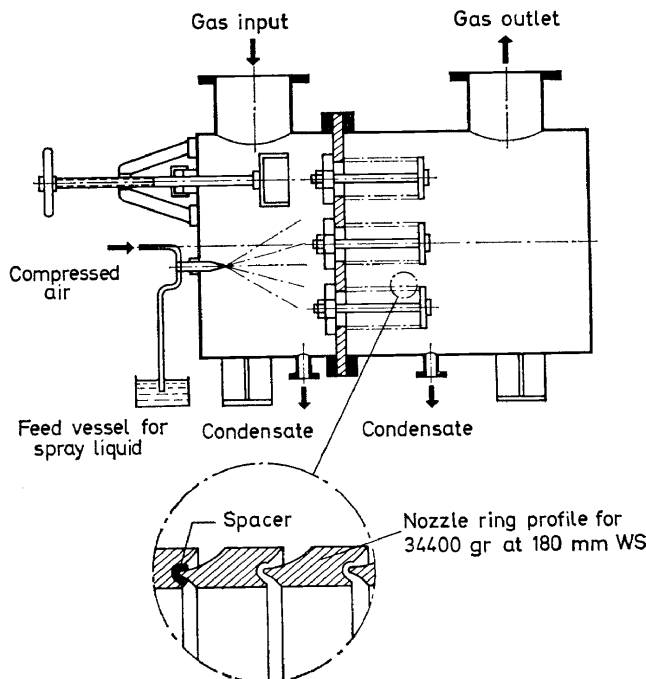


Figure 5. Pressure drop separator, Petersen System

simultaneously injected water. The apparatus has been used successfully to separate sulphuric acid and hydrochloric acid mists, dyestuff dusts, mixtures of salt and acid mists, which would be difficult to deal with in any other way. The effectiveness is over 99% with only slight loss of pressure.

Here are some examples of special purification measures:

(i) *Chlorine emissions*—The annual chlorine production in Western Germany is at the present time approximately 1.2 million tons. As the very low MAC value of 0.5 ppm = 2 mg/m<sup>3</sup> and the very much lower immission limiting value of the Technical Code of 0.1 ppm shows, exceptionally careful measures are required to prevent emissions in operations with chlorine.

Chlorine is transported and used in a fluid and gaseous condition. In the production process—electrolysis—every point where chlorine or chlorine-containing exhaust gas can escape is sealed off and linked to a central purification installation. The bonding of chlorine usually takes place by means of caustic soda lye, also by means of milk of lime. For example, an electrolysis which produces 1000 tons of chlorine per day purifies 12,000 m<sup>3</sup>/hr of exhaust gas containing 20 g Cl<sub>2</sub>/m<sup>3</sup>, on a residual content of 2 mg/m<sup>3</sup>—thus to an effectiveness of 99.9%.

A chlorine-consuming process—we are concerned here with the chlorinating calcination of pyrite slag—purifies 2000 m<sup>3</sup> per hour of chlorine-containing exhaust air by scrubbing with a ferro-salt solution to the extent that testing the exhaust air with potassium iodide solution yields a negative result.

An indirect means to prevent greater chlorine emissions is a chlorine alarm system installed in a large factory. In every area of the factory where chlorine is transported in conduits, or stored in containers, or processed, chlorine alarm signals—similar to fire alarms—are installed. These are yellow in colour and fitted with alarm knob and telephone. The alarm reaches simultaneously the telephone exchange of the chlorine factory and the works fire brigade. Counter measures are taken from both points depending on the gravity of the episode which may extend to evacuation of the staff, discontinuing chlorine production and informing the authorities.

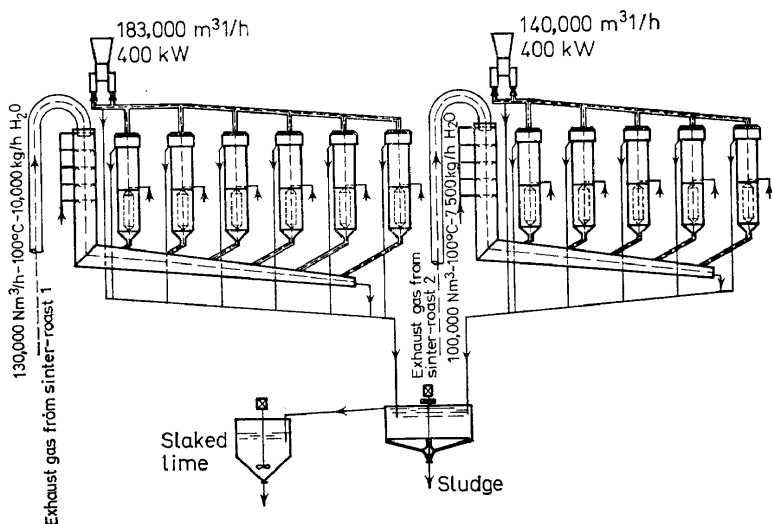
(ii) *Emission of fluorine compounds*—Extra attention is also devoted to the emissions of fluorine compounds—especially hydrofluoric acid and silicon tetrafluoride. As is known fluorine is stored in vegetation and several types of plant life are irreversibly harmed by the continuing influence of micrograms F'/m<sup>3</sup> in the atmosphere. A branch of the chemical industry where both the above compounds are produced in large quantities is superphosphate production. Since the emission problem of this industry is discussed in a later paper, it is only touched on here.

Superphosphate production in Western Germany at the present time amounts to about 370,000 tons per year. This is 40% of European production. The emission problem arises from the content of calcium fluoride and silicates in the crude phosphate. On decomposition with sulphuric acid, fluoric acid and silicon tetrafluoride, which are physiologically harmful, are developed.

They are removed by means of water and alkaline liquids. A basic difficulty in the scrubbing process is caused by the fact that silicic acid or sodium hexafluorosilicate which is difficult to dissolve are precipitated.

This can lead to blockages of the scrubber. Nor should the scrubbing water be drained into the river. The aim should be to produce concentrated scrubbing solutions and to extract the fluorine compounds from that. Scrubbers with large cross-sections are used. In practice, types like the Doyle scrubber, the gyratory scrubber, the disc scrubber, Venturi scrubber and jet scrubber have proved successful and degrees of effectiveness up to 95–99% have been reached.

Another important source of the emission of hydrofluoric acid is the sintering plants for the manufacture of pebbles from crude phosphates for the phosphorus furnaces. This involves the purification of quantities of exhaust gas up to 130,000 m<sup>3</sup>/hr—with contents of approximately 200 mg F'/m<sup>3</sup>. The treatment takes place in the swirl scrubber systems (*Figure 6*) associated with the sintering plants.



*Figure 6.* Swirl-scrubber-system for the elimination of HF from a sintering plant

The exhaust gas is scrubbed in advance in two scrubbing towers with weak lime alkaline water. The swirl scrubber is operated with the same liquid. The purified gas contains 6–7 mg F'/m<sup>3</sup>. The effect is 97%. The fluorine is precipitated by lime in the scrubbing water.

The nitrogen–phosphorus–potassium fertiliser plants are equally an emission source of HF. The hydrofluoric acid arises from the decomposition of crude phosphorus with nitric acid. The exhaust air content of 30–35 mg HF/m<sup>3</sup> is reduced by means of a two stage jet scrubber to 1 mg/m<sup>3</sup>.

In a larger plant processing hydrofluoric acid, all containers are linked with a central scrubbing tower. The yield of an average 4 kg HF/hr is reduced to 0.01 kg/hr with an effect of 99.7%.

(iii) *Organic emissions*—The emissions of the chemical industry which most frequently evoke objection among the public are the odours. They are mainly associated with the emissions of organic materials.

The destruction of malodorous substances is effected in many cases by oxidation which is accomplished by means of combustion or with chemicals. In a large chemical works, hydrocarbons which contain some malodorous substances are burnt in 18 flares. The quench water of a petrochemical plant containing hydrocarbons with a strong smell and which could therefore not be discharged directly into the stream are stripped. The strip gas is catalytically burnt.

In a plant manufacturing carbon electrodes for the electrochemical industry with a monthly production of 4000 tons of electrode material, there is an output in the same period of 100 million cubic meters of exhaust gas with 50 tons of tar. The tar mist causes a strong smell in the general neighbourhood of the factory. The remedy was the installation of an electrostatic gas purification plant which keeps back 90% of the tar mist. There were difficulties at first as the exhaust gas mixture is inflammable. Detonations and chimney fires occurred. However, it was possible to overcome the difficulties.

A similar unexpected effect occurred in the scrubbing of malodorous exhaust gases in a factory producing insecticides. Perchlorates giving rise to explosions are formed in the sodium hypochlorite used as a scrubbing liquid. This was avoided by preliminary water scrubbing.

These two examples show that known processes often cannot be applied directly to similar problems.

A smell problem also arose in the drying of mycelium residues in penicillin production. After various unsuccessful efforts, e.g. scrubbing the gases with acid solutions, a good result was obtained when sulphur dioxide was introduced into the dryer. The treated exhaust air—20,000 m<sup>3</sup>/hr—is scrubbed subsequently with water.

In another large chemical works, the exhaust gases containing ammonia and organic amines of 9 plants are first scrubbed in a central pressure water scrubber. After subsequent distillation of the scrubbing liquid, in which a part of the material is recovered, the residual impurities are burnt with hydrogenous exhaust gas from the formaldehyde production.

Exhaust gas problems of viscose factories—we are concerned with hydrogen sulphide in particular—are treated in various ways according to the locality. Active carbon or iron hydroxide are used in wet and dry processes. The 'Sulfosorbon Process' of the Lurgi-Gesellschaft für Chemie und Hüttenwesen, Frankfurt-Main, deals with hydrogen sulphide and carbon disulphide, in one process stage. The absorbers are filled with active carbon containing iodide. In its lower part, the hydrogen sulphide is separated up to 95% in the form of sulphur and up to 5% as sulphuric acid. In the upper part the hydrogen sulphide is absorbed. The sulphur is periodically extracted with carbon disulphide, the carbon disulphide is desorbed with steam. The residual exhaust gas contains less than 1 ppm hydrogen sulphide and 50–100 mg/m<sup>3</sup> carbon disulphide. The exhaust gas purification processes are still partly in the development stage in this industry.

It is of interest to note that recently work has been carried out on the combatting of malodorous materials by means of ozone. Such a process appears to be economically feasible also with values of exhaust gases of less than 10 ppm mercaptan.

## II. Indirect methods of reducing emissions

It is obvious to the specialist that emissions cannot be totally prevented in chemical engineering processes. All that can be achieved is to see that it does not reach intolerable proportions. The atmosphere within the factory area and in its vicinity must therefore be continually inspected.

The larger chemical factories have established special departments for this purpose. These are immediately under the top management. They control general pollution of the air, determine the contribution of individual emitting sources, plan improvement measures and establish their effects. In acute cases they carry out measurements to determine the critical conditions. Some works conduct routine inspections of the emissions of the factory and the atmosphere with a television camera.

In one plant measuring cabins have been set up at 3 significant positions where the most important emissions,  $\text{SO}_2$ ,  $\text{NO}_2$ ,  $\text{NH}_3$ , carbon dioxide, are measured continuously and the measurements recorded. There is a dust measuring device and some test plants on the roof of these cabins.

The following illustration (*Figure 7*) shows the total inspection system. In addition to the measurements in the cabins, the atmosphere in the works is tested daily at the control points indicated by black points.



*Figure 7.* Air pollution surveying and control system in a chemical plant (by courtesy of the Farbwerke Hoechst AG)

To conduct routine measurements in the immediate vicinity and in the general neighbourhood of the factory and for employment in special cases, the works have introduced measuring vans which are equipped with analytical apparatus, measuring instruments, including wind direction and wind force, and with radio-telephone.

The development of special methods of analysis is also part of the function of these departments. Gas chromatography is finding extensive application.

The results of all these controls are evaluated with regard to meteorological factors and given in reports to the top management and the factory. They serve too as a basis for further measures of improvement.

## RESEARCH ON DAMAGE TO PLANT LIFE THROUGH EXHAUST GASES

The need of and the effort of preventing emissions of foreign matter into the air is based, in the final analysis, on the harm caused to human beings, animals and plants. It is therefore of fundamental importance to have thorough knowledge of these effects in order to avoid unrewarding investments in the measures to maintain clean air.

Plants are particularly sensitive to some of the main chemical emissions. To investigate these phenomena big chemical factories have set up experimental stations on plant fumigation.

Plants of economic and horticultural value are fumigated under various conditions with air containing foreign matter. The fumigation takes place in small greenhouses into which a measured current of air with a specific concentration of foreign matter is introduced. These houses are of plastic which is transparent to ultra-violet. They are tilted overnight so that the plants are under natural conditions during this period.

Tolerance limits are determined and the effects of intermittent fumigations and the dependence of the damage on the state of the vegetation, on climate and on nutrition. These experiments are carried out over long periods with  $\text{SO}_2$  and nitrogen monoxides. They have yielded informative results which have been published.

## Conclusion

Only a few examples could be given here of the efforts of the West German chemical industry to improve its emission conditions. Many problems still remain. Outsiders are often inclined to overlook the fact that the purification of exhaust gases means the transfer of a material from one medium into another. Thus, an effluent problem must not be allowed to arise from this and the disposal of semi-liquid or solid waste materials arising from it is equally a problem often fraught with difficulties. Specially prepared places must be provided for which often no site is available or can only be reached via long routes. The problem of the quantitative determination of smells is still unsolved. Also not satisfactorily solved is the calculation of chimney heights from the emission and immission conditions which is required by the authorities.

From the size of the contribution of the West German chemical industry to exports arise problems of competition with those countries where such far-reaching legislation on the maintenance of clean air does not exist. All these measures are unproductive and should be carried out only to the extent needed but not as extensively as possible. They must be practised 'by reasonable means.'

In view of the multiplicity of the problems of clean air maintenance

in the chemical industry, an extensive exchange of information is urgently needed and is taking place among the firms. It is supported by special departments in the Federal Association of German Industry, the Chemical Industry Association, in the VDI† Commission on Clean Air Maintenance and through the activity of the Institute for Industrial Water Economy and Clean Air Maintenance in Cologne.

We know that much valuable work on the maintenance of clean air has been carried out also in the chemical industry of other countries. It is necessary here also to exchange information and to learn from one another. Various effective beginnings have been made already. I think of the European Conference on Air Pollution in Strassburg in 1964, on the International Clean Air Congress in London in 1966 and the work carried out over a number of years of the Working Party on Air Pollution in the European Federation of Chemical Engineering. This exchange of information should be continued on a greater scale. What is highly desirable is international uniformity of concepts, systems of measurement, measuring methods, evaluation of results and methods of analysis.

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