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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
INVESTMENT CO-OPERATIVE PROGRAMME BRANCH

ELECTROCHEMICAL INVESTMENT OPPORTUNITIES

August 1985

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TERMS OF REFERENCE

The UNIDO Investment Co-operative Programme Branch has on hand a number of investment project proposals based on hydrogen from water electrolysis.

Based on his knowledge and experience in the subject matter, the consultant will provide information on the most recent technologies in the use of electrical power for the production of hydrogen for fertilizers and basic chemicals, with special reference to the processes used by the de Nora Company in Milan, Italy, and the Norsk Hydro Company in Oslo, Norway. He will provide indicative figures for power consumption and investment cost and an outlook for future developments, especially regarding high pressure electrolysis.

He will visit the de Nora Company for one day and contact the Norsk Hydro Company by telephone and/or letter. He will also report on his findings regarding progress in new developments made by other spezialized firms, including Canada Electrolysors.

He will prepare a comprehensive report on the above (about 20 to 25 pages) and submit it to UNIDO/ICPB by August 31, 1985.

SUMMARY

Beginning with the early days of industrial chemistry electric power has been applied as source of energy in a number of processes, including the electrolysis of water, the electrolytic production of chlorine and caustic soda, the production of phosphorus and calcium-carbide and several applications of the electric arc as well as the electrolytic production of metals, such as aluminium and magnesium. Development centers and centers of industrial production were those areas where electric power was - and still is - available at reasonably low cost: hydroelectric power in Scandinavia, in Canada and in various dam-regions like Aswan, Nangal and others; power from coal-fired power stations in mining areas in the USA, in the USSR in the German Democratic Republic, and in the Federal Republic of Germany in the Cologne area; certain other thermal power stations, where the primary fuel is available at low cost, and certain nuclear power stations.

With the availability of fossil fuels as raw materials and as energy at reasonably economic rates, with the development of processes to produce synthesis gas from such raw materials and - last not least - with the development of the petrochemical routes via ethylene the development of the traditional electrochemical routes was not further persued for 20 years and many electrochemical processes became obsolete, i.e. the so-called carbide-acethylene route.

Since the dramatic increases of the prices for petrochemical raw materials, mainly gas and naphtha, the possibility of a re-activation of traditional electrochemical routes has been studied under various provisions, the most important being the availability of surplus electric power in a region, where for a foreseeable number of years requirements of the industrial development and the private

consumers can be guaranteed without major cuts into the availability of power to the electrochemical plant. Such regions will be in Africa, in South America, and in Asia. Technological development work has been directed towards the improvement of existing technologies: decrease of specific power consumption and applicability in to-day's commercial scale plants.

These efforts have produced success essentially in all areas where electricity cannot be substituted by other forms of energy, i.e. chloro-alkali electrolysis and production of metals. They have still not produced an acceptable solution in other areas like large scale water-electrolysis and the re-activation of the carbide-acethylene route, although some development-teams, like the one of Prof. L. Bölkow in Munich predict, that the electrolytic production of hydrogen may play a major role in the economics of energy on our globe in the foreseeable future. This refers to a time-span of 50 to 80 years. The detailed analysis of the status of the development efforts of various teams in Switzerland, Italy, Canada, the USSR, Japan and in other countries would go far beyond the terms of reference of this paper and may not produce practical and applicable results before 3 to 4 years from now.

It may however be recommended to continuously monitor the scenario. A conference where various teams could report on the results of their studies could produce a good survey if it is carefully prepared and scheduled for 1986.

Any specific investment proposals have to be individually studied and analyzed in view of the most probable development of the power supply/power demand situation during the expected lifetime of the proposed plant.

Introduction

Since 1766, when Henry Cavendish first discovered an electrolytic method to separate water into its elementary components hydrogen and oxygen, researchers in science and in industry have put a great deal of effort into the investigation of the effect of electric power on all kinds of chemical individuals or reactions. Electrochemical processes in the context of this paper will include such processes, where electricity as a source of energy takes actively part to initiate or to make feasible a specific chemical reaction. Such reactions may take place in aqueous or other ionic solutions, in gaseous media or in mixtures of solid or molten materials. A manifold of industrial processes have been developed into commercial-size applications and quite a number of them have been continuously improved and kept up to the latest state of the art as far as technological possibilities and economics are concerned. There are processes which continue to have a well defined field of application and others which have been forgotten over the years, but still may be of interest under certain specific conditions.

The Process of Sam Eyde and Kristian Birkeland and other Electric Arc Processes

The production of nitrogen oxydes in an electric arc process was named after the two gentlemen who have studied the phenomena of the influence of the electric arc in an air-filled glass flask and developed this reaction into a "commercial scale" operation. At the beginning of this century the first few kilogram of HNO_3 were obtained and the basis for the synthetic production of explosives and fertilizers was laid, independent from natural nitrates which were to be imported to Europe from South America and which, until then, were the only source for nitric acid, nitrates and all products and chemical individuals derived from these raw materials. (Attachment I)

To-day this process is only of historical importance. The product yield in relation to the consumption of energy was never able to compete with the ammonia synthesis/ammonia combustion route as it was developed to technical application by Haber, Bosch and Oswald. Nevertheless other teams have continued to investigate chemical reactions under the influence of the electric arc. One of the processes which is still in commercial operation in several plants in Europe (HÜLS electric arc process) and in the United States (Du Pont electric arc process) is the production of acetylene and ethylene from methane and other hydrocarbons. The capacity of VEBA-HÜLS is indicated to be appr. 130.000 tpy of acetylene and 60.000 tpy of ethylene. A second plant in Europe is operated in Rumania.

Some years ago an electric arc/plasma method has been published by HÜLS and by HOECHST under the name **WLP** (Wasserstoff-Lichtbogen-Pyrolyse). The technologies of the two inventor companies are slightly different: Whereas HÜLS activates the hydrogen stream which is used as heat transfer media with a direct current electric arc, HOECHST obtains the elctric arc from three phase current. Contrary to the direct electric arc process from HÜLS, this technology is capable to utilize a wide range of hydrocarbons with good results in acetylene/ethylene-yield (80%) and low quantities of carbon black as a by-product.

There is only one project in a developing country known to the author, where the utilization of the electric arc technology is considered for the production of acetylene and ethylene from methane. This project is part of the petrochemical scheme in Bangladesh where besides of natural gas no other petrochemical feedstock is locally available. So far nobody has been able to prove the feasibility of this route for a new plant in Bangladesh and the autnor is quite convinced that the plant may never be built - at least not in the foreseeable future.

The Production of Hydrogen and Oxygen by Means of Water-electrolysis

Although its large scale commercial application started only much later, this process is certainly the oldest but perhaps also the most potential application of electric power in the field of transformation of materia. In the past it has been applied in regions where electric power constitutes a source of energy which is more economically available than coal, hydrocarbons or other fossil feedstocks for the production of large volumes of hydrogen. In these regions the electrolysis of water became the basis for the ammonia and fertilizer industry for many years. In the early '30ies NORSK HYDRO as a pioneer of this technology started the large scale production of hydrogen in two locations in Scandinavia: Rjukan and Glomfjord and until to-day the electrolytic production of hydrogen in these two locations still continues at a combined level of 60.000 Nm^3/h. In other locations such as Nangal in India, Aswan in Egypt and Cuzco in Peru, electrolytic hydrogen has been or will be replaced by hydrogen from petrochemical feedstocks or the product-range of the plant has been converted to higher value products in order to justify the application of electric power which became more valuable as the demand increased with the ongoing industrial development of the individual regions.

Electrolytic hydrogen to-day is produced in a great number of smaller installations, where limited quantities of pure hydrogen are used for the finishing of edible oil and fat or for various chemical reactions in many industrial fields, including pharmaceuticals and perfumes.

With the considerable price increase for fossil feedstocks on the one hand and with the availability of surplus electricity in some specific locations of the globe on the other hand, various studies have been initiated to investigate the economics of the application of hydrogen for the production of fertilizers. Such locations are the Inga-Dam in Zaire, the surplus electricity regions in Brazil

and in Paraguay as well as in Borneo and possibly in Canada, to name only the spots with the highest potential.
(Attachment II)

Besides of its direct utilization as a raw material in chemistry, the hydrogen from the electrolysis of water may well become an important factor in the economics of energy storage and energy transport in the foreseeable future, and of course hydrogen is a fuel which can be utilized without creating any problems to the environment. Some authors have estimated that even under to-day's conditions the transport of compressed or liquified hydrogen for distances above 400 km is more economic than the transport of electric power in the main electrical grid. They further predict that it may become feasible to produce hydrogen in the immediate vicinity of glacial power stations in Greenland and to ship the liquified material to terminals in continental Europe (Ludwig Bölkow).

Even if this may sound a bit futuristic, it is quite clear now, that electrolytic hydrogen **will play a major role** in the scenario of energy economics in the future. It is also quite clear that the presently available and proven technology for the electrolytic production of hydrogen - which is based upon the electrolyzation at a slightly elevated pressure of about 6 kg/cm² - has to be revolutionary improved in order to open a new era for this resource. Efforts into this direction are under way in some specialized firms and institutions like:
ASAHI CHEMICALS, Japan
ASAHI GLASS, Japan
BROWN BOVERI & CIE., Switzerland
CANADIAN ELECTROLYSORS, Inc., Canada
GENERAL ELECTRIC COMP., USA
ICI, United Kingdom
NORSK HYDRO, Norway
ORONZIO DE NORA S.p.A., Italy
and others.

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The direction of these efforts include the zero-gap electrodes and the introduction of membranes in order to optimize the specific power consumption per Nm^3 of product and the operation of the electrolyzer-cell at an elevated pressure far beyond the present limits. I may very well be expected that new impulses for the further development in this field will result from space technology and it will certainly be of interest to follow-up the status of this developments in regular intervalls of one or two years.

The Production of Chlorine and Caustic Soda from Sodiumchloride or Natural Brine and the Production of Chlorine from Muriatic Acid

The first of these two processes is perhaps the most important industrial application of electrolysis in aqueous solution. With chlorine consumers in plastics, chlorhydrocarbons, and many other chemicals and with its direct application in the water treatment and in the pulp and paper industry, chlorine is one of the traditional inorganic bulk chemicals. The second product, caustic soda, is mostly consumed in the production of aluminium and in the chemical industry itself. The electrolytic production of chlorine from muriatic acid is used for balancing the regional chlorine demand versus the caustic soda market on the one hand and in order to solve a disposal problem which occurs if there is no reasonable outlet for surplus muriatic acid available. Wherever relatively huge quantities of HCl are an unavoidable by-product in certain chlorination processes it may - also from an economic point of view - be advisable to consider this electrolytic process in order to recycle the chlorine.

With the slow-down in demand of PVC and chlorine chemicals both processes have not kept pace with the growth rates they reached in the '60ies and early '70ies. For environmental (mercury, asbestos) and economic (power rates) reasons however, very active development efforts have been invested into this technology, resulting in a remarcable decrease of specific power consumption per ton of chlorine and in the elimination of environmental and health hazards resulting from the application of mercury as a cathode and diaphragmas made from asbestos.

In this field the technology development has done several big steps in the past few years: DSA, Zero-gap, and Membrane Technology to name only a few. It is essentially carried by the same group of companies who are actively working in the field of water-electrolysis, namely
ORONZIO DE NORA S.p.A., Italy
ICI, United Kingdom
ASAHI GLASS, Japan
ASAHI CHEMICALS, Japan
and a German Group consisting of
BAYER AG, HOECHST AG and UHDE GmbH.
From an economic point of view one should consider the trade with and the transport of liquide chlorine or VC monomere as a trade and a transport of an energy concentrate.

It is anticipated that with the realization of the objectives of the present development the power consumption per ton of chlorine will come down very close to the theoretic possible level, and health and environmental hazards are completely eliminated or minimized.
(Attachments III, IV)

For the direct chlorination of seawater ORONZIO DE NORA S.p.A. developed their SEACLOR system for the on-site instantaneous generation of hypochlorite solutions. This system is widely used in seawater intakes for power stations and seawater desalination units.
(Attachment V)

A very interesting combination of technology may be the combination

of a chloroalkali electrolysis with the production of phosphoric acid. This process eliminates the difficulties which result from the need to utilize or sell or dispose off the chlorine from a plant which is mainly operated to produce sodium hydroxyde. The chlorine obtained as a by-product in this case is converted into HCl and utilized in this form for the treatment of phosphate rock for the production of fertilizer-grade phosphoric acid. This process route has been jointly studied by DE NORA and ICL Ltd. It will be of interest wherever NaCl, electric power, and phosphate rock are available and sulfur would have to be imported for the sulfuric acid - phosphoric acid route. The copy of a preliminary feasibility study is attached to this paper.
(Attachment VI)

The Production of Hydrochloric Acid from Chlorine and Hydrogen

This process is only of very limited importance to-day as huge quantities of muriatic acid are available as a by-product from various chlorination processes. As mentioned above, this product in certain cases creates rather a disposal problem and is recycled via a special electrolytic process to produce hydrogen and chlorine.

The Electrolytic Production of Sodium Chlorate and Potassium Chlorate and the Production of Bleaching Chemicals

These processes are to be considered as a manufacturing of specialty chemicals rather than a posibility to use surplus power in a way which would influence the economy of energy.
(Attachment VII)

The Electrolytic Production of Aluminium and Magnesium

This technology includes two of the major power-consuming industrial processes of to-day. Whereas aluminium is produced in huge quantities at many locations in the world, magnesium is still the specialty of a few production units only. Similar to the transport of liquid chlorine or VCM the transport of aluminium ingots means transporting energy in a manageable form. Unfortunately there are only a few places in the world where the two resources, electric power and bauxite, can be found so close to each other that one could say "this is an ideal place to build an aluminium factory". One location which has both is in the northeast of Brazil and it may be predicted that a substantial aluminium capacity will be installed in this region as soon as infrastructural and other problems have been solved.

NORSK HYDRO is one of the pioneers in both processes and the company is operating several plants based on the availability of hydroelectric power in Scandinavia.
(Attachment VIII)

The Calciumcarbide - Acetylene - Chemical Route

This process has been the basis for the development of many chemical products and for the commercial production of plastics, plastizisers, solvents, and other materials over many years, until - with the availability of hydrocarbons from petroleum fractions - the petrochemical routes were established. Besides of calcium carbonate and coke, electric power is the main "raw material" for this process route. Coke, according to the results of development work which was mainly executed in recent years, may be replaced partly or as a whole by other suitable carbon-carrying materials from charcoal to scrap tires.
(Attachment IX)

With the price increase in petrochemical feedstocks since the early '70ies a number of projects has been studied with the objective to determine the feasibility and the economics of a possible re-vitalization of the calciumcarbide-acetylene-chemical route under various local conditions, in Zaire, in Bhutan, and in other locations. To the best knowledge of the author until to date none of the consulting parties has been able to justify a re-vitalization of the old route, although some capacities are still in operation in the Buna-Werke in Schkopau/GDR and in South Africa. In all other locations where carbide is produced, the bulk of the material is sold to the iron and steel industry and only very limited portions are used for chemical purposes, i.e. - after reacting with air - as $CaCN_2$, a nitrogen-fertilizer with special properties and a raw material for certain synthesis routes, as it is produced by SKW, Trostberg/Germany.

The Electrothermal Production of Elemental Phosphorus

Until about 15 years ago the electrothermal production of elemental phosphorus was about the only way to obtain the purity needed for many processing steps in the detergent industry, the food industry and for many technical applications of phosphorus and phosphorous compounds. Since then a considerable progress has been made with the purification of wet phosphoric acid and the demand for the product from the elctrothermal route has decreased. The dramatic downtrend in sulfur prices has provided an additional impact to this development.

Economic Operation of Electrochemical Installations

For any region where there is surplus electric power available in quantities changing between daytime and nighttime or in any other cyclus, the electrolytic processes as well as the electrothermal processes listed above may well be controlled in accordance to that time-table in a way to utilize the surplus electric power whenever it is available and to give priority to other consumers during times when these consumers have their peak demand. In Europe such time-tables normally are a part of the contract between the power supply company and the industrial power consumer and the price which the consumer finally has to pay for the energy depends upon the accuracy with which he follows the quantities agreed upon in the time-table. This flexibility of course has its limitations as it can only be exercised on the basis of an installed surplus capacity in the electrochemical plant and accordingly it demands an increased capital investment. This naturally is a disadvantage especially for developing nations: The balance between additional capital cost on the consumer side versus idle investment on the side of the power generation plant is to be figured very carefully. In the case of hydroelectric power the investment in the power production (dams, turbines etc.) is generally higher than the investment of the consumer. Still the author is convinced that it would be very irresponsible to dare any generalized conclusion or recommendation at this point. It is rather absolutely unavoidable to study the specific conditions at a specific site over a well defined time span (which should coincide with the expected lifetime of the proposed plant) in order to develop a recommendation pro or contra a proposed investment.

Conclusions/Recommendations

The survey which has been executed by the author under UNIDO-Contract Nr. CLT 85/184 is based upon visits/discussions and communications with 11 companies specialized in the design and construction and/or operation of electrochemical plants. The list of companies includes:

BBC Aktiengesellschaft, Mannheim
Chlorine Engineers, Tokyo
DE NORA S.p.A., Milano
HOECHST Aktiengesellschaft, Frankfurt
ICL, Tel Aviv
LURGI GmbH, Frankfurt
MBB GmbH, München
NORSK HYDROA/S, Oslo
SKW Aktiengesellschaft, Trostberg
UHDE GmbH, Dortmund
VAW Aktiengesellschaft, Bonn

During ACHEMA 1985 the presence of many experts in Frankfurt was utilized to exchange information which provided additional background to define the following conclusions:

- Electric power is considered a high-value energy ("Edelenergie") and accordingly it is priced in almost all industrial regions of the world. Under to-day's scenario it is economically not feasible to utilize electric power in electrochemical processes
  - . whenever another process route with easily available raw materials and other sources of energy will make available the same products.
  - . whenever industrial or private consumers have developed a demand for the capacity of electric power which is available in the specific region.

- For the above reason, research and development efforts in the electrochemical field during the last few years have been concentrated in areas where such alternative routes are not available:
  - the production of chlorine and caustic soda from sodiumchloride
  - the recycling of chlorine from HCl
  - the production of phosphorus and calciumcarbide for consumers who cannot replace the electrothermically manufactured product in their processing lines for reasons of technology or quality
  - the production of small quantities of pure hydrogen, which is used for hydrogenation processes in the food industry, the pharmaceutical and cosmetics industry and for small-scale consumers in the chemical industry
  - the production of aluminium and magnesium
  - the production of metallurgical alloys like ferrosilicium, ferrochromium, ferromangan etc.

In all these areas up to date highly economic processes are available which comply with the latest standards of operating safety, environmental protection and product quality. For the large-scale electrolytic production of hydrogen however and for the processing of this hydrogen, be it for the direct conversion to ammonia and fertilizers or for transport as raw material or as source of energy it would be necessary to come to more economic technical solutions which have to include the electrolysis at an elevated pressure of at least 20 to 30 kp/cm^2 and the reduction of the specific energy consumption.

As long as natural gas is available and with to-day's cost of transport with the presently available technology the author can hardly imagine the revival of a fertilizer production based upon electrolytic hydrogen (a commercial size ammonia plant would require about 80.000 Nm^3/h hydrogen).

A similar situation exists with regard to the calciumcarbide - acetylene route for the production of plastics and chemicals. It is certainly a more economic utilization of natural resources to produce vinylchloride-monomere or polyolefine-granulates from the C_2-fraction of natural gas via ethylene and to establish the processing units in the consumer region step by step in accordance with the growing demand.

In view of the above it is recommended to continuously monitor the scenario, the status, and the eventual results of the developmental efforts of the variuos teams. A conference where selected teams would be invited to present the results of their work could be a good instrument to up-date detailed knowledge and to motivate for further efforts.

In view of certain "unique" locations in developing nations like Zaire, Paraguay/Brazil, Malaysia, Indonesia, and others with much smaller surplus power capacities like Bhutan and Malawi, it may be recommended to study the present chances of power utilization and to draw up diagrams of the most likely development of the general power consumption and the availability of surplus quantities over the expected lifetime of an electrochemical plant. This includes the necessity to answer the question what would be done in order to keep an industrial and social environment full of vitality after a plant (i.e. a fertilizer plant) becomes obsolete due to a diversion of electric power to other consumers. This situation is expected to arise in the Aswan area shortly.

In view of the above status the author may draw the attention of the reader to attachments II - IX where the most up-to-date development status which is presently available for the important process routes is presented, including specific figures of power consumption.

As far as investment figures are concerned, in view of the ongoing development it is considered not recommendable to collect any such information from contractors at this state, and quote it in a general paper like this study. The value of these figures would be very limited or rather negative due to the potential of confusion which they include.

List of Attachments

ATTACHMENT I

The Electric Arc Process of Sam Eyde and Kristian Birkeland

ATTACHMENT I

CHAPITRE IX — A LA CROISÉE DES CHEMINS

I — LES PREMIERS ESSAIS DE SYNTHÈSE AMMONIACALE :

LA SYNTHÈSE AMMONIACALE SE POSE EN CONCURRENT DU PROCÉDÉ A L'ARC

NOUS avons vu au chapitre VI, page 118, comment la Badische Anilin & Sodafabrik consentit en 1911 à résilier l'accord de collaboration qu'elle avait conclu en 1907 avec la Société de l'Azote. Sam Eyde put, à ce moment, s'estimer favorisé par le destin ; car la bonne volonté dont les Allemands firent preuve à cette occasion fut plus grande qu'on aurait pu s'y attendre ; et au surplus elle était agréable aux Français. Il n'en reste pas moins que, comme nous l'avons dit, cette attitude des Allemands s'expliquait par le fait qu'ils avaient décidé de suivre une voie différente : la méthode à arc, avec sa forte consommation d'énergie, ne convenait pas aux conditions de production dont ils disposaient ; de plus, leurs essais en vue de la production synthétique de l'ammoniaque étaient déjà assez avancés à ce moment pour que le succès de la nouvelle méthode parut assuré : effectivement, nous l'avons vu au chapitre VIII, page 193, leur première production d'ammoniaque synthétique eut lieu dès 1913.

Le moment est venu maintenant, nous semble-t-il, de donner au lecteur un aperçu du procédé de la synthèse ammoniacale.

Tandis que la méthode à arc consiste à combiner l'azote et l'oxygène de l'air, la méthode Haber-Bosch fixe l'azote de l'air sur l'hydrogène, sous forme d'ammoniaque, dans des fours de synthèse à haute pression.

Pour cela, il faut disposer d'un mélange gazeux composé de ces deux éléments dans la proportion de 1 part d'azote (N_2) pour 3 parts d'hydrogène (H_2), correspondant au rapport de la molécule d'ammoniaque (NH_3). La réaction de la synthèse elle-même

$$N_2 + 3\,H_2 \rightleftarrows 2\,NH_3$$

aboutit à un équilibre dépendant des conditions de pression et de température. Une haute pression augmente le pourcentage d'ammoniaque tandis qu'au contraire une température élevée le diminue. Il semblerait donc que l'on obtienne le meilleur rendement en ammoniaque en travaillant à une haute pression et à une basse température ; mais avec une température peu élevée, la réaction, tout en s'opérant bien, se produit lentement, c'est-à-dire que l'équilibre s'établit trop tard. Il faut donc travailler dans le champ des températures moyennes de 400 à 700 °C pour arriver à un résultat intéressant. Mais même dans ces conditions il est nécessaire d'accélérer la réaction au moyen d'un *catalyseur*, c'est-à-dire d'un corps qui provoque la réaction sans y participer et donc sans être consommé. En général, il est impossible de prévoir quel catalyseur permettra d'obtenir une réaction déterminée ; aussi sa composition ne peut-elle être établie qu'à la suite de recherches longues et systématiques ; et de ce fait elle est considérée comme un secret de fabrication.

Jusqu'à la fin de la guerre, en 1918, les informations qui perçaient sur les conditions techniques et économiques de la méthode Haber-Bosch restèrent fort rares. Le professeur allemand Bernthsen, chef du service des brevets de la Badische, avait bien fait, en 1913, une conférence sur « Haberverfahren » aux États-Unis ; et en 1915 il fut question d'introduire la méthode dans ce pays. Mais on estima que l'azote qui serait ainsi obtenu reviendrait trop cher comparativement avec le procédé à la cyanamide de calcium et avec la méthode à l'arc — aussi étonnant qu'une telle opinion puisse nous paraître maintenant, car il était avéré dès ce moment que la méthode de la synthèse ammoniacale avait été couronnée de succès en Allemagne. Par la suite, cependant, les autorités américaines désignèrent un Comité spécial (The Nitrate Supply Committee), dont un représentant, le Dr Charles P. Parsons, alors chimiste en chef du Bureau des Mines, se rendit en 1916 pour un voyage d'étude en Italie, en Angleterre, en France, en Norvège et en Suède.

Ajoutons ici que ce Comité en arriva plus ou moins à la conclusion que, si la guerre n'était pas survenue, la Société de l'Azote n'aurait pu continuer à exploiter sa méthode de production : c'était là, on le voit, une opinion pessimiste, — à laquelle cependant bien des gens se rallièrent par la suite. Quant à nous, nous ne nous considérons pas en mesure de dire quel aurait été le sort de la Société de l'Azote si la guerre mondiale n'avait pas éclaté, et si le conflit ne lui avait pas permis de consolider sa situation financière ; mais — devons-nous ajouter — nous ignorons tout autant si l'Allemagne se serait engagée aussi énergiquement dans la voie de la synthèse ammoniacale si elle n'y avait pas été poussée par les nécessités nées de la guerre.

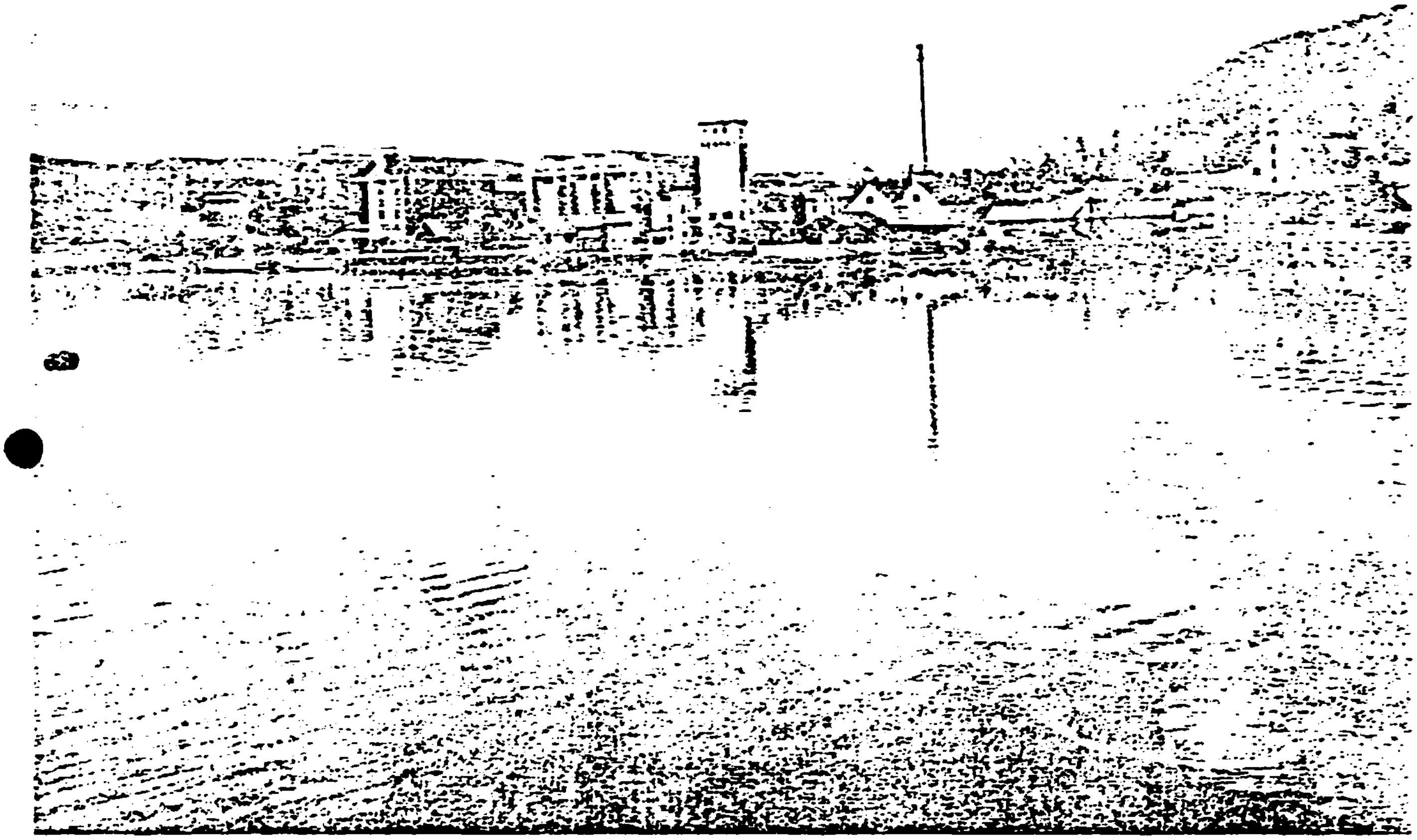
Quoiqu'il en soit, un fait, qui devait à partir de ce moment dominer tout le problème, demeure : par kilogramme d'azote obtenu, le procédé à l'arc Birkeland-Eyde exigeait 68 kWh alors que la synthèse ammoniacale Haber-Bosch n'en consommait que 17 : soit du simple au quadruple. Encore cette comparaison n'est-elle correcte que sous la condition que l'hydrogène nécessaire pour la synthèse ammoniacale soit obtenu par électrolyse de l'eau : si, au contraire, l'hydrogène est produit en partant du charbon (ou d'huile minérale, de gaz naturel, etc...), les besoins en énergie électrique sont minimes. Cela signifiait que, à partir du moment où la synthèse ammoniacale serait techniquement réalisée, la production d'engrais azotés synthétiques ne constituerait plus un privilège absolu pour les pays disposant d'énergie hydraulique bon marché.

Ainsi donc, une question se posait pour la Société de l'Azote : la méthode à l'arc pourrait-elle continuer à soutenir la concurrence? A la longue, l'avantage résultant du prix extrêmement faible de l'énergie hydraulique s'avérerait-il suffisant?

Convenons en tout cas que, par suite de la guerre, la Société eut une chance et un délai supplémentaires pour préparer le passage à la nouvelle méthode au moment où il devint inévitable ; car, comme nous l'avons vu dans les chapitres précédents, la Société put ainsi atteindre sa pleine capacité et même, grâce à des achats d'eau ammoniacale et de cyanamide, augmenter sa production au delà de sa capacité effective. Les prix qu'elle obtint pendant cette période n'eurent d'ailleurs rien d'excessif, puisque la hausse qu'ils faisaient ressortir resta inférieure à celle accusée par la moyenne générale des prix. Bien plus : lorsque par la suite le marché mondial enregistra une forte baisse — c'est-à-dire durant la période de crise qui suivit la fin de la guerre —, la Société de l'Azote resta dans une situation relativement avantageuse, grâce à la chute de la couronne, qui jouait le rôle d'amortisseur. Et c'est donc seulement au moment où la Norvège entra dans la phase de hausse de la couronne et de déflation, — époque qui fut aussi celle pendant laquelle la forte augmentation de la capacité de production de l'industrie de l'azote commença à faire sentir ses effets —, qu'il devint évident que *la Société de l'Azote se trouvait à la croisée des chemins.*

Un certain temps devait pourtant s'écouler avant qu'une décision fût prise et que la direction de la Société se décidât à abandonner la méthode à l'arc pour passer à la synthèse ammoniacale. C'est qu'en effet l'on disait assez couramment — disons que c'était une sorte de parti-pris d'optimisme — que le procédé à l'arc resterait en mesure de soutenir la concurrence pour la production de l'acide nitrique et des nitrates, argument pris de ce que l'ammoniaque synthétique devait être convertie en acide nitrique, ce qui nécessitait d'importantes installations et entraînait, en outre, des pertes en azote.

Il peut y avoir intérêt, à cette occasion, à mentionner les remarques bien symptomatiques qu'échangèrent au cours d'une réunion qui eut lieu en 1924, l'un des dirigeants de la Société de l'Azote et l'expert français Schloesing, très réputé en matière d'azote, et que nous avons déjà mentionné pages 68 et 120. Le professeur Schloesing ayant déclaré que la synthèse ne donnerait pas seulement de l'ammoniaque, mais aussi de l'acide nitrique et des engrais azotés meilleur marché que dans la méthode à l'arc, le représentant de la Société de l'Azote répondit : « Si vous aviez « raison, Monsieur Schloesing, j'abandonnerais



Les Fabriques de Notodden vers 1926

« l'industrie de l'azote et deviendrais agriculteur en Norvège... »

Comme nous l'avons dit, l'avantage de la méthode ammoniacale était que, par unité de référence, elle ne nécessitait qu'un quart de l'énergie utilisée par le procédé à l'arc. On pouvait cependant espérer remédier, dans une certaine mesure, à l'infériorité de la méthode à l'arc en se servant du four à arc Schönherr dont il a déjà été fait mention : effectivement, des essais réalisés avec un petit modèle de four avaient montré qu'en augmentant la pression jusqu'à 10 atmosphères, le rendement pouvait être porté d'environ 600 kg de NO_3H par kW-an à environ 730 kg, c'est-à-dire augmenté de 22 % environ ; et en outre, si l'on se servait d'un mélange d'oxygène et d'azote au lieu d'air, il semblait, d'après la loi d'action de masse, que le rendement dut augmenter encore d'environ 24 %, et atteindre environ 900 kg de NO_3H kW-an : il paraissait donc possible d'augmenter le rendement des fours de 50 % par rapport au rendement de ceux installés à Rjukan et à Notodden.

La Société de l'Azote comprit assez tôt l'intérêt qu'elle avait à entreprendre l'étude systématique des fours à pression : et en effet elle construisit, à Notodden, un four de ce type en connexion avec un appareil à oxygène Claude dont elle avait fait l'acquisition. Les essais de ce four commencés en 1916 furent poursuivis jusqu'en 1922, — époque à laquelle fut construit un four de 1 000 kW, dont la charge n'excéda cependant jamais 400 kW. Les essais effectués avec ce nouveau four durèrent jusqu'en 1925. On constata alors qu'en le faisant démarrer avec un réfrigérateur cylindrique en cuivre, on obtenait 680-700 kg de NO_3H par kW-an, et avec un mélange oxygène-air à 50 %, 800 à 830 kg NO_3H par kW-an, c'est-à-dire sensiblement moins que ce que l'on avait espéré. En revanche, en mettant le four en marche avec un réfrigérateur en argent, en aluminium ou en acier inoxydable, on obtint tout d'abord de meilleurs résultats ; mais ceux-ci ne furent pas durables ; et l'on retomba ensuite aux mêmes rendements que ceux obtenus avec le réfrigérateur de cuivre.

En connexion avec le grand four à pression, une petite installation d'absorption sous pression fut également construite. Elle se composait d'une seule tour, au sommet de laquelle on introduisait de l'eau pour retirer en bas l'acide, les gaz de four circulant en sens inverse (la chaleur résultant de l'absorption était éliminée à l'aide d'éléments réfrigérants encastrés dans la tour même). Le procédé se révéla satisfaisant ; et d'ailleurs il fut cédé à la Société Du Pont de Nemours lorsque celle-ci acheta la licence du procédé à l'arc : aujourd'hui encore cette firme l'utilise dans son système d'absorption sous pression.

Malgré l'intérêt des améliorations qui avaient été ainsi obtenues dans le rendement en azote par kilowatt-heure, il fut reconnu que celles-ci étaient insuffisantes pour permettre à la méthode à l'arc de soutenir la concurrence. Et finalement une série de problèmes électrotechniques et mécaniques, qui s'étaient révélés très onéreux, contribuèrent à la décision de mettre fin aux essais.

Comme nous l'avons déjà dit, les informations qui avaient percé pendant la guerre sur les conditions techniques et economiques de la méthode synthétique allemande étaient fort rares. On avait cependant l'impression, d'après certains brevets pris avant guerre, et d'après la conférence déjà mentionnée qui fut donnée aux États-Unis par le professeur Bernthsen, que l'emploi de la méthode était extrêmement difficile : il semblait que la moindre impureté dans les gaz utilisés risquait de polluer le catalyseur et donc d'arrêter toute la fabrique ; l'on ajoutait que l'acier, qui devait supporter une pression et des températures élevées, devenait cassant comme du verre si l'on faisait l'erreur de construction la plus minime ; et l'on disait aussi que des milliers de catalyseurs devraient être essayés avant que l'on en trouvât un qui puisse donner satisfaction, etc...

Lorsque, en 1919, les Puissances de l'Entente envoyèrent des experts inspecter les installations allemandes de synthèse ammoniacale, il se révéla que les Allemands n'avaient pas exagéré : les installations en question étaient effectivement très compliquées, et le travail qui y avait été accompli en si peu d'années apparaissait comme véritablement impressionnant. La Badische avait vraiment effectué une œuvre de pionnier en construisant ces fours à synthèse — qui devaient d'ailleurs servir plus tard de point de départ pour tant de fabrications nouvelles de caractère révolutionnaire.

A cette époque la question primordiale était de savoir comment procéder à la construction d'une première usine à Rjukan. A Notodden, pour l'essai des fours Schönherr, la fabrique dite d'acide avait été mise à la disposition de la Badische Anilin und Sodafabrik avec la force d'une génératrice de Svaelgfos ; et de toute évidence une concurrence allait s'établir entre les fours Birkeland-Eyde et les fours Schönherr pour l'installation de Rjukan.

Il importait donc de se mettre rapidement à l'œuvre ; et un grand four fut mis en marche dès février 1910. Le rapport de la fabrique pour le mois en question indique que les espérances exprimées quant aux conditions de marche du nouveau four avaient été réalisées et même dépassées. Tout paraissait donc aller de ce côté. Mais depuis un certain temps des doutes s'étaient fait jour quant à l'exactitude des mesures d'énergie électrique : la firme Siemens Halske fut donc chargée de procéder à un examen approfondi des instruments de mesure ; et elle constata sur les kilowattmètres des fours un écart de 7 à 8 %. La consommation réelle d'énergie était donc beaucoup plus élevée que les chiffres indiqués ; ce fut une dernière déception, au moment où l'on s'apprêtait à procéder aux essais définitifs.

Les instruments correctement réglés, tout fut préparé pour la comparaison des deux modèles de fours. Une importante commission, composée de comités désignés par les deux parties — la Badische et la Société de l'Azote —, fut nommée pour décider, diriger et surveiller les essais et rédiger un rapport à ce sujet. Les essais devaient comprendre une période de marche continue de 3 semaines pour chaque type de four, le four Schönherr devant être essayé d'abord, le four Birkeland-Eyde ensuite.

La tension était grande. On travailla activement et énergiquement pour tout préparer le mieux possible ; en particulier Harald Bonnevie, personnellement chargé du four Birkeland-Eyde, ne prit plus une minute de repos.

Les deux fours avaient un rendement très comparable, et il était donc impossible de prévoir le résultat définitif des essais ; mais comme le four à 3 300 kW fonctionnait assez bien, on devait espérer qu'il pourrait être utilisé dans ces expériences : ce qui — au cas où il triompherait du four Schönherr — permettrait à Rjukan une installation plus simple et plus méthodique ; car, dans le cas contraire, un nombre quatre fois plus important de fours Schönherr devrait être installé. C'était là une contrepartie à l'avantage présenté par le four Schönherr, dont le système de concentration du gaz permettait de simplifier la méthode d'absorption.

La mise au point de ces expériences fut longue et délicate, et ce ne fut que le 15 juin 1910 que celles-ci purent commencer avec les fours Schönherr de la fabrique d'acide. Les calculs de rendement devaient s'opérer pendant 3 semaines... Mais brusquement, le 21 juin, à la grande surprise des membres du Comité de la Société de l'Azote , les Allemands interrompirent les essais. La raison qu'ils donnèrent officiellement était que l'eau de réfrigération des fours ne donnait pas satisfaction ; et en effet dans leur procès-verbal du 22 juin les membres du Comité norvégien écrivirent : « A une question directement « posée par le professeur Birkeland demandant « si les essais avaient été interrompus du fait « d'un rendement insuffisant, le Dr Schönherr « répondit que tel était bien le cas, et que la « raison en était le dépôt boueux que l'eau de « réfrigération déposait sur les chaudières ».

En tout état de cause, les membres du Comité norvégien étaient convaincus que l'interruption des essais avec le four Schönherr représentait une victoire pour le four Birkeland-Eyde.

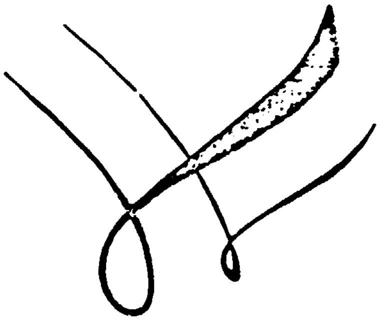
Si malgré cela il fut décidé que le premier aménagement de Rjukan — Rjukan I — se ferait avec 4/5 de l'énergie pour les fours de la Badische et 1/5 seulement pour les fours Birkeland-Eyde, ce fut pour des raisons d'ordre politique et non pas technique. Un accord venait, en effet, d'être conclu avec la Badische Anilin und Sodafabrik, d'apres lequel avait été fixée la proportion d'utilisation des deux modèles de fours — bien que le four Birkeland-Eyde eût un rendement dépassant parfois de 20 kg NO_3H par kW-an celui du four Schönherr.

Par la suite, cependant, le triomphe du four Birkeland-Eyde fut confirmé lors de l'aménagement de Rjukan II. Il ne fut plus alors question des fours Schönherr ; et seuls les fours Birkeland-Eyde y furent installés.

On prévoyait toutefois que la mise en concurrence entre les deux modèles de fours interviendrait plus tard. La Commission précitée était en effet restée en fonctions. Mais des difficultés s'élevaient constamment ; et un beau jour, les fours Schönherr furent démontés dans la fabrique d'acide et envoyés à Rjukan. Ce fut le dénouement de la compétition à Notodden ; le four Birkeland-Eyde restait vainqueur.

Pendant tout ce temps, le grand four avait continué à fonctionner sans interruption — entouré des plus grands soins, car on voyait en lui le triomphateur. A la fin de l'été 1910, un nouveau four de grand modèle fut mis en service ; et des essais furent tentés, durant le mois de décembre, avec des puissances encore supérieures. Nous lisons en effet dans le rapport de la fabrique pour ce mois de décembre 1910 : « Au cours des essais opérés « avec le four, celui-ci fonctionna avec une « charge de 4 000 kW — la plus grande « puissance qui ait jamais été employée pour « un seul four ; et nous sommes heureux de « pouvoir dire que la marche a été aussi bonne, « pour ne pas dire meilleure avec 4 000 kW « qu'avec 3 000 kW ».

Ainsi l'on en était arrivé à fixer les dimensions définitives du four. Cependant certains essais eurent encore lieu ; et l'on procéda en particulier à des modifications à l'intérieur du four, à l'effet d'obtenir une exploitation continue avec un minimum de frais de réparation, et afin de s'assurer le meilleur rendement possible. Pourtant le type même du four n'avait pas changé depuis le premier four à bouclier de Vassmoen.



DEUXIÈME PARTIE

LA SOCIÉTÉ DE L'AZOTE PENDANT LA PÉRIODE DE LA MÉTHODE A L'ARC 1905-1927

CHAPITRE IV — LES DÉBUTS DE LA SOCIÉTÉ DE L'AZOTE

I — UNE NAISSANCE DIFFICILE

L'ASSEMBLÉE GÉNÉRALE CONSTITUTIVE SE TIENT A RAADHUSGATEN 20

ELLE N'ÉTAIT guère nombreuse, cette assemblée constitutive de la Société Norvégienne de l'Azote et de Forces Hydro-Électriques en date du 2 décembre 1905, qui devait prendre la plus importante décision sans doute intervenue jusqu'à ce jour dans l'histoire de l'industrie norvégienne, et qui se tint dans les bureaux de Sam Eyde 20 Raadhusgaten à Kristiana. Elle se composait en effet, en tout et pour tout, de 3 personnes, à savoir : Marcus Wallenberg, banquier ; le frère de celui-ci, le capitaine J. O. Wallenberg, et Sam Eyde lui-même, dont la personnalité était à l'époque encore relativement peu connue du grand public. Mais, si restreinte qu'elle fût, cette Assemblée comptait d'autant plus du point de vue de l'autorité. Ces trois hommes avaient en effet derrière eux un considérable potentiel en capitaux suédois, et plus encore français. Pour l'instant, en tout cas, Marcus Wallenberg, J. O. Wallenberg, et Sam Eyde représentaient, du fait de leurs propres titres et des pouvoirs dont ils étaient porteurs, 11 112 actions de préférence, émises en numéraire, pour une valeur nominale de KrN 4 000 320 et 8 334 actions ordinaires, émises en rémunération d'apports, pour un montant de KrN 3 000 240 : soit la totalité des KrN 7 000 560 qui allaient constituer le capital de départ de la nouvelle société.

En tête de la liste des actions de préférence souscrites figurait la Banque de Paris et des Pays-Bas, avec 1 000 titres, soit KrN 360 000 ; venait ensuite une série de noms se rattachant à cette banque et qui représentaient, à leur tour, 3 600 actions, soit KrN 1 296 000 ; parmi ces personnalités, qui comprenaient pratiquement tout le Conseil d'Administration et la direction de la Banque, il faut citer notamment, pour l'importance de leur souscription, Edmond Moret, directeur, avec 400 actions, soit KrN 144 000, et Hugo Finaly, père d'Horace Finaly, qui devint par la suite Directeur Général de la Banque, avec 500 actions, soit KrN 180 000. Figuraient ensuite : la Société Générale pour favoriser le développement du Commerce et de l'Industrie en France, avec 1 000 actions, soit KrN 360 000 ; la Banque de l'Union Parisienne, avec 400 actions, soit KrN 144 000. Venait enfin la Dresdner Bank, avec 200 actions, soit KrN 72 000. La participation française, dans laquelle était inclus le petit chiffre de la Dresdner Bank, représentait ainsi un total de 7 000 actions, soit KrN 2 520 000.

Les intérêts suédois étaient représentés par les banquiers Knut A. Wallenberg, Marcus Wallenberg et Knut Tillberg, qui détenaient chacun 1 100 actions, soit KrN 396 000, et par J. O. Wallenberg, qui détenait 112 actions, soit KrN 40 320.

Venait enfin la quote-part norvégienne, celle de Sam Eyde, constituée par 700 actions, soit KrN 252 000.

Quant aux actions ordinaires, qui étaient destinées à rémunérer les apports dont il sera parlé ci-après, elles étaient entièrement réparties entre les actionnaires suédois précités et Sam Eyde.

L'Assemblée se tint sous la présidence de Marcus Wallenberg, qui déclara que l'on avait l'intention de fonder la société sur les bases ci-après :

« 1. La Société est une société anonyme norvégienne, régie par la Loi commerciale norvégienne, et dont le siège est actuellement à Notodden, Norvège.

2. Cette Société a pour objet :

a) *l'acquisition et l'exploitation de toutes forces hydrauliques naturelles et artificielles;*

b) *l'acquisition et l'exploitation en tous pays de tous brevets et inventions concernant la production et la fabrication de l'acide nitrique et de tous produits azotés ou dérivés;*

c) *l'acquisition, la construction et l'exploitation de tous établissements industriels destinés à la mise en valeur des procédés, brevetés ou non, concernant la production et la fabrication de l'acide nitrique et de tous autres produits azotés ou dérivés, ainsi que l'utilisation de toutes forces hydrauliques, naturelles et artificielles, en vue de toutes industries;*

d) *et, généralement, toutes opérations et entreprises commerciales, financières et industrielles, même immobilières, se rattachant aux objets ci-dessus indiqués* ».

L'Assemblée Générale approuva ensuite divers projets de contrats :

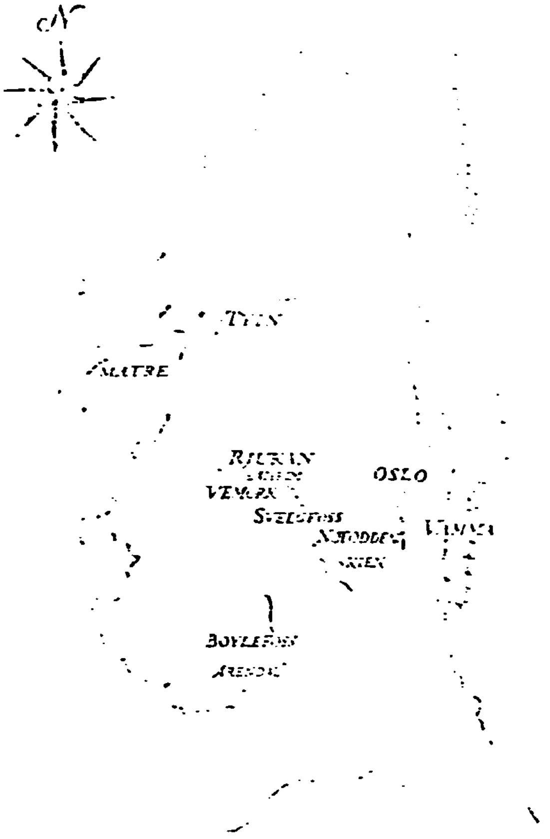
— contrat avec les propriétaires de la chute de Svaelgfos, MM. Knut Wallenberg, Marcus Wallenberg, Knut Tillberg et Sam Eyde, en vue de l'achat de cette chute avec les terrains nécessaires, de manière à garantir à la Société la pleine et entière propriété de cette chute, et cela contre remise des 8 334 actions ordinaires précitées, pour une valeur nominale de KrN 3 000 240, plus un montant en espèces de KrN 315 000, à payer comptant. Les vendeurs s'engageaient également à céder à la Société toutes les chutes d'eau situées en Norvège dont ils deviendraient propriétaires, la Société Norvégienne de l'Azote et de Forces Hydro-Électriques ayant le droit de participer éventuellement pour moitié à la société à créer en vue de l'exploitation de telles chutes ;

— contrat avec la société anonyme A S Det Norske Kvaelstofkompagni, en vue d'obtenir une option, au prix de KrN 500 000, sur le droit de propriété en Norvège de MM. Birkeland et Eyde sur tous brevets existants et futurs concernant des procédés pour la fabrication d'acide nitrique et de produits azotés ou dérivés. Cette option stipulait que la Société Norvégienne de l'Azote et de Forces Hydro-Électriques aurait le droit de disposer en Norvège, en vue de leur cession, des brevets en question, et cela pour une période de dix-huit mois après la pleine entrée en exploitation de la fabrique projetée pour l'utilisation de toute la puissance de Svaelgfos, soit 29 000 CV. Un versement de KrN 2,00 par kilowatt-an devait aussi être assuré à la Société Norvégienne de l'Azote et de Forces Hydro-Électriques par toute société qui serait éventuellement fondée en vue d'utiliser les brevets sus-mentionnés, grâce à l'aménagement des chutes de Rjukan, Vamma et Boïle, ou d'autres chutes en Norvège appartenant aux vendeurs ci-dessus mentionnés ou à la société Det Norske Aktieselskab for Elektrokemisk Industri. Cette clause était applicable même au cas où la Société Norvégienne de l'Azote et de Forces Hydro-Électriques ne ferait pas l'acquisition de ces brevets pour la Norvège. Dans le cas contraire, la Société Norvégienne de l'Azote et de Forces Hydro-Électriques ne devait pas s'opposer à ce que les brevets fussent utilisés en vue de l'exploitation des chutes de Rjukan, Vamma et Boïle. En revanche, pour l'aménagement d'autres chutes, le consentement de la Société Norvégienne de l'Azote et de Forces Hydro-Électriques devait être obtenu. Celle-ci avait, en outre, droit à 30 % des bénéfices nets réalisés sur la vente des brevets français de la Société Kvaelstofkompagni, et à 10 % de ceux qui le seraient dans les autres pays.

— contrat avec Det Norske Aktieselskab for Elektrokemisk Industri, portant octroi à la Société Norvégienne de l'Azote et de Forces Hydro-Électriques d'une option sur les actions de la Société de Rjukanfos, avec tous les terrains nécessaires pour le plein aménagement des 220 000 CV prévus (hauteur de chute 552 m), moyennant un prix de KrN 5 000 000. La Société Norvégienne de l'Azote et de Forces Hydro-Électriques se voyait en même temps assurer un droit de préférence sur les chutes de Böile (25 300 CV) et de Vamma (40 000 CV), ainsi que sur toutes les chutes éventuellement en possession de la Société Elektrokemisk en Norvège, dans chaque cas au même prix que celui des offres dont il aurait été justifié. Ce droit de préférence comprenait, également ici, la faculté de participer par moitié à toutes sociétés éventuellement créées en vue de l'aménagement des chutes ; et la Société Norvégienne de l'Azote et de Forces Hydro-Électriques se réservait les mêmes droits d'annuités que ceux figurant au contrat précité. La Société Norvégienne de l'Azote et de Forces Hydro-Électriques obtenait enfin une option, valable jusqu'au 1er juin 1906, en vue de l'achat, moyennant remise de KrN 500 040 en actions de préférence supplémentaires entièrement libérées mais ne portant intérêt que deux ans après leur création, de « la petite usine nitratière actuellement sise à Notodden », avec tous les terrains nécessaires pour permettre son agrandissement en vue de l'utilisation de la totalité de la puissance de Svaelgfos. Il s'agissait donc là de la première fabrication destinée à faire l'essai de la méthode Birkeland-Eyde à l'échelle industrielle. Et il était ajouté que la Société Norvégienne de l'Azote et de Forces Hydro-Électriques devait procéder, le plus tôt possible, à l'aménagement de la chute de Svaelgfos et à l'installation de la nouvelle « Grande Usine ».

Pour couvrir les frais d'établissement, la nouvelle société s'était assurée les fonds nécessaires pour le cas où le capital de préférence ne serait pas suffisant : la Stockholms Enskilda Bank s'était en effet déclarée disposée à lui consentir un emprunt obligataire de KrN 2 499 840 à 5,50 %, en échange d'une hypothèque sur les propriétés immobilières de la Société (c'est un fait d'ailleurs que la Société n'eut pas à recourir à cette émission obligataire).

Aux termes des statuts, pouvoir était en outre donné au Conseil d'Administration pour procéder à une augmentation du capital-actions de KrN 500 040, sous forme d'actions de préférence, pour le cas où il déciderait de lever l'option dont il a été question ci-dessus, en ce qui concerne l'achat de l'usine de Notodden.



Carte des ressources hydrauliques de la Société de l'Azote à ses débuts

Un droit préférentiel, portant sur 1/4 des actions émises lors de chaque augmentation de capital, fut accordé aux premiers souscripteurs des actions de préférence, des actions ordinaires et de l'emprunt obligataire susmentionné. Il fut prévu à cette occasion de procéder à l'émission de 2 639 certificats de souscripteur originaire — à raison d'un certificat pour KrN 3 600 en titres de l'une des 3 catégories (en définitive, par suite de la non-réalisation de l'emprunt obligataire susmentionné, seuls 1945 certificats furent créés).

Au sujet de la direction de la Société, il fut stipulé dans les statuts que la Société serait gérée par un Conseil d'Administration comprenant un Directeur Général, élu par l'Assemblée

Générale pour le temps qu'elle déterminerait, et 6 à 8 autres membres nommés par l'Assemblée Générale, par périodes successives de trois années, et toujours rééligibles. La majorité des membres du Conseil d'Administration devait toujours être de nationalité norvégienne ou suédoise, étant précisé que, si le Conseil était composé de 7 personnes, il devait comprendre au moins 2 membres norvégiens, et 3 membres norvégiens au moins s'il était composé de 9 personnes. Le Conseil d'Administration devait se diviser en deux sections, l'une composée des administrateurs domiciliés en Scandinavie, et l'autre de ceux domiciliés soit en France soit ailleurs en dehors de la Scandinavie. Sous le nom de Comité de Paris, les administrateurs domiciliés en dehors de la Scandinavie constitueraient la délégation et la représentation de la Société en France. Les délibérations devaient être prises, dans chaque section, à la majorité simple des membres présents ou représentés, cette majorité devant grouper au moins deux administrateurs. Pour être définitivement valables, les délibérations devaient être approuvées par les deux sections ou par une majorité composée d'au moins les 2/3 de l'ensemble des membres du Conseil d'Administration ; si ces conditions n'étaient pas remplies, les délibérations devaient être soumises à une Assemblée Générale.

Les pouvoirs du Conseil d'Administration étaient très étendus et généraux, sous les seules exceptions stipulées en faveur de l'Assemblée Générale, c'est-à-dire les élections des membres du Conseil d'Administration et des Commissaires aux comptes, la fixation du dividende et l'augmentation ou la réduction du capital social.

En ce qui concerne la répartition des excédents, 5 % devaient servir à la constitution d'un Fonds de réserve jusqu'à concurrence du 1/20 du capital social ; sur le solde, 10 % devaient être alloués au Conseil d'Administration à titre de tantièmes, et 90 % aux actionnaires. Sur ces 90 %, il devait être d'abord prélevé la somme nécessaire pour servir aux actions de préférence un dividende de 8 %, puis celle correspondant à un dividende de 8 % aux actions ordinaires. Sur le reliquat éventuel, l'Assemblée Générale pouvait décider des dotations à un Fonds de Prévoyance ; et le solde devait être réparti également entre les deux groupes d'actions, proportionnellement au nombre de titres de chaque catégorie.

L'Assemblée Générale désigna unanimement Eyde comme Directeur Général, à des conditions stipulées en détail dans un contrat comprenant 7 articles. En vertu de ce contrat, Eyde était nommé pour une période de dix ans. En échange, il était exigé de lui « qu'il consacre en tout premier lieu son temps et son travail au service de la Société ». Si ses forces le lui permettaient, il pouvait continuer à agir comme directeur administratif (1) de la Société Elektrokemisk et de la Kvaelstofkompagni, et pouvait occuper des fonctions analogues dans des sociétés éventuellement créées en relations avec la Société de l'Azote.

L'Assemblée Générale décida que le Conseil d'Administration serait composé de 8 membres en plus du Directeur Général, et élut le premier Conseil d'Administration ainsi composé :

1. M. URBAN JACOB RASMUS BÖRRESEN, CONTRE-AMIRAL, KRISTIANIA ;
2. M. GUSTAV SMIDTH, DIRECTEUR DE LA SOCIÉTÉ UNION CO, SKOTFOS, PRÈS DE SKIEN ;
3. M. KNUT AGATHON WALLENBERG, DIRECTEUR DE LA STOCKHOLMS ENSKILDA BANK, STOCKHOLM ;
4. M. MARCUS LAURENTIUS WALLENBERG, DIRECTEUR DE LA MÊME BANQUE, STOCKHOLM ;
5. M. KNUT ROBERT TILLBERG, STOCKHOLM ;
6. M. JOSEPH MARIE EDMOND MORET, DIRECTEUR DE LA BANQUE DE PARIS ET DES PAYS-BAS, PARIS ;
7. LE COMTE CHARLES GEORGES DE GERMINY, PARIS ;
8. M. EMILE FRANÇOIS MAURICE GIROD DE L'AIN, PARIS.

(ces deux derniers étaient des amis de la Banque de Paris et des Pays-Bas, avec laquelle ils avaient des liens étroits).

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(1) En Norvège, le titre de directeur administratif équivaut à celui de Directeur Général. Mais dans le cas de la Société Norvégienne de l'Azote, et dans quelques rares autres entreprises norvégiennes où il y a un Directeur Général, il correspond sensiblement à ce que l'on appelle en France un Directeur Général-Adjoint.

Comme Commissaires aux comptes, conformément à l'article 34 des statuts, furent désignés : M. Gunnar Knudsen, ancien ministre, Borgestad ; M. Th. Frölander, banquier, Stockholm, et M. de Laselve, Paris. Le Professeur Kr. Birkeland fut nommé conseil technique à vie de la Société. Comme Commissaires vérificateurs furent élus : M. O. Nickelsen, consul, Kristiania, et le beau-frère du banquier Knut Wallenberg, M. R. Klingenberg, Kristiania.

La séance fut ensuite levée. La Société Norvégienne de l'Azote était fondée.

Au cours de la première réunion du Conseil d'Administration qui eut lieu le 16 décembre, Marcus Wallenberg fut élu Président du Conseil d'Administration, situation qu'il devait occuper jusqu'au moment où il se retira en 1942, un an avant sa mort ; et le Comte G. de Germiny fut nommé Vice-Président, en même temps que Président du Comité de Paris.

Il fut procédé aux engagements suivants : comme Directeur du Bureau central, M. Alf Scott-Hansen, et comme Chef des travaux de construction à Svaelgfos, M. S. Kloumann, Ingénieur.

LA CONJONCTION DE SAM EYDE ET KRISTIAN BIRKELAND DONNE NAISSANCE A LA MÉTHODE QUI PORTERA LEUR NOM

Ce qui avait eu lieu dans les bureaux de Sam Eyde, le 2 décembre 1905, n'était pas, à proprement parler, le commencement de la Société Norvégienne de l'Azote ; c'était au contraire, peut-on dire, la conclusion d'un chapitre introductif long et intéressant. C'est celui-là que nous allons maintenant écrire.

Tout au début, la première personne qui entre en scène n'est autre que le héros principal de la pièce : Sam Eyde. Il était né en 1866 et était le fils d'un armateur d'Arendal. Sa vocation d'ingénieur constructeur s'était révélée en Allemagne. A 31 ans, il remporta, de concert avec son ami et collaborateur allemand l'ingénieur G. O. Gleim, le premier prix dans un concours international pour la construction de la gare de l'Est à Kristiania. L'année suivante, en 1898, il revint dans son pays natal et fonda à Kristiania un « Bureau d'ingénieurs » avec succursale à Stockholm : ce Bureau réussit dans une série de concours pour la construction de gares et ports, entre autres à Stockholm.

Ces premiers succès avaient eu pour résultat de faire connaître le nom d'Eyde aussi bien en Norvège qu'en Suède, — et cela d'autant plus que son mariage avec la comtesse Anna Ulrika Mörner de Morlanda et son charme personnel comme homme du monde lui avaient donné accès aux meilleurs salons de Suède et d'Allemagne. Ajoutons que, dès le temps de ses études et de ses premières activités comme ingénieur à Dortmund et à Lübeck, il s'était fait des relations dans les milieux scientifiques et industriels allemands : tout cela devait jouer un très grand rôle dans son activité future en Norvège. C'est d'ailleurs lui-même qui devait écrire plus tard, dans son livre intitulé « Ma vie et l'œuvre de ma vie » : « grâce à mon travail à Lübeck, j'avais dix ans « d'avance sur d'autres jeunes ingénieurs ».

Arrivons au 13 février 1903, jour faste et décisif. Ce jour-là, — ainsi que l'ont déjà relaté précédemment MM. Keilhau p. 7 et Bödtker Naess p. 31 — Eyde rencontra le professeur Kristian Birkeland à dîner chez son ami, l'ingénieur Gunnar Knudsen, ancien Ministre.

Or, on l'a vu, sept jours auparavant, le 6 février, Birkeland avait provoqué un accident, dans l'amphithéâtre de l'Université de Kristiania, pendant qu'il y faisait une démonstration avec son canon électrique... et cet accident l'avait mis sur la voie de la découverte qui allait illustrer son nom : le four à arc électrique.

Le hasard avait bien fait les choses : depuis quelque temps le cycle force hydraulique-azote fermentait dans le cerveau d'Eyde. Et voici que, grâce à un accident, la Fortune venait sourire à cet ingénieur et à ce physicien norvégiens que le hasard d'un dîner avait réunis chez un ami... Nous répéterons ici la formule saisissante d'Eyde : « c'est le 13 février 1903, « que naquit l'industrie norvégienne de l'azote ».

Ce propos n'est pas excessif : c'est bien ce jour-là en effet que jaillit dans le cerveau de Sam Eyde, comme une étincelle, l'idée à laquelle la Société de l'Azote doit d'être venue au monde...

LA CONJONCTION DE SAM EYDE ET FREDRIK HIORTH LEUR PERMET DE S'ASSURER L'ÉNERGIE HYDRAULIQUE

Aujourd'hui, la constellation Birkeland-Eyde est connue du monde entier. Et cependant, la flamme du professeur Birkeland aurait jailli en vain et n'aurait donné naissance à aucune étincelle dans le cerveau d'Eyde, si celui-ci n'avait pas rencontré auparavant une autre personnalité : celle de l'un de ses collègues ingénieurs, le Directeur Fredrik Hiorth, qui l'avait conduit devant ce qui allait être le point d'appui de tout son effort : la force hydraulique de la Norvège (voir page 6).

C'est déjà en 1902 que Eyde et Hiorth avaient acquis les chutes de Vamma, sur le fleuve Glomma, à la latitude de Moss (province de Ostfold), et de Rjukan (province de Telemark). Et pourtant, à cette époque, ni l'un ni l'autre, ni les amis suédois d'Eyde sur lesquels celui-ci s'appuyait, n'avaient de plans déterminés pour l'utilisation de ces chutes. Comme Eyde l'écrit : « ce n'était pas un « problème simple que de trouver l'emploi de « ces quelques centaines de mille chevaux-« vapeur ». Il raconta même qu'il avait compté, dès le commencement, que les chutes de Vamma contribueraient à l'approvisionnement en électricité de la capitale ; et cependant, à l'époque, personne n'était près de prévoir le prodigieux développement que prendraient les besoins dits domestiques. Fallait-il alors se tourner vers l'industrie pour trouver l'emploi de cette énergie? Là aussi les perspectives étaient incertaines, l'industrie électrochimique du monde entier traversant une crise qui n'avait pas épargné les grandes sociétés suédoises et allemandes (voir page 27).

Parmi les papiers privés laissés par Marcus Wallenberg se trouve un « carnet de notes de voyage », où il consignait de nombreux télégrammes et lettres. Selon ce carnet, c'est dès août 1902 qu'il aurait eu des conversations avec Eyde et Hiorth : il s'agissait alors des chutes du fleuve Glomma. Il ressort effectivement de différents documents que le projet établi pour l'aménagement de Vamma prévoyait la cession à la commune de Kristiania d'une partie de la force en vue — et il semble que ce dut en être la partie essentielle.

Il est vrai que, quelques jours après la visite de Eyde et Hiorth chez Wallenberg, ce dernier envoyait un câble ainsi conçu à Eyde à Kristiania : « J'ai réussi à amener « G. Wenström, directeur de Västerås, et « A. Sjögren, directeur d'Avesta, à visiter pour « mon compte l'installation de Kykkelsrud. »

Wallenberg mentionnait, on le voit, Kykkelsrud, et non Vamma. Pourquoi? Certes, il peut y avoir là une confusion ; mais cela n'est pas certain non plus. Car c'est justement à ce moment-là que le Conseil d'Administration de la Société Norvégienne A/S Glommens Traesliberi (Fabrique de pâte de bois de Glommen), qui possédait Kykkelsrud, s'efforçait de réunir les fonds nécessaires à la constitution du capital social de l'entreprise, conformément à l'accord conclu avec Schuckert & Co Nuremberg ; et c'est un fait que, parmi ces administrateurs, figurait M. Saetren, directeur des canaux, qui participa au premier achat de chutes opéré par Eyde. Ajoutons que, pour finir, la Société Schuckert & Co reprit les actions en mains norvégiennes à 36 % de leur valeur nominale, bien qu'elle se trouvât elle-même dans une situation financière difficile, et que la Compagnie proposa à la commune de Kristiania de lui céder l'usine, — son offre, datée du 22 octobre 1903, étant valable jusqu'au 1er février 1904. En tout cas, Marcus Wallenberg parle, dans une dépêche du 10 décembre 1903, de l'exploitation des brevets Birkeland-Eyde « à Rjukan, à Vamma et éventuellement à Kykkelsrud ».

De toute manière, le Conseil municipal de Kristiania rejeta la proposition de la Société A/S Glommen Traesliberi et donna également une réponse négative à une offre reçue simultanément de Sam Eyde en vue de la fourniture de courant en provenance des chutes de Vamma, aussitôt que l'installation de force aurait été aménagée « en 1908 ».

Un autre nom doit encore être prononcé lorsque l'on remonte aux origines de la Société Norvégienne de l'Azote, celui de N. Kielland-Torkildsen, directeur de la Skiensfjordens Kreditbank : car il était de ceux qui, à partir de 1890, s'assurèrent des chutes d'eau.

De concert avec Borchgrevink, ingénieur, il possédait donc diverses chutes. Mais les perspectives qu'elles lui offraient lui paraissaient manifestement lointaines. Cependant, dans le memorandum par lequel il lança pour la première fois son plan tendant à établir la Centralbank for Norge (Banque Centrale de Norvège), il fit mention de la différence de prix existant entre la force hydroélectrique à Kristiania et à Skien : « tandis que l'on évalue « le prix d'installation d'une chute d'eau à « Kristiania à 1 000 KrN par CV, les mêmes « personnes escomptent que ce prix pourrait etre « de 300 KrN à Skien, et encore moins ailleurs ».

Quoi qu'il en soit, Kielland-Torkildsen parvint à réaliser son vaste projet concernant la Centralbank, — et cela surtout grâce aux frères Wallenberg, dont il s'était assuré la collaboration en 1897 ; la Stockholms Enskilda Bank souscrivit un gros chiffre d'actions : pas moins de KrN 525 000. D'autre part, Knut Wallenberg introduisit Kielland-Torkildsen auprès des banques de Copenhague, Berlin, Paris et Londres : comme devait l'écrire Kielland-Torkildsen, le nom de Wallenberg agissait, à cette époque-là déjà, comme un « Sésame ouvre-toi ! » dans toutes les banques européennes et dans les cercles financiers du monde entier.

Malgré de telles relations, malgré l'esprit d'initiative exceptionnel dont il témoignait, Kielland-Torkildsen n'avait guère eu de résultats concrets avec ses projets d'équipement de chutes.

C'est dire que, lorsque Hiorth se présenta, il l'accueillit à bras ouverts.

Eyde, Hiorth et Saetren obtinrent d'abord, le 9 août 1902, une option sur l'hôtel de Rjukan. Etant devenus propriétaires de cet hôtel, ils fondèrent deux jours après, de concert avec Kielland-Torkildsen et Borchgrevink, une société en nom collectif qui fit l'acquisition de l'hôtel de Rjukan et des chutes de Rjukan et de Skar. Bientôt la part laissée aux vendeurs fut rachetée et, le 30 avril 1903, la Société de Rjukanfos fut créée à Stockholm entre Eyde, Tillberg, Rappe et Hiorth.

Ce n'était pas là un achat fait au hasard : six semaines auparavant, le 13 février, Eyde et Birkeland s'étaient rencontrés au dîner chez Gunnar Knudsen et là ils avaient conclu — nous l'avons dit — un accord à l'effet de demander, en commun, un brevet sur l'utilisation de la flamme électrique à la production de dérivés de l'azote : l'application de la méthode Birkeland-Eyde était en vue. Il fallait donc maintenant qu'Eyde entrât dans la seconde voie qui s'ouvrait devant lui : l'utilisation de la force hydraulique.

En la circonstance Sam Eyde allait faire preuve de ses éminentes qualités d'animateur : en un tourne-main, et avant que les vendeurs pussent deviner les projets en fermentation, il s'assura les droits d'eau et les propriétés nécessaires, soit les 552 mètres de hauteur de chute de Rjukan, et 2 000 hectares de terrain.

Hiorth lui fut, en cette occasion, d'un précieux concours, et Eyde rend hommage à sa manière de prendre les paysans et à son talent pour s'assurer des options. Eyde fait aussi l'éloge des avocats Carl Lundh et Per Rygh, qui agissaient auprès de lui comme conseils juridiques. Dans son livre, Eyde fait également mention des ingénieurs Heggstad et Ugland « qui ont été d'une grande utilité « au cours de la réunion de toutes ces pro- « priétés, souvent dans des circonstances assez « dramatiques : une nuit, par exemple, l'on « obtint des options sur tout un district sans « que personne n'eût vent de ce qui se passait. « Mais, écrit Eyde, tous ceux à qui nous avons « acheté ont obtenu un bon prix pour leurs « droits et propriétés compte tenu des condi- « tions de l'époque ; et partout où cela était « possible nous leur avons laissé l'usufruit « des biens fonciers à vie, sans redevance ».

UN CADRE EST TRACÉ DANS LEQUEL LA RÉALISATION DE L'IDÉE SERA ENTREPRISE

Revenons maintenant à l'idée du four de synthèse.

Le 5 juillet 1903, les premiers fonds furent trouvés pour entreprendre les essais à son sujet, grâce à la création d'une première société en nom collectif à laquelle participèrent, aux côtés de Birkeland et Eyde, les amis de ce dernier, ainsi que Tillberg et N. Persson, consul à Helsingborg (ce dernier participait déjà largement à des consortiums norvégiens).

Les essais qui suivirent ont fait l'objet du chapitre précédent, rédigé par E. Bödtker Naess. Nous nous contenterons donc de rappeler ici qu'ils coûtaient cher et nécessitaient donc de nouveaux financements : en fait deux années devaient s'écouler encore en expériences compliquées et onéreuses.

Mais tout de suite — nous nous reportons ici à ce qu'a dit à ce sujet le professeur Keilhau (page 8) — il apparut qu'il serait très difficile de trouver les capitaux voulus pour expérimenter la méthode à l'échelle industrielle : à l'automne 1903, en effet, toute l'entreprise apparaissait encore comme fantastique à qui n'avait pas la foi inébranlable de Sam Eyde et du cercle des initiés. En tout cas, il n'était pas possible de recourir aux établissements bancaires à ce moment-là : il était donc nécessaire de faire appel à des capitalistes privés et, parmi eux, à des gens animés d'une audace allant de pair avec celle d'Eyde, puisqu'il leur faudrait évaluer les possibilités pratiques d'une entreprise fantasmagorique aux yeux de leurs contemporains. En d'autres termes, il n'y avait pas d'autre parti que de trouver des gens qui fussent assez liés avec Eyde pour être influencés par son ardente foi.

Eyde a écrit à cet égard : « il me fut malheureusement impossible de trouver les fonds « nécessaires en Norvège ». C'est donc qu'il a essayé. Ajoutons que, même s'il y avait eu suffisamment de bon vouloir dans le pays, la possibilité de fournir un effort financier important était fort limitée à l'époque : la Norvège se trouvait encore dans les remous de la crise de 1899, le marché financier était étroit et l'esprit de spéculation étouffé. En bref, la conjoncture était défavorable.

Eyde devait donc continuer à compter sur ses amis et relations en Suède : parmi ceux-ci, Tillberg était encore, et comme toujours, le plus proche et le mieux disposé ; par la suite le consul Persson se joignit de nouveau à eux.

Effectivement, le 11 décembre 1903, la société Det Norske Kvaelstofkompagni fut constituée à Stockholm ; elle était au capital de KrN 500 000, et avait l'objet social suivant : « l'exploitation, la vente ou toute autre appli- « cation des brevets et inventions de « MM. Birkeland et Eyde appartenant à la « société et concernant la fabrication et la « production de dérivés de l'azote par voie « électrique, ainsi que de tous autres brevets « et inventions dont la société ferait l'acquisi- « tion ». Tillberg et Birkeland furent élus administrateurs, avec Scott-Hansen comme suppléant, tandis que Sam Eyde fut nommé directeur administratif pour une période de dix ans, et Birkeland, conseiller technique, avec droit de conserver cette situation à vie.

La fondation de la Kvaelstofkompagni n'était qu'un des échelons du plan qu'Eyde avait conçu pour l'organisation et le financement de l'affaire. Le second fut constitué par la création de la société Det Norske Aktieselskab for Elektrokemisk Industri, au capital de KrN 5 000 000, qui eut lieu immédiatement après, soit le 2 janvier 1904, et également à Stockholm : cette société devait reprendre les actions des sociétés de chutes et la majorité des actions de la Kvaelstofkompagni, qui détenait le droit exclusif d'exploitation des brevets Birkeland-Eyde.

C'est alors que les frères Wallenberg, que nous avons déjà cités plusieurs fois, firent leur première apparition officielle dans l'histoire de la Société. Le Conseil d'Administration de l'Elektrokemisk se composa en effet de Knut A. Wallenberg, Marcus Wallenberg et Knut Tillberg. Ici également, Eyde fut nommé directeur administratif pour une durée de dix ans, et Birkeland fut attaché à la Société en qualité de conseiller technique.

Il est dit dans le procès-verbal de l'assemblée: « Il a été décidé de fonder la société grâce « à l'apport de l'ensemble des actions de la « Société Vamma Fossekompagni et de la Société « de Rjukanfos, ainsi que de 251 actions de « la Société Det Norske Kvaelstofkompagni. Il « a été décidé que le capital social se monterait « à KrN 5 000 000, entièrement versé par la « cession à la société des actions précitées des « sociétés Vamma Fossekompagni, Rjukanfos, « et Det Norske Kvaelstofkompagni, tandis que « des actions devaient être souscrites en espèces « pour les KrN 100 000 restantes, moyennant « paiement comptant selon les besoins de la « société, la totalité du montant en question « devant cependant être versée le 1er juillet « 1905 au plus tard ».

Nous nous trouvons donc devant la constellation suivante : la Kvaelstofkompagni détient les droits d'exploitation des brevets Birkeland-Eyde : et l'Elektrokemisk possède les chutes de Vamma et Rjukan ; la tâche de cette seconde société sera donc d'utiliser dans l'application de la méthode Birkeland-Eyde l'énergie à provenir des dites chutes et, en tant que propriétaire de ces dernières, de trouver les fonds nécessaires pour le financement des installations industrielles nécessaires. Comme Eyde l'a écrit dans son livre, c'étaient les chutes qui constituaient le véritable actif fondamental du groupe jusqu'au moment où l'exploitation de la méthode de production d'azote serait devenue une réalité.

Ainsi moins de deux ans s'étaient écoulés depuis la rencontre de Birkeland et Eyde jusqu'au moment où la Société Norvégienne de l'Azote allait commencer à prendre tournure. Mais si l'on suit par la pensée les événements qui, pendant ce temps, se sont produits sur les deux fronts (d'une part expérimentation technique de la méthode, d'autre part financement), le temps ne paraît pas long. Aussi ne peut-on qu'admirer la persévérance, la conscience et la foi en l'œuvre à accomplir dont firent preuve les promoteurs de l'affaire, et qui seules peuvent expliquer que des résultats aient été si rapidement obtenus. Certes le nombre des personnes attelées à cette tâche allait toujours croissant, et le mérite de la réussite doit donc en être attribué à plusieurs. Il n'en reste pas moins que c'est à Sam Eyde que revient l'honneur d'avoir commencé et mené à bien toute l'entreprise : sa vitalité, son aptitude à inspirer la confiance et à stimuler ses collaborateurs, son ardeur à déclencher et à coordonner les forces, à trouver des solutions, à méditer des projets et au besoin à en improviser, méritent que nous nous inclinions devant sa mémoire avec une réelle admiration. Durant ces années où, dans un tourbillon ininterrompu, il courait d'une capitale à l'autre, il apparaissait en vérité comme une sorte de magicien, qui aurait pu donner le vertige à bien des braves gens...

ATTACHMENT II

De Nora Water Electrolysers for Hydrogen Production

Durantes Vincent

Attachment II

ORONZIO DE NORA
IMPIANTI ELETTROCHIMICI
S. p. A.
MILANO

VIA BISTOLFI, 35 - 20134 MILANO
TELEGR. ORDENOR - MILANO
TELEFONO 23941-235031
TELEX: 310552 - 322231 ODENOR I

DE NORA WATER ELECTROLYSERS

FOR HYDROGEN PRODUCTION

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LIM/DAP/mc

July 1984

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PARTITA IVA N. 05997010153

2. PROCESS

Hydrogen and oxygen gases are obtained by electrochemical decomposition of water according to the reaction:

$$H_2O \xrightarrow{2F} H_2 + \tfrac{1}{2}\,O_2$$

Hydrogen evolves from cathode and oxygen from anode.

Since the resistivity of water is too high for the electrolytic process, the electrolyte is usually an aqueous solution of caustic potash at 29 % KOH concentration. The continuous feed of demineralized water keeps constant the caustic concentration into the electrolyzer.

According to the Faraday law the amount of gases generated by the electrolysis is directly proportional to the impressed current. Quantitatively, 96.494 Coulomb (26.8 A h) generate 1 g eq. (1.0081 g or 11.206 Ndm^3) of hydrogen and ½ g eq. (8.00 g or 5.603 Ndm^3) of oxygen.

Consequently, the theoretic production of 1 A h is:

- 0.418 Ndm^3 hydrogen, and
- 0.209 Ndm^3 oxygen.

The actual production is lower than the above mentioned figures, since it depends on the current efficiency of the electrolysers which can be considered in the range 98 to 100 %.

The direct current flows through the electrolyser under a voltage which depends on the reversible electrode potentials, polarizations, drop in electrolyte, drop in the metallic structure of the cell.

The total practical voltage drop of one cell averages 1.9 V, at a current density of 2000 A/m^2.

3. DESIGN

The deNora water electrolyzer consists of several bipolar elements assembled in electrical series and clamped together by external tie rods terminating in positive and negative end plates, constituting a filter-press assembly.

The single cell is basically a bipolar plate supporting the anode and cathode structures on its opposite faces. Two adjacent bipolar plates are separated by a diaphragm, consisting of two asbestos sheets, permeable to the electrolyte but preventing the diffusion of gases.

The gases (hydrogen and oxygen) evolving from the cathodic and anodic compartments of each cell flow through individual outlet pipes and are collected in manifold installed on the electrolyzer.

The gases (hydrogen and oxygen) from the respective manifolds pass through the gas coolers where they are cooled (and dehumidified) at a temperature of few degrees higher than the cooling water temperature. Hydrogen and oxygen from respective coolers flow to the "pressure balancing tank" through bubble pipes which allow the gases to be washed and sent to the down-stream processing facilities.

The operation parameters of the electrolyzer such as electrolyte level, gas pressure and temperature are controlled by proper instrumentation. Each controlled variable and relevant alarm, if required, is repeated in a control panel.

The electrolyzers are usually installed indoors in an electrolysis room which is equipped with associated facilities including:

- Electric conversion equipment (transformer and rectifier)
- Copper bus-bars to connect the electrolyzers to the conversion equipment
- Electrolyte receiving and pumping facilities
- Demineralized water feeding facilities
- Cooling water and inert gas (nitrogen) distribution net.

4. TECHNICAL CHARACTERISTICS OF A TYPICAL DE NORA WATER ELECTROLYZERS FOR MEDIUM CAPACITY PLANTS

- Electrolyzer type		190D-50C	190D-100C
- Number of individual cells		50	100
- Current	A	3600	
- Voltage, per cell	V	1.9	
- Current efficiency	%	98.0	
- DC power consumption	kWh/Nm^3 H_2	4.7	
- Production			
. H_2	Nm^3/h	72.72	145.44
. O_2	Nm^3/h	36.36	72.72
- Electrolyte	% KOH	29	
- Operation temperature	°C	75	
- Overall dimensions			
. width	m	2.2	
. height	m	4.0	
. depth	m	3.24	5.79
- Approx. weights			
. empty	Ton	17.4	30.8
. in operation	Ton	25.2	45.7

5. PRODUCTS QUALITY

The double diaphragm which constitutes a peculiar characteristic of the De Nora electrolyzer allows the production of particularly pure gases with the following typical analysis :

Hydrogen Gas (dry basis, at Electrolyzer outlet)

- H_2	min	99.8	% v/v
- O_2	max	0.2	% v/v
- Pressure		200	mm H_2O
- Temperature	max	40	°C

Oxygen Gas (dry basis, at Electrolyzer outlet)

- O_2	min	99.6	% v/v
- H_2	max	0.4	% v/v
- Pressure		200	mm H_2O
- Temperature	max	40	°C

6. REQUIREMENTS

Typical consumption figures, relevant to the production of 1 Nm^3 hydrogen, are the following :

- DC electric power, measured at electrolyzer terminals, at 75°C with 29 % KOH electrolyte	4.7	kWh
- Demineralized water	0.85	1
- Cooling water	60	1
- Instrument air and nitrogen	negligible.	

The demineralized water fed to the electrolyzers shall have the following characteristics:

- Resistivity	min	200.000	Ohmxcm
- pH		5 ÷ 8	
- Insolubles	max	2	ppm
- Retention time of $KMnO4$	min	10	min.

7. THE COMPLETE PLANT

Depending on the final destination and uses, both hydrogen and oxygen gases can be further on processed to obtain :

- Compressed gas

- Purified gas, using Pd-catalyzed reactors suitable to reduce the oxygen content of hydrogen gas or the hydrogen content of oxygen gas to level of 1 ÷ 10 ppm by volume

- Dried gas, using alumina or silica gel columns, or molecular sieves to reduce the moisture content of the gas down to values corresponding to dew-point -30 to -75 °C (referred to the atmospheric pressure).

The processed gas can be stored in low, medium or high pressure tanks.

ATTACHMENT III

Chloroalkali Electrolysis
De Nora Monopolar Electrolyser
De Nora Bipolar Membrane Electrolyser

ATTACHMENT III

DE NORA MONOPOLAR ELECTROLYSER

Simple and solid construction together with easy, safe, and economic operation are the main characteristics of the de Nora monopolar membrane electrolyser which follows filter press design arrangements.

A series of positive and negative electrode elements separated by gaskets which also retain the membranes, are clamped between two end assemblies (non current bearing). The gaskets are simple flat sections of resilient material resistant to attack by chlorine and caustic soda with an expected life of at least two years.

Each electrode element can normally operate at 3,500 to 4,000 ampère. The chlorine, hydrogen and caustic soda outlets together with provisions for recirculation of electrolytes, are fabricated into the metallic electrode elements. Thus there are no connections between plastic joints or tubes to contend with, and the simple parts form a compact cell that is easily assembled and disassembled.

In view of its simplified construction and long-lived elements the maintenance costs are very low and due to the stability of the system under load, the operating attention required is minimal. Monopolar cells usually require large amounts of copper in their design but in de Nora design this has been overcome by an ingenious arrangement minimizing the copper employed.

The cells are easily installed on a firm concrete floor, from which they are insulated by the use of simple insulators.

In the de Nora monopolar membrane electrolyser, electrolyte circulation is by means of self induced gas lift, thus there is no need for external circulation pumps to move fluids within the electrolyser. The design provides for safe, easy and fast cut out of the electrolysers from circuits and the electrolyser is further characterized by being fabricated of light weight components, which do not require heavy lifting equipment for assembly.

The materials of construction used for the metal parts of the de Nora monopolar membrane electrolyser assure a life of many years; further, with gasket life being equal to membrane life premature replacement of gaskets is avoided.

The range of capacity available in monopolar electrolysers varies according to the number of cells grouped in an electrolyser unit.

The electrolysers are designed for operation at approx. 3.3 kA/m2 current density, and can be equipped with membranes suitable for zero-gap or narrow-gap design.

DE NORA BIPOLAR MEMBRANE ELECTROLYSER

De Nora bipolar membrane electrolysers are characterized by a compact design, long lived components and low operating costs.

The electrolysers are formed by assembling modular bipolar elements together with inert cathodic and anodic frames held together by end plates with an inexpensive tie rod compression system. The rated amperage capacity of the electrolyser can be as high as 11.5 kA with the total output of an electrolyser being a direct function of the number of bipolar elements installed.

Similar to the design of the de Nora monopolar electrolyser, fluid handing in the bipolar electrolyser is by means of internal ducting thus avoiding the use of a multiplicity of separate tubes for introducing and removing electrolyser fluids from each bipolar frame. Recirculation of electrolyte is simply provided for by maximizing the use of gas lift created by the evolved chlorine and hydrogen. Thus no recirculation pump is required.

The electrolyser consists of ten to twenty bipolar elements and operates at a design current density of approx 3.5 kA/m2.

Both narrow-gap and zero-gap type membranes can be installed in the de Nora bipolar electrolyser.

PROPRIETARY CATHODE PACKAGE

A peculiar feature of the de Nora electrolysers of both monopolar and bipolar design, consists in the possibility to install different types of membranes without modification of the structure of the individual cells.

A proprietary cathode package, which includes an elastic metallic element and an activated cathode net, allows the de Nora electrolysers to be equipped indifferently with:

a) membranes suitable for narrow-gap design

b) membranes for zero-gap design

c) membranes having electrodes applied to its surfaces (S.P.E. system)

The elastic element introduced by de Nora in its cell design accomplishes the double function to keep the membrane compressed against the anode surface (system a)) and to lead the current to the activated cathode (systems b) and c)).

S.P.E. TECHNOLOGY APPLIED TO DE NORA ELECTROLYSERS

Included in the research was the development of the world famous S.P.E. membrane technology by General Electric under technical and financial support from Oronzio de Nora Company. The employment of the S.P.E. concept in the de Nora designs provides special advantages in regard to power savings.

The work of Oronzio de Nora has led it to the construction and operation of successful commercial S.P.E. bipolar and monopolar membrane electrolysers. These new de Nora S.P.E. electrolysers represent a substantial step forward in the evolution of idealized electrolysers because they offer the chlor-alkali producer almost complete freedom from pollution problems and greatly improved plant working conditions for the protection of human health, as well as lowered energy requirements, improved product quality, simplified operation and low maintenance.

TREND AND DEVELOPMENTS

In its pursuit of technical excellence and commercial practicability, Oronzio de Nora also joined hands with the Dow Chemical Company (U.S.A.) in 1981 for the development of an S.P.E. type bipolar membrane electrolyser for use in large scale chlor-alkali plants.

ACHIEVEMENTS

- Over four years of operation, continuous and trouble free, of several small size cells.

- Over two years of operation, continuous and trouble free, of an industrial size bipolar electrolyser. This electrolyser, complete with all ancillary equipment including brine preparation, is interconnected with an operating chlor-alkali plant.

- An industrial size monopolar electrolyser, complete with all ancillary equipment including brine preparation, in operation in series with an existing mercury cell circuit.

- A 5,000 TPY NaOH capacity plant in operation at P.N. KERTAS LETJES - PROBOLINGGO, INDONESIA.

- A plant of 12,000 TPY capacity, expansible to 24,000 TPY - final customer BASIC CHEMICAL INDUSTRIES LIMITED - in operation at DAMMAM (Saudi Arabia).

- Contract signed with SREE RAYALASEEMA ALKALIES AND ALLIED CHEMICALS LTD - INDIA, for a plant of 18,000 TPY NaOH capacity

- Agreement signed with Messrs. DOW CHEMICAL - Midland, USA for a joint further development of membrane electrolysers towards "jumbo" size electrolysers.

Technical Characteristics of De Nora Monopolar Module

Operation data (with zero-gap membranes)

- Current (rated)	50	kA
- Number of cells	24	
- Active surface, per cell	0.635	m2
- Active surface, total	15.24	m2
- Current density, at rating	3,28	kA/m2
- Voltage, at cell electrodes	3.15	V
- Current efficiency, cathodic	95 ÷ 96	%
- D.C. energy consumption, at cell electrodes	2200	kWh/T NaOH 100%
- Catholyte concentration	32 ÷ 34	% NaOH
- Operating temperature	90	°C
- Membrane life	over 2	years
- Production:		
-- NaOH (100% basis)	1.70	TPD
-- Cl_2 (100% basis)	1.50	TPD
-- H_2 (100% basis)	505	Nm^3/day

Dimensions and weight

- Overall dimensions (approx).		
-- length	1.5	m
-- width	0.8	m
-- height	2.0	m
- Weight (approx):		
-- empty	2.1	tons
-- in operation	3.2	tons

Technical Characteristics of De Nora Bipolar Electrolyser type 3 M 20

Operation data (with zero-gap membranes)

- Current (rated)	11.5	kA
- Number of cells	20	
- Active surface, per cell	3.3	m2
- Active surface, total	66	m2
- Current density, at rating	3.5	kA/m2
- Voltage, at cell electrodes	3.15	V
- Current efficiency, cathodic	95 ÷ 96	%
- D.C. energy consumption, at cell electrodes	2200	kWh/T NaOH 100%
- Catholyte concentration	32 ÷ 34	% NaOH
- Operating temperature	90	°C
- Membrane life	over 2	years
- Production:		
-- NaOH (100% basis)	7.82	TPD
-- Cl_2 (100% basis)	6.92	TPD
-- H_2 (100% basis)	2320	Nm^3/day

Dimensions and weight

- Overall dimensions (approx).		
-- length	1.8	m
-- width	3.3	m
-- height	2.5	m
- Weight (approx):		
-- empty	13.5	tons
-- in operation	21.0	tons

Products characteristics (typical)

- Chlorine (dry basis, by volume)

Cl_2	min.	99	%	
H_2	max.	0.1	%	
O_2	max.	0.5	%	
CO_2		0.3	%	(*)
Temperature		85 ÷ 90	°C	
Pressure (negative)		50 ÷ 100	mm H_2O	

(*) average value, depending on CO_3^{--} ions in brine

- Catholyte (by weight)

NaOH	32 ÷ 34	%
NaCl	30 ÷ 40	ppm
$NaClO_3$	20 ÷ 30	ppm
Na_2CO_3	400 ÷ 500	ppm
Temperature	85 ÷ 90	°C

- Hydrogen (dry basis, by volume)

H_2	min.	99.95	%
O_2	less than	0.05	%
Temperature		85 ÷ 90	°C
Pressure (positive)		50 ÷ 100	mm H_2O

Brine, Water and Hydrochloric Acid Specification

- Feed brine specification

NaCl	min.	300	GPL
Ca + Mg	max.	20	ppb
Fe	max.	10	ppb
Al	max.	50	ppb
SO_4^{--}	max.	6	GPL
$NaClO_3$	max.	10	GPL
SiO_2	max.	3	ppm
Heavy metals	max.	10	ppb
Ferrocyanide	-	absent	
Suspended solids	max.	100	ppb
Temperature		70 ÷ 75	°C

- Anolyte (as returned to the brine system)

NaCl	min.	180 ÷ 200	GPL
SO_4^{--}	max.	7.5	GPL
$NaClO_3$	max.	15	GPL
Dissolved chlorine		saturated	
pH		2,2 ÷ 2.5	
Temperature		85 ÷ 90	°C

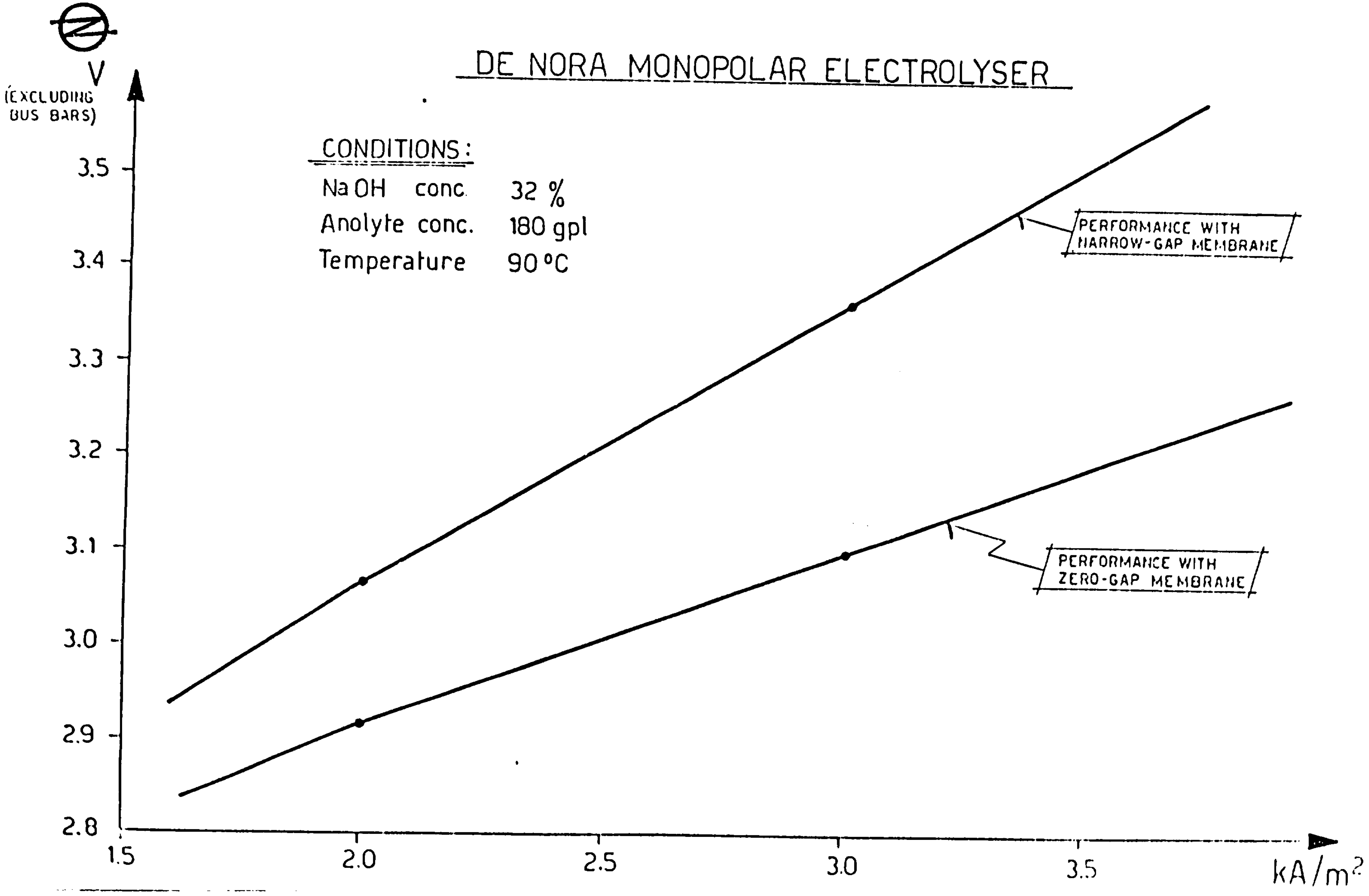
- Feed water specification

Conductivity	max.	10	micro S xcm
Total hardness	max.	40	ppb as Ca^{++}
SiO_2	max.	100	ppb
Fe	max.	20	ppb
Organics	max.	100	ppb as O_2
Temperature		30 ÷ 35	°C

- Hydrochloric acid (for brine acidification)

HCl		30 ÷ 33	%
Ca + Mg	max.	100	ppb
Fe	max.	50	ppb

		MONOPOLAR			BIPOLAR		
ELECTROLYSER TYPE		12 K40 (1 Module)	24 K40 (2 Modules)	36 K40 (3 Modules)	3 M10	3 M15	3 M20
TOT. RATED CURRENT	kA	50	100	150	115	172.5	230
CURRENT DENSITY	kA/m2	3.28	3.28	3.28	3.5	3.5	3.5
D.C. CELL VOLTAGE	V	3.15	3.15	3.15	3.15	3.15	3.15
D.C. ELECTROL. VOLTAGE	V	3.15	3.15	3.15	31.5	47.25	63
CURRENT EFF., CATH.	%	95 ÷ 96	95 ÷ 96	95 ÷ 96	95 ÷ 96	95 ÷ 96	95 ÷ 96
D.C. ENERGY CONSUMP.	kWh/T NaOH	2200	2200	2200	2200	2200	2200
NaOH CONCENTRATION	%	32 ÷ 34	32 ÷ 34	32 ÷ 34	32 ÷ 34	32 ÷ 34	32 ÷ 34
NaOH PRODUCTION	TPD	1.70	3.40	5.10	3.91	5.86	7.82
Cl_2 PRODUCTION	TPD	1.50	3.00	4.5	3.46	5.19	6.92
ANODE/CATHODE ELEMENTS	N°	12	24	36	10	15	20
MEMBRANES	N°	24	48	72	10	15	20
CELL UNIT SURFACE	m^2	0.635	0.635	0.635	3.3	3.3	3.3
ELECTROLYSER SURFACE	m^2	15.24	30.48	45.72	33	49.5	66
DIMENSIONS: - H	m	2.0	2.0	2.0	2.5	2.5	2.5
- W	m	0.8	0.8	0.8	3.3	3.3	3.3
- L	m	1.5	2.85	3.9	1.1	1.5	1.8
WEIGHT: - Empty	T	2.1	3.9	5.3	8.5	11.0	13.5
- Oper.	T	3.2	5.8	8	13.0	17.5	21.0

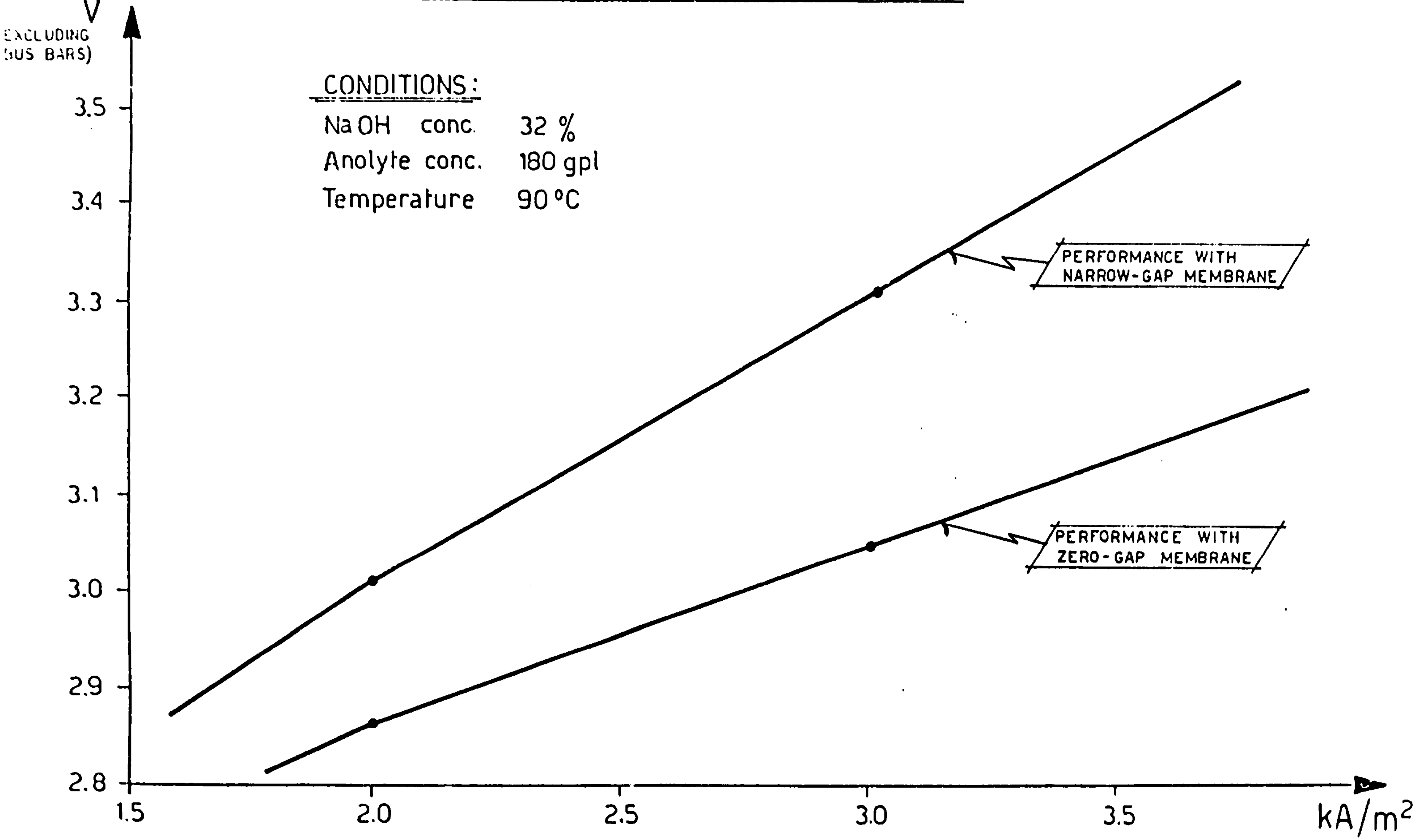


DE NORA MONOPOLAR ELECTROLYSER

CONDITIONS:

NaOH conc.	32 %
Anolyte conc.	180 gpl
Temperature	90 °C

DE NORA BIPOLAR ELECTROLYSER



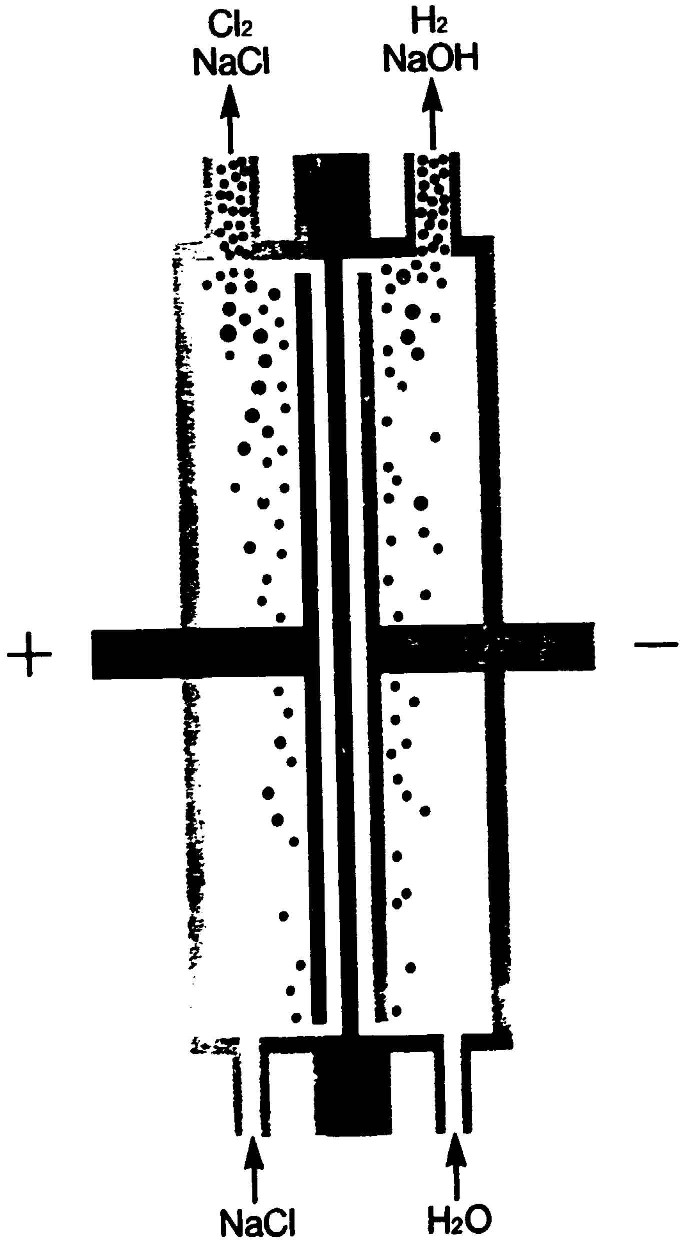
ATTACHMENT IV

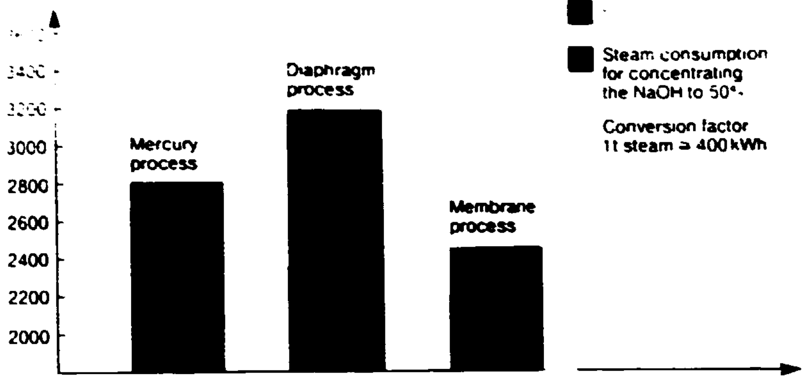
Uhde Alkaline Chloride Electrolysis by the Membrane Process

UHDE

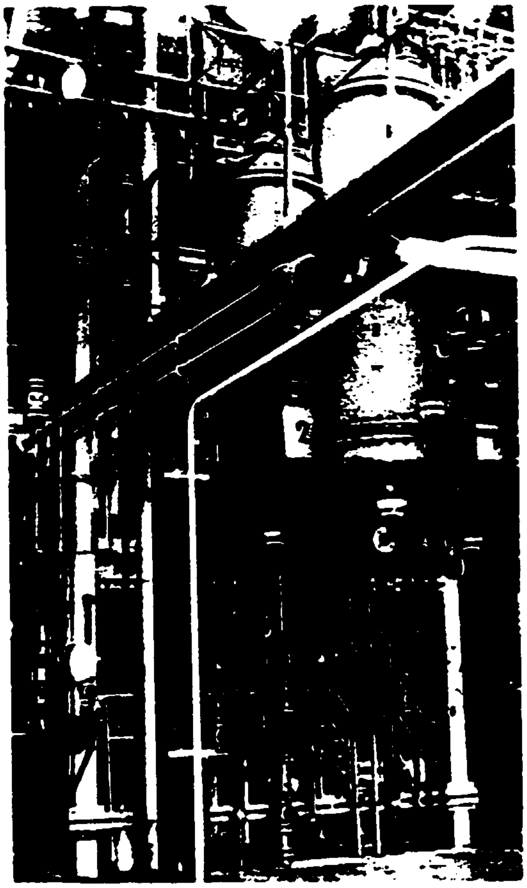
Alkaline chloride electrolysis by the membrane process

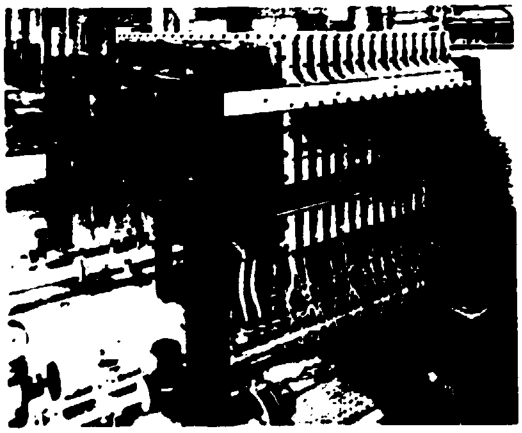
ATTACHMENT IV



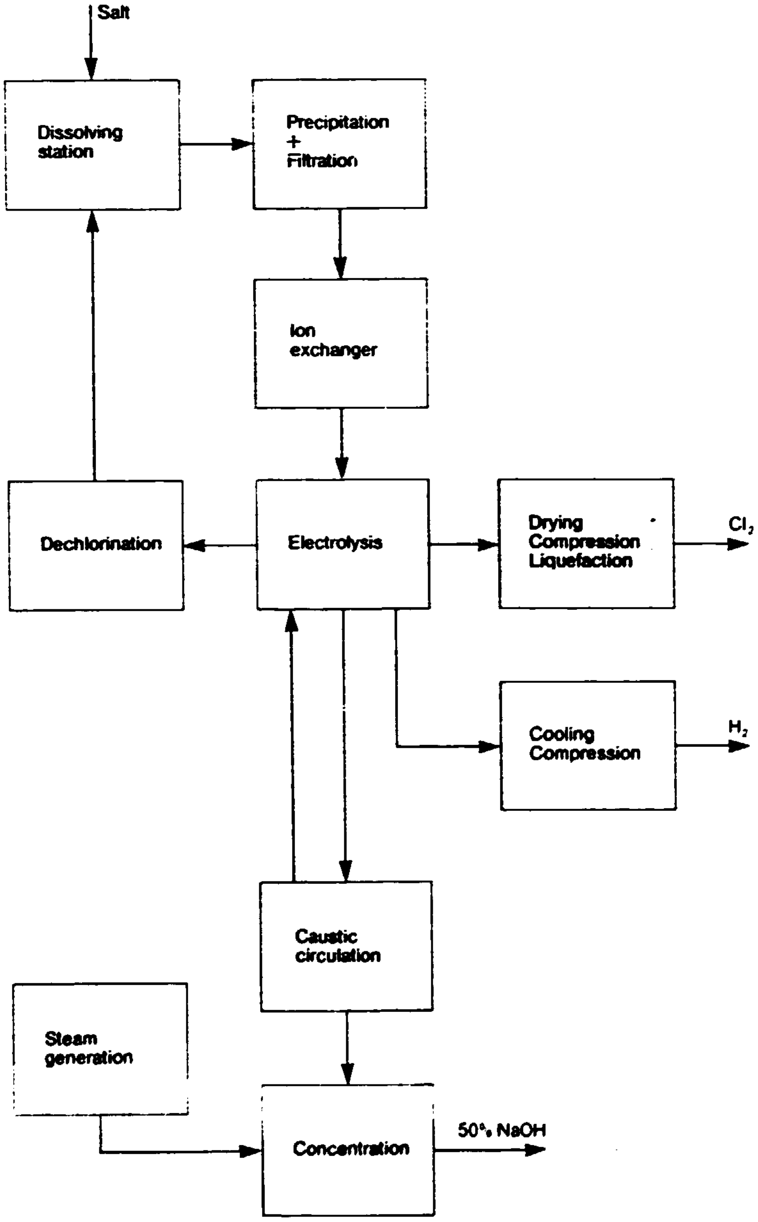


Comparison of energy consumption figures





Membrane process

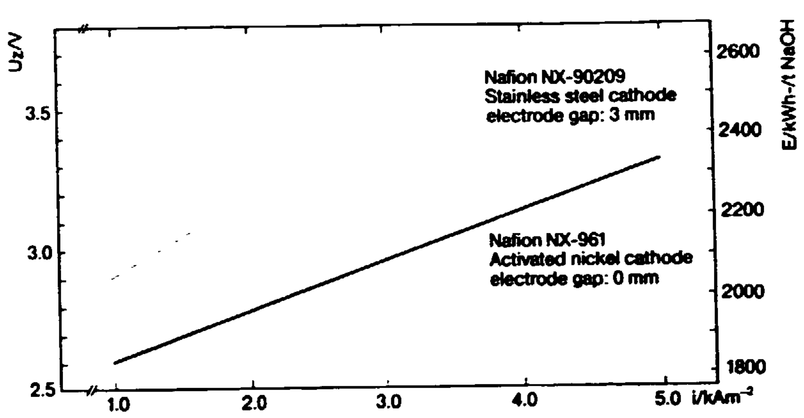


Uhde membrane cells
Technical data

■ Power consumption

The Hoechst-Uhde membrane cells require only 2100 kWh/t NaOH (at a current density of 3 kA/m²), this being one of the lowest achievable with today's membrane technology. The graph reflects the power consumption of two different bipolar membrane cell types as a function of current density.

Power consumption as a function of current density



■ Optimum current density

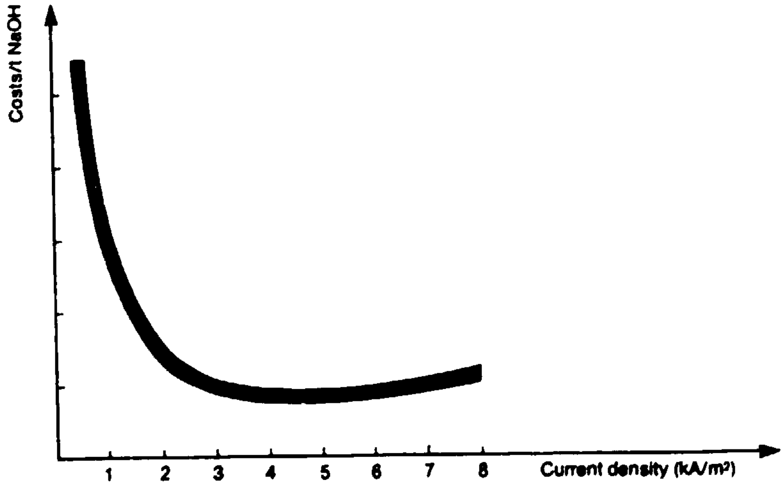
The current density of Hoechst-Uhde membrane cells can be varied over a wide range. This makes it possible to select the economically optimum current density in consideration of cost factors such as

- ☐ electricity price
- ☐ product price
- ☐ depreciation
- ☐ service life of membranes and electrodes.

The graph illustrates the production costs at a fixed electricity price and varying current densities.

Uhde's services include the computerized optimization of the current density.

Optimization of the current density



Operating data:

NaOH concentration:	up to 35 % by wt. (depending on type of membrane)
Power consumption:	2100–2500 kWh/mt NaOH at 3 kA/m^2 (depending on cathode and membrane material)
Service life of membrane:	2–3 years
Lifetime of electrode activity:	$>$ 5 years

Product quality:

Caustic soda solution

NaOH	up to 35 % (wt.)
NaCl	$<$ 100 ppm (referred to 100 % NaOH)

Gaseous chlorine

Cl_2	$>$ 97 % (vol.)
O_2	$<$ 1.5 % (vol.)
H_2	$<$ 0.05 % (vol.)

Hydrogen

H_2	99.9$<$ (vol.)

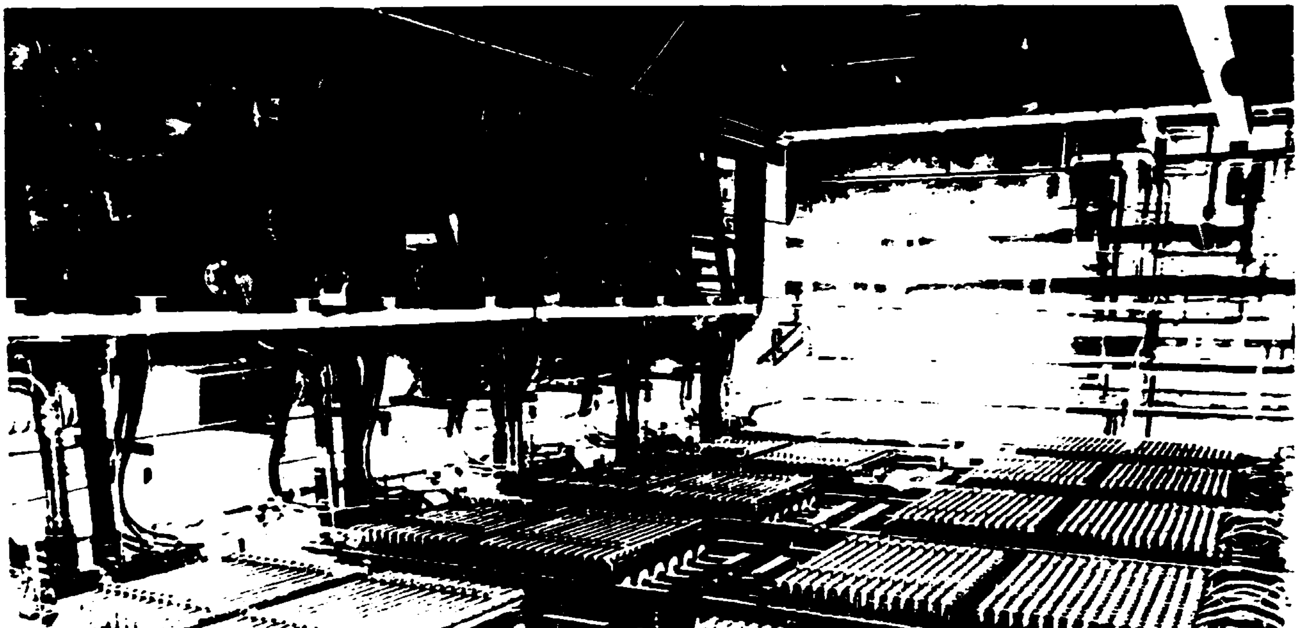
Sizes and production rates of the Hoechst-Uhde bipolar membrane cells

Electrode surface area in m^2	Electrolyzer with 100 cell-elements at 4 kA/m^2	
	Amperage in kA	NaOH production in mtpd
1.2	4.8	16
1.8	7.2	25
2.4	9.6	33
2.7	10.8	37
3.0	12.0	41

Larger cell elements are obtainable if required in special cases.

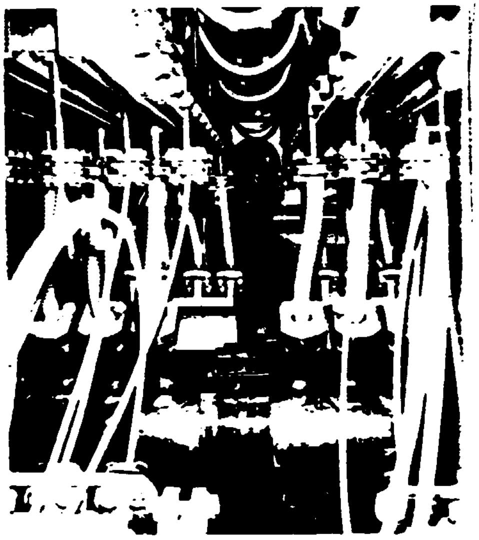
Uhde membrane electrolysis plants

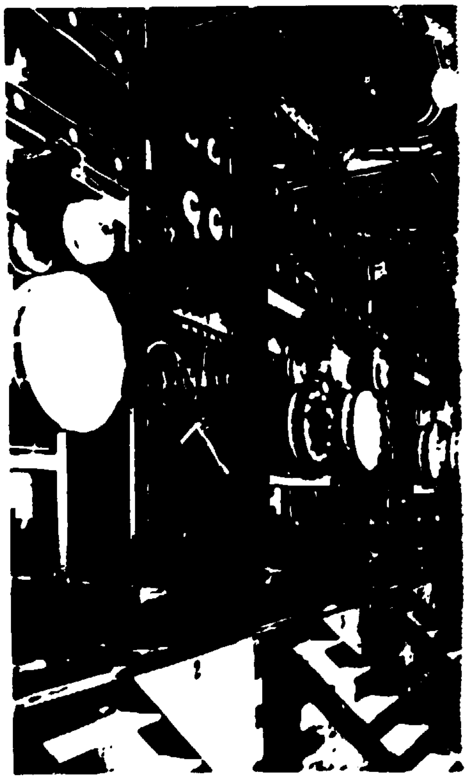
Membrane cells
in Norway
have proved a success



[illegible] plant
for Tofte Industrier AS, Tofte
(top)

Details of a cell room
(bottom)





Due to the restrictions imposed on the transport of liquid chlorine, Tofte Industrier A.S. were compelled in 1979 to produce this chemical, which is necessary for bleaching the pulp, in situ. Tofte Industrier aimed at meeting the applicable pollution abatement and safety requirements at the same time. What technology was to be used? The cost of electric power, operating expenses, raw materials as well as flexibility, i.e. integration into the existing plant complex, were the parameters to be taken into account. Uhde was finally awarded the contract in the face of competition from other experienced European plant contractors.

Among the decisive factors were Uhde's experience of more than 30 years' standing and some 5 million tons of installed chlorine capacity.

The Uhde engineers hat to complete the plant within a construction period of only 14 months (mechanical completion).

[illegible]

Together with the customer, Uhde decided to adopt the bipolar membrane cell technology. But it was by no means an easy task to arrive at the trouble-free operation of today. Uhde, too, gained new experience.

This plant which is equipped with the modern Hoechst-Uhde bipolar membrane cells, went on stream using the modern bipolar membrane cells in late 1983 and has been operating economically ever since without any trouble or impact on the environment.

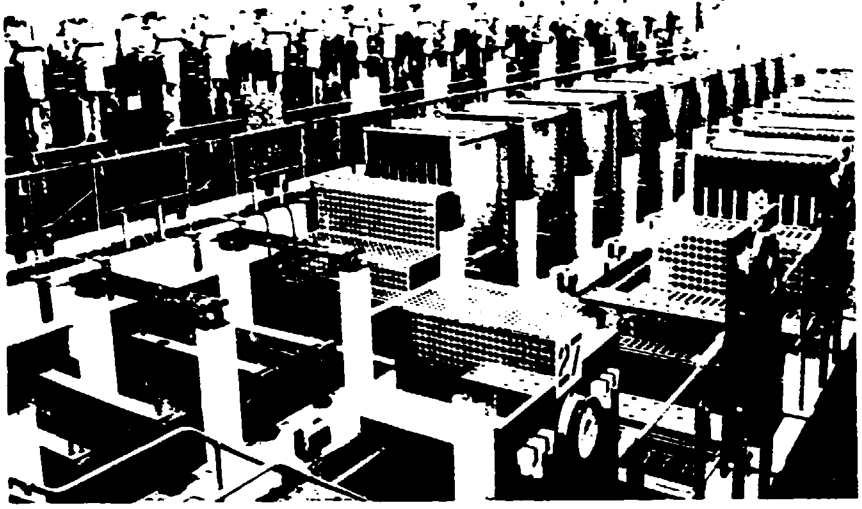
This is where Uhde's consistent design pays off: The highly corrosion-resistant materials used for the all-metal cells and their simple construction minimize the frequency of shut-downs.

The simple and safe maintenance achieved by using exchangeable individual elements minimizes the duration of shut-downs.
Result: extremely high on-stream factor – 99.7 %.

Day by day, this plant produces 40 tons of chlorine and 45 tons of caustic soda solution. And the power consumption is very low indeed.

Another reason for the customer's complete satisfaction: The plant output can be varied in line with the requirements of the pulp and paper factory.

Follow-up orders thanks to the high reliability of Uhde membrane cells



The experience gained in the Tofte reference plant, the operation of the membrane electrolysis plant equipped with monopolar cells at Roche Products, Scotland, the results obtained from the research and development work carried out in the pilot plants of Hoechst and Bayer: These were some of the decisive factors why Uhde was being awarded a number of follow-up contracts in short succession from Pakistan (where the plant is already under construction), Indonesia and from Arab coutries as well as a Letter of Intent from General Electric Plastics of the Netherlands.

For the Kertas Letjes paper factory of Java/Indonesia, a membrane electrolysis plant is being set up by Uhde in cooperation with Uhde S.A. of Paris. This plant will increase the capacity of the existing diaphragm electrolysis plant by some 2500 tpa NaOH.

The plants mentioned will be using the proven Hoechst/Uhde bipolar membrane cells.

	Uhde membrane electrolysis plants		Commissioning	NaOH capacity in tpa
1	Hoechst AG Frankfurt/Main	Fed. Rep. of Germany	1977	500
2	Hoechst AG Frankfurt/Main	Fed. Rep. of Germany	1981	1500
3	Bayer AG Leverkusen	Fed. Rep. of Germany	1981	3500
4	Roche Products Ltd. Dalry	Scotland	1983	24000
5	Tofte Industrier A/S Tofte	Norway	1983	18000
6	Potasse et Produits Chimique S.A. Thann	France	1984	1400
7	P. N. Kertas Letjes Probolingo	Indonesia	1985	2500
8	Bela Chemical Ind. Ltd. Karachi	Pakistan	1985	16000
9	Hoechst AG Frankfurt/Main	Fed. Rep. of Germany	1984	1700
10	Confidential	Middle East	1987	10000
11	General Electric Plastics B.V. Bergen op Zoom	Netherlands	1987	confidential

Monopolar membrane cells, Roche Products Scotland (top)

Applications

New plants

In general, the membrane process is favourable for new plants with regard to both the consumption figures and the investment costs. This is illustrated by comparing the production costs of state-of-the-art membrane, diaphragm and mercury plants:

Typical production costs:

[redacted]

diaphragm 120%

Assumptions:

Capacity: 50 000 tpa NaOH

Current price: 0.10 DM/kWh

Current
densities: 4 kA/m² membrane
10 kA/m² mercury
2 kA/m² diaphragm

Even under totally different operating conditions, the membrane process ist always a winner on economic grounds.

Conversion of existing plants

The technology selected for revamping an existing plant depends on the specific operating conditions. However, because of the flexibility in layout, Hoechst-Uhde cells can be adapted to most requirements at reasonable cost when converting mercury or diaphragm cell plants.

The following options offer advantages and should be given due consideration:

☐ Complete or step-by-step replacement of mercury or diaphragm cells

☐ Capacity unchanged/increased

Possible use of

☐ existing rectifiers

☐ piping system

☐ bus bars

☐ brine purification facilities

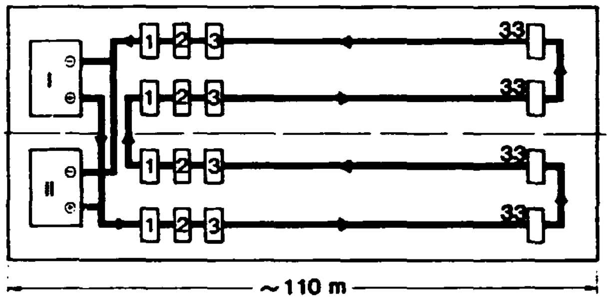
☐ cell room equipment (racks, hoist)

Examples of converted plants are shown in the following.

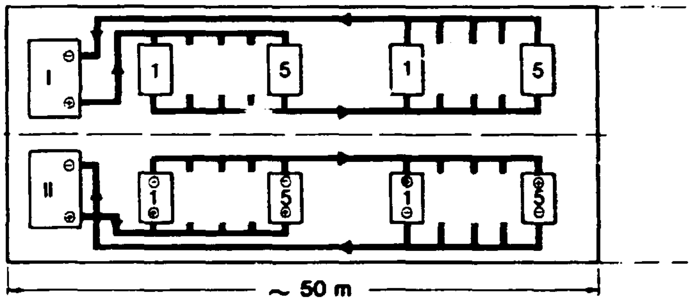
The small space requirements of the membrane cells open up numerous alternatives.

Owing to the fact that more existing plant sections can remain virtually unchanged, conversion to monopolar rather than bipolar membrane cells can under certain circumstances offer even greater advantages. Uhde can also offer these monopolar cells in such cases.

Conversion of diaphragm cells to bipolar membrane cells
(schematic)

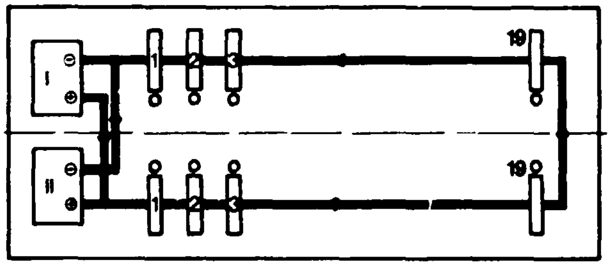


Existing diaphragm cell room
132 cells in 4 rows
2 rectifier units parallel
2 x 60 kA; max. 500 V
capacity: 528 mtpd NaOH 100 %

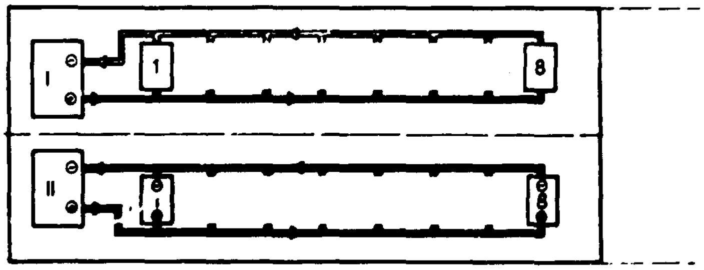


Converted membrane cell room
20 bipolar cells in 2 rows
1 rectifier per cell row
60 kA; max. 500 V
capacity: 543 mtpd NaOH 100 %

Conversion of mercury cells to bipolar membrane cells
(schematic)



Existing mercury cell room
38 cells in 2 rows
2 rectifier units parallel
2 x 90 kA; max. 180 V
capacity: 235 mtpd NaOH 100 %



Converted membrane cell room
16 bipolar cells in 2 rows
1 rectifier per cell row
max. 90 kA; max. 180 V
capacity: 305 mtpd NaOH 100 %

UHDE

Design and construction
of chemical and
other industrial plants

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- Gas purification
- Coal technology
- Fertilizer
- Foodstuffs
- Biotechnology
- Breweries
- Plastics
- Synthetic fibres
- Organic chemicals
- Pharmaceuticals
- Cosmetics
- Electrolysis processes
- Nuclear technology
- Electrothermal processes
- Environmental protection
- Miscellaneous processes
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- Energy supply systems
- Infrastructure

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ATTACHMENT V

The Generation of Hypochlorite from Seawater

ATTACHMENT V

I. THE GENERATION OF HYPOCHLORITE FROM SEAWATER

1. The chemistry of the process is based on the partial electrolysis of sodium chloride contained in raw seawater as it flows between direct current energized anodic and cathodic electrodes in an apparatus (named an electrolyzer) and on successive chemical reactions which take place in the seawater between the products of electrolysis.

On passing a direct current through an aqueous solution of sodium chloride (NaCL), which is totally dissociated to Na^+ and Cl^-

1) free chlorine is generated at the anode:
$2\,Cl^- \rightarrow Cl_2 + 2e^-$

2) hydrogen is evolved at the cathode with the corresponding formation of OH^- ions:
$2\,H_2O + 2e^- \rightarrow 2OH^- + H_2\uparrow$

OH^- ions migrate from the cathode area and react with Na^+ and Cl_2 near the anode, thus producing sodium hypochlorite NaClO:

3) This overall chemical reaction can be expressed ad follows:
$2\,NaOH + Cl_2 \rightarrow NaClO + NaCL + H_2O$

Side reactions, both chemical and electrochemical, take place simultaneously with the basic reactions, such as the decomposition of hypochlorite to chloride, the anodic oxidation of hypochlorite to chlorate (traces only), the cathodic reduction of hypochlorite to chloride and the anodic evolution of oxygen.

Moreover, some cations which are present in seawater (e.g. calcium, magnesium and other metals) form hidroxides and carbonates resulting in suspended solids which are carried out of the electrolyzer by the seawater stream.

These side reactions reduce the current efficiency, such that the actual amount of electric power required to produce hypochlorite is higher than the theoretical requirement by approximately 10%.

In the chemical literature, hypochlorite concentrations are commonly referred to in terms of available or « active » chlorine, i.e. the quantity of chlorine having the same oxidizing effect as the hypochlorite when analyzed by standard methods.

The available chlorine concentration in hypochlorite solutions from pre-engineered **SEACLOR** Systems is in the range of 1000 to 2500 ppm.

Hypochlorite produced from seawater is sufficiently stable to tolerate, without substantial loss of chlorine, the storage conditions required for shock treatment with chlorine injections regularly spaced during the day and corresponding renewal of the hypochlorite solution in the storage tank.

Long storage periods, such as two days or more, should not be considered as a design datum.

Hydrogen gas is produced in the electrolyzer at the rate of about 0.35 m^3 kg chlorine

Dilution of the hydrogen with air is practiced to reduce the hydrogen concentration to less than 2% (v/v) immediately as it disengages from the liquid effluent in the hypochlorite collecting tank wherever the release of hydrogen to the atmosphere as an undiluted gas may create hazardous conditions.

2. Seawater is delivered to **SEACLOR** Systems at a constant flow rate. Seawater is to be taken downstream the hypochlorite injection point because it is essential that the seawater delivery system contain some active chlorine, as provided by the **SEACLOR** System, to protect pipelines and other equipment (such as the screens) from organic fouling.

Before entering a **SEACLOR** System, seawater is strained through 0.5 mm screens to remove suspended solids which would otherwise affect the normal functioning of the installation. Automatic self-cleaning screens are normally used form medium and large capacity plants.

The required seawater pressure varies with the capacity of the **SEACLOR** System and the circuit characteristics from 1 to 2.5 Bar g.

Location of seawater intakes in waterways, harbours, estruaries or deltas frequently means contaminated seawater; the same may occur in the vicinity of industrial or urban discharge.

Seawater containing high amounts of suspended organic material and oil may not be suitable for electrolysis as such. In certain cases the seawater quality can be improved by filtration and/or treatment to make it suitable. Where possible alternative sources of seawater should be considered, e.g. by tapping salty aquiferous layers.

In all such cases complete analysis or reprensentative samples of seawater to be used should be sent to de Nora to ascertain its suitability and/or the required treatment.

3. After long operation periods, the electrolyzers should be cleaned of cathodic deposits consisting mainly of the hydroxides and carbonates formed in the side reactions mentioned at above point 1.

These deposits are removed by dissolving them in a diluted solution of hydrochloric acid which is circulated through the electrolyzers by means of a centrifugal pump.

The cleaning cycle for one **SEACLOR** System takes approximately one hour and is carried out after shutting off the electric current and draining the seawater from the electrolyzers.

The acid solution has a concentration of 5% HCL (w/w) when freshly prepared and can be used for several cleaning cycles until the HCL concentration is down to approx. 2.5%.

The weak solution can be strengthened agian to 5% HCL concentration by the addition of some commercial hydrochloric acid and reused for more cleaning cycles.

The consumption of hydrochloric acid is minimal and without any significant incidence on the operating costs.

It should be noted that no design of hypochlorite generator, on the market today, totally eliminates the need for periodical cleaning.

The cleaning by acid washing has no effect on the performance and life of the specialized electrodes which equip **SEACLOR** Electrolyzers.

II. SEACLOR® SYSTEMS

1. **SEACLOR** Systems consists basically of:

- One or more **SEACLOR** elctrolyzers
- A source of direct current (rectifier unit)
- D.C. bus bars or cables for the interconnection between the electrolyzers and for the connection of the electrolyzers to the rectifier unit
- Piping between the electrolyzers including hydrogen separators when required and connections to the seawater supply, the hypochlorite collection and the acid cleaning systems
- Instrumentation required for the efficient operation and control of the **SEACLOR** System.

As a general rule the equipment is supplied pre-assembled or pre-fabricated to the maximum possible extent copatible with transport and handling limitations.

SEACLOR Systems are suitable for operation in marine and tropical environments. They are designed for continuous and unattended operation and require only periodic checking.

Electric power rectification, instrumentation and all other components are designed to assure effective performances of the Systems.

As far as the installation of stand-by Systems is concerned, de Nora suggests that it schould be considered only in cases where local conditions are likely to hamper timely replenishment of the spare parts taken from inventory for use or if difficulties are foreseen in carrying out un-scheduled repair work within a reasonable time.

In case that the hypochlorination plant consists of more than one **SEACLOR** System and the actual chlorine requirement is lower than the installed capacity, it is advisable that all installed **SEACLOR** Systems be kept in operation, as energy is saved by operating more Systems at lower D.C. current levels for the same production rate.

2. The standard electrical interconnection of the **SEACLOR** electrolyzers of a System is in one [illegible] series. This arrangement gives the best possible conversion efficiency and power factor of the rectifier unit at all operating conditions, that is, the lowest power cost, and the lowest possible capital cost for the System and particularly for its rectifier unit.

3. Typical hydraulic flow paths of **SEACLOR** Systems are shown in figure 9. Normal hydraulic interconnection of the **SEACLOR** Electrolyzers of a System is one single series. Higher values of available chlorine concentration in the effluent solution are usually obtained with more electrolyzers in series.

4. Hydrogen separators made of plastic materials (such as FRP with PVC internal liner) are inserted in the hydraulic path between two adjacent electrolyzers – when the eletrolyzers are designed for installation in a vertical position – or between series of two-three electrolyzers – when they are designed for installation in a horizontal position.

They are used to separe most of the hydrogen which is generated in the preceding electrolyzers, or group thereof, from the chlorinated seawater stream.

By this provision, also the following electrolyzers are fed with seawater which is substanzially gas free and a saving in power consumption is achieved, as overall seawater conductivity increases as its content of hydrogen gas is decreased.

The hydrogen separators work as vessels totally filled with seawater and do not create, in any condition, hydrogen pockets.

Hydrogen gas outflowing from the top of the separators entrains a small flow of chlorinated seawater, which is recovered in the hypochlorite collecting and degassing tank placed next to the **SEACLOR** System.

Plastic materials are preferred to lined steel for the piping within the **SEACLOR** Systems because lined steel may lose its insulating property and become, sometimes, a safety hazard too.

Moreover any hole, however small, which may occur in the lining by wear or shock (during maintenance, for example) causes a quick perforation of the pipe because of chemical and electrochemical corrosion.

For the same reasons, valves in molded plastics are preferred to lined metal valves.

5. The standard instrumentation and protective devices which are included in a **SEACLOR** System consist of:

- an automatic electronic control system to stabilize the D.C. current supply to the electrolyzers
- devices required to adjust the D.C. current to the desidered value
- meters to indicate the D.C. current and voltage supplied to the System
- meters to indicate the D.C. voltage across each electrolyzer of the System
- meters to indicate the seawater flowrate to each hydraulic path of the System
- devices required to protect each electrolyzer of the System against abnormal D.C. voltage levels
- protection of each hydraulic path against failure of the seawater supply sistem
- protection of the rectifier unit against internal failures, external A.C. overvoltages and D.C. side overcurrents.

All the above mentioned instruments and protective devices are mounted on a control panel provided with an annunciator system, which is usually incorporated in the same rectifier cubicle, with the exception of the flow indicators and switches which are installed on the seawater feed line.

If any abnormal condition arises, the associated protective device operates a luminous and acoustical signalling device and, according to the fault gravity, gives an alarm or shuts down the rectifier unit, actuating the tripping coil of the associates power circuit breaker.

The annunciator system is provided with spare alarm points for additional protections or interlock devices external to the **SEACLOR** System.

The basic indications on the working conditions of the **SEACLOR** Systems can be repeated for display on the annunciator of a panel located in a remote central control room.

These indications are generally limited to:

- Systems in or out of operation
- The occurrence of alarm conditions (one general alarm signal per each System)
- The occurrence of a failure followed by shut down (one general lockout signal per each System).

6. Electrical equipment is confined within enclosures of type and material adequate to the intended use and local conditions.

Weather-proof enclosures are provided for outdoor installation in unclassified areas and air purged and or explosion proof enclosures for installation in hazardous areas.

It should be noted that the installation of the equipement indoors in a safe area is to be preferred whenever feasible because of the lower capital cost of the equipment, easier maintenance and repair work and longer life of the equipment.

This applies particularly in severe weather conditions where heavy rains or sandstorms are frequent.

7. Figure 12 shows a typical indoor layout of a hypochlorination plant using two **SEACLOR** Systems.

The diagram at Figure 13 shows the average covered area as related to the total installed capacity for typical hypochlorination plants.

Substantial variations to the plant area may result from specific requirements and or additional equipment.

8. For very low production capacities, 0.5 to 2 Kg h available chlorine, standard units named **Mini SEACLOR**® Systems are provided.

Figures 27 and 28 show a 1.5 Kg h available chlorine production capacity **Mini SEACLOR**® System.

III. SEACLOR® ELECTROLYZERS

1. **SEACLOR** electrolyzers consist of electrolytic cells of modular construction: these are combined in electrical and hydraulic series and fastened together to form an « alectrode assembly » (Figure 14) which is placed in a cylindrical electrolyzer body (Figure 15). Standard electrolyzers contain 10 modular cells: however, electrolyzers containing 6-8-9- cells are also in current use.

The electrolytic cells are bipolar in design. This means that the cathodes of every cell are directly connected to the anodes of the next cell.

The paths of current, seawater and electrolysis products through the electrolyzers are show in Figure 16.

A unique feature of an « electrode assembly » is the ease of replacement of the electrodes installed in the electrolyzers: it can be inserted into or removed from the electrolyzer body in a short time without need for special tools or specialized mechanics.

SEACLOR electrolyzers are available for installation both in a horizontal and in a vertical position.

2. The materials used in the construction of the **SEACLOR** electrolyzers are as follows:

- The electrolytic cells – anodes and cathodes – are made of titanium ASTM B265 grade 1.
- The anodes are DSA® – dimensionally stable anodes– with a coating of platinum group metal particularly ruthenium.
- The hardware to secure the electrolytic cells is made of titanium ASTM B265 grade 2.
- The elctrode spacers are made of Teflon®.
- The casing of the electrode assembly is made of PVC.
- The electrolyzer body is a solid, cylindrical shell of filament wound FRP with an internal liner of PVC; it is highly resistant to stress and corrosion and is electrically insulating.
- The flanged ends are made of hard rubber lined steel.
- Hot dip galvanized steel and stainless steel are used for the external hardware.
- Electrical connectors are made of 99.9% electrolytic copper.

3. It is preferable that the electrolyzers operate under constant seawater flowrate, while the D.C. current is adjusted so that the generation of chlorine instantaneously matches the requirement for the water treatment.

The voltage across the electrolyzers in operation is measured with D.C. voltmeters installed on the rectifier control panel.

The readings of the voltmeters shall be periodically taken, checked and recorded as they reflect the working conditions of the electrolyzers.

The above readings will be helpful too in providing, after years of continuous operation, an early warning on the near exhaustion of the catalytic properties of the anode coating.

This occurence shows itself by gradually rising voltage levels, in sharp contrast with the steady voltage characteristic that has been maintained throughout the life of the coating and which is one of the properties of DSA®.

Should the voltage across any electrolyzer of the System deviate from its normal operating value and approach a level which is dangerous to the electrode metal structure, an automatic device installed in the rectifier control section will signal the fault and/or shut off the electric power supply to the electrolyzers befor damage occurs.

4. **SEACLOR** electrolyzers are available in several sizes to cover a very wide range of System capacities.

Number and size of electrolyzers are in relation to the System capacity.

IV. RECTIFIER UNITS

1. The rectifier units are specifically designed to feed **SEACLOR** electrolyzers with D.C. current which is continuously and automatically controlled.

Direct current can be adjusted within a range of 20 - 100% of the full rated current.

The rectifier is provided with an automatic electronic control system which stabilizes the direct current value with an accuracy of ± 1% rated full current.

2. Whenever feasible, the A.C. supply voltage to the rectifier transformer should be related to the power of the rectifier unit in order to have a cost-effective electrical installation, including A.C. power breaker, protections, cabling and rectifier transformer.

A correlation of suitable A.C. voltage levels with power levels is as follows:

- Power up to 200 kW (corresponding approx. to a 50 kg/h **SEACLOR** System): 380 to 500 V, 50 or 60 Hz, 3 phase
- Power from 200 to 2000 kW (500 kg/h **SEACLOR** System): 3 to 13.8 kV, 50 or 60 Hz, 3 phase.

3. Rectifier units consist mainly of:

- one rectifier transformer
- one thyristor rectifying section
- one control section

4. The rectifier trasformers are fitted with taps to be selected off-load in order to operare the rectifier at the best possible power factor in relation to:

- the steady-state primary supply voltage level
- the actual D.C. voltage level, which is influenced by the D.C. current level as well as by seasonal changes of seawater conductivity.

5. The rectifier units rated up to approx. 140 kW (corresponding approx. to a 35 kg h **SEACLOR** System) are contained in one common cubicle, inclusive of:

- one general circuit breaker
- one dry type rectifier transformer
- one thrystor type rectifying section
- one control section.

Heat losses can be removed from the cubicle using the once-through forced air or the recirculating forced air cooling system indicated in the following point 8.

Heat removal by natural convection through the walls of the cubicle is feasible only for the rectifiers which equip low capacity **SEACLOR** Systems.

The rectifier units entirely contained in one cubicle, provided with recirculating forced air cooling system and with an air purged enclosure, can be designed with the requirements for use in hazardous areas of Class 1, Division 1 and 2.

6. Rectifier units consisting of a transformer and rectifier assembly totally immersed in an oil tank with natural air cooling and a control section housed in a separete panel can be provided on request.

7. The rectifier units with a power rating higher than approx. 140 kW have the rectifying and the control sections contained in a common cubicle: the transformer, either of the dry type or of the oil immersed type, is a separate piece of equipment to be connected to the rectifier cubicle with A.C. bus bars or cables.

8. The cooling systems used for the **SEACLOR** rectifier cubicles are:

- **The once-through forced air system:** the cubicle has one or more axial fans making the air circulate through the fins of the thrystor heatsinks.

  Ambient air is brought into the cubicle through openings placed on the lower part of the lateral walls and blown out from the top side of the cubicle.

  This system is the most suitable for rectifier cubicles located in a room provided with adequate air ventilation or conditioning to remove the heat losses.

- **The recirculating forced air system:** it differs from the once-through forced air system in so that air circulates in closed circuit with a built-in water cooler.

- **The deionized water system:** it consists mainly of a circuit in which deionized water is passed through cupronickel tubes (driven into the aluminium heatsinks of the thyristor) by a mechanically sealed pump and circulated through a deionized water water or deionized water forced air heat exchanger. The materials of the deionized water circuit components are particularly designed to resist corrosion.

  An ion-exchange deionizer forms part of the circuit. The conductivity of the deionized water is monitored by a gauge with a maximum conductivity alarm contact which can ben preset at about 50 µS cm.

  This system is used for only high power rectifier cubicles with power ratings approx. 2000 kW and over.

9. The rectifier units are designed, manufacture, assembled and shop tested in accordance with the requirements of Publication No. 146 1973 of I.E.C. (International Electrotechinical Commision) « Semiconductor Converters ».

The basis of rating is the following:

- 100% rated current continuously

- The rectifier unit shall be energized at rated A.C. voltage and operated continuously at 100% of the rated amperes until a constant temperature-rise has been reached by all parts of the rectifier unit.

  When the temperature-rise of all parts of the rectifier unit is at or below that corresponding to full load value, it shall be capable of withstanding a momentary overcurrent of such magnitude and duration as is necessary to allow the automatic load regulating equipment or overcurrent protective equipment to protect all the parts from damage.

The reliability of the rectifier unit is assured by the use of high quality components selected for functioning in tropical and corrosive environments and by an unmatched experience in the design and construction of rectifiers specifically intended for use in heavy duty electrochemical plants.

V. POWER CONSUMPTION

1. The power consumption of **SEACLOR** electrolyzers depends on D.C. current level, seawater salinity and temperature as well as on the concentration of available (active) chlorine in the effluent solution.

When referring to operation at D.C. rating with seawater at 20°C and of standard composition (Figure 26) and normal chlorine concentration, the average specific D.C. power consumption of pre-engineered **SEACLOR** Systems is lower than 4 kWh/kg available chlorine.

The available chlorine concentration in the effluent hypochlorite solution affects both the production capacity and the power consumption of the electrolyzers, so that a higher chlorine concentration means a lower production and a higher power consumption at the same D.C. current level.

However, the bands of variation of these quantities are narrow (approx. 2% of average value) if chlorine concentration is kept within the range of 1000 to 2500 ppm.

2. Specific A.C. power consumption, including all loses in the **SEACLOR** System (transformer, rectifier, A.C. and D.C. conductors, electrolyzers) can be obtaine multiplying the specific D.C. power consumption by a factor ranging from 1.04 to 1.10.

Figure 26

COMPOSITION OF STANDARD SEAWATER
(according to the Hydrographic Laboratory of Copenhagen)

Cations	mg/l	me/l	Anions	mg/l	me/l
Na^+	11,035	479.8	Cl^-	19,841	559.6
Mg^{++}	1,330	109.4	SO_4^{--}	2,769	57.6
Ca^{++}	418	20.9	HCO_3^-	146	2.5
K^+	397	10.2	Br^-	68	0.9
Sr^+	13.9	0.3	F^-	1.4	

Total salinity: 36,047 mg/l
Total alkalinity: 119.8 mg/l

Its upper value should be normally referred to **SEACLOR** Systems equipped with only one electrolyzer and its lower value to **SEACLOR** Systems equipped with four electrolyzers in one electric series.

The results of long-time operations are proving that the direct generation of active chlorine from seawater using the **SEACLOR** Systems requires the lowest overall energy consumption, when comparison is made at the same operating conditions with competing systems.

VI. PREVENTIVE MAINTENANCE

1. Preventive maintenance is not the universal panacea for continuous equipment operation; however, it is a major step in the right direction for reducing non scheduled downtime and the following practices have been demonstrated as being useful.

a) Establish and enforce regular inspection schedules.

b) Have the Production Department provide advance notice on any scheduled shutdown: this is an ideal time for inspection and/or repair.

c) Maintain and adequate supply of spares.
When ordering spare parts, give a detailed description of the parts and complete nameplate data on the devices, as well as the position in the schematics.

d) Keep records of operating data, maintenance works and inspections.

e) Under normal conditions the protective devices do not operate; therefore these devices need careful inspection. In case of any scheduled shut-down the manual tripping of a protective device will afford an opportunity to observe the manner in which the device is operating.

f) Accumulation of dust, dirt and corrosion, particularly on stand-by equipment, may cause faulty operation of many devices. Therefore, a periodic routine of cleaning and inspections should be established.

2. The most difficult area for establishing a sound preventive maintenance program is determining the frequency of inspection and testing.

A schedule of inspection and maintenance operations may be ad follows:

DAILY

- Record operating parameters on log sheets
- Test alarm lights
- Check air-circulation monitoring device of forced-air cooled rectifier cubicles

WEEKLY

- Check flow switches on seawater supply line to the electrolyzers

FORTNIGHTLY

- Clean the electrolyzers by recirculating weak hydrochloric solution; record operation on log sheets

Note: It it possible to schedule less frequent cleaning operations; however, they require a time usually longer than the average one-hour time (refer to I.3) and are less advisable for what concerns effectiveness and equipment overall downtime.

MONTHLY

- Check for cleanliness of control cabinets, rectifier cubicle and outside surface of transformers and insulators.

YEARLY

- Check for tightness of all bolted connections
- Check for correct operation of all protective devices (actuate them manually)

The above schedule may be adjusted to meet the local operating conditions, after a first trial period.

3. Replacement of the electrode assemblies

The procedure for the replacement of the electrode assemblies may vary in relation to the number of installed and operating electrolyzers and other specific conditions of the plant, but generally in a staged manner, whenever the plant includes more than one electrolyzer.

The first step is to use an electrode assembly which may be an existing spare or ordered a few months before the time scheduled for starting replacement.

The electrode assembly which has been removed, is shipped to the factory for inspection and recoating of DSA® and reassembled for use.

As soon as it is received from the factory, the reconditioned assembly is used to replace another electrode assembly.

This procedure may start with one or more electrode assemblies, depending on the number of installed electrolyzers; it is repeated until all the operating electrolyzers have been re-equipped with reconditioned electrode assemblies and the same number of renewed electrode assemblies, used to start the replacement procedure, is in stock at the plant.

The reconditioned electrode assemblies are expected to have the same operating life as new electrode assemblies before a further reconditioning is required.

ATTACHMENT VI

Preliminary Feasibility Study for a Combined Plant to Produce 146.000 t/y of Sodium Hydroxyde and 60.000 t/y of P_2O_5

ATTACHMENT VI

STUDIO DI FATTIBILITA' PRELIMINARE

PER UN IMPIANTO DI PRODUZIONE

CLORO SODA E ACIDO FOSFORICO

Capacità : 146.000 T/A di NaOH soluzione 50% base 100%

60.000 T/A di P_2O_5 come acido fosforico soluzione 75% e 85%

BEN/gc
13.10.83

A. COSTO DI PRODUZIONE IMPIANTO CLORO SODA

		Quantità/ Anno	Prezzo unit. US $	Prezzo/Anno US $
1. Materie Prime				
NaCl 99,96%	t	220.000	12	2.640.000
Reattivi		-	-	250.000
2. Utilities				
E.E. C.A. per elettrolizz.	KWh	324.000.000	0.015	4.860.000
E.E. per motori	"	18.000.000	0.015	270.000
H_2O demi	mc	250.000	0.5	125.000
Vapore	t	88.000	5	440.000
H_2O raffreddamento T 8°C	portata mc/h	5.000	-	500.000
H_2O processo	mc	400.000	0.03	12.000
3. Materiali di esercizio				
Membrane		-	-	1.350.000
Guarnizioni elettrolizzatori		-	-	125.000
Attivazione catodica		-	-	18[illegible].[illegible]00
Attivazione anodica		-	-	970.000

4. Lavoro Diretto

Produzione : 25 addetti in turno + 10 giornalieri x 19.000/Anno = 665.000

Manutenzione : 10 addetti x 19.000/Anno = 190.000

5. Lavoro Indiretto			
30% del Lavoro Diretto		-	255.000
6. Materiali Manutenzione ([illegible] delle apparecchiature)			500.000
7. Materiali Vari Produzione			250.000
8. TOTALE COSTO ANNO			[illegible]

9. PRIMO COSTO INDUSTRIALE SODA CAUSTICA SOLUZ.50% BASE 100% :

US $ 13.582.000 : 146.000 t = 93 US $/t

Il primo costo industriale della soda caustica è stato ricavato tenendo presente che l'acido cloridrico prodotto nell'impianto, nella quantità di 132.000 t/a base 100% viene trasferito all'impianto di produzione acido fosforico a valore "0".

3. COSTO DI PRODUZIONE IMPIANTO ACIDO FOSFORICO

	Quantità/ Anno	Prezzo unit. US $	Prezzo/Anno US $
1. Materie Prime			
Fosforite 32% P_2O_5	t 193.200	30	5.796.000
HCl 100%	t 132.000		
2. Utilities			
E.E.	kWh 30.000.000	0.015	450.000
Vapore per H_3PO_4 75%	t 33.000	5	161.000
Vapore per H_3PO_4 85%	t 120.000	5	600.000
H_2O raffreddamento T 8°C	portata mc/h 1.000	-	95.000
H_2O processo	mc 210.000	0.03	6.000
3. Materiali di esercizio			
Calce	t 18.000	18	324.000
NaOH	t 960	93	90.000
Solvente (consumo)	t 600	750	450.000
4. Lavoro diretto			
Produzione: 20 addetti in turno + 10 giornalieri x 19.000 US $/Anno			570.000
Manutenzione: 10 addetti x 19.000 US $/Anno			190.000
5. Lavoro indiretto			
30% del lavoro diretto		-	228.000
6. Materiali Manutenzione (2% delle apparecchiature)			560.000
7. Materiali Vari Produzione		-	125.000
8. TOTALE COSTO ANNO			9.645.000

9. PRIMO COSTO INDUSTRIALE DELL'ACIDO FOSFORICO:

US $ 9.645.000 : 60.000 t = 161 US $/t

Il valore medio dell'acido fosforico prodotto secondo i più recenti dati di mercato può essere assunto in 500 US $/t per un ricavo totale di US $ 30.000.000.

Il valore della soda caustica secondo i più recenti dati di mercato può essere assunto in 260 US $/t per un ricavo totale di US $ 23.360.000.

L'utile lordo dei due impianti presi in considerazione viene calcolato in:

US $ 55.360.000 - 23.231.000 = 32.129.000 US $

L'investimento per i due impianti può valutarsi in 100.000.000 US $ con un ritorno di investimento di 3 anni.

ATTACHMENT VII

Bleaching Chemicals

UHDE

Bleaching chemicals

ATTACHMENT VII

Chlorine dioxide
Chlorine
Sodium hypochlorite
Sodium hydroxide

Chlorine dioxide
Uhde/Munich process

Unless only minor quantities are required (i.e. less than 5 kg/h ClO_2), chlorine dioxide is produced by the reduction of chlorate in an acid solution.

Numerous processes are available for the production of chlorine dioxide, the main difference between them being the reductant used. The Uhde/Munich process described here uses hydrochloric acid as the reductant. The Uhde/Munich process is normally coupled with a sodium chlorate electrolysis plant using the latest cell technology. However, in the absence of such an electrolysis facility, chlorine dioxide can still be produced using purchased chlorate brine.

It is recommended that the chlorine dioxide unit be located in the immediate vicinity of the consumer, because the transportation of aqueous chlorine dioxide solutions is not practicable over long distances.

The production of chlorine dioxide by the Uhde/Munich process is based on the reduction of sodium chlorate by means of hydrochloric acid:

$$NaClO_3 + 2HCl = NaCl + H_2O + ClO_2 + \tfrac{1}{2} Cl_2$$

The side reaction

$$NaClO_3 + 6HCl = NaCl + 3H_2O + 3Cl_2$$

is suppressed by selecting the correct ratio of sodium chlorate to hydrogen chloride.

The residual solution, which still has a relatively high $NaClO_3$ content, is fed to a chlorate electrolysis unit coupled with the chlorine dioxide production facility.

In the chlorate electrolysis unit, the sodium chloride recovered from the chlorate is reoxidized to $NaClO_3$.

Chlorate production takes place in two process steps:

1. Chloride is decomposed electrolytically at a pH of 6.2 to 6.6 into hypochlorous acid and hydroxyl ions according to the following equation:

$$3Cl^- + 6H_2O \xrightarrow{6\,e^-} 3HClO + 3OH^- + 3H_2O$$

2. The subsequent chemical reactions proceed for the major part outside the electrolyzer, i.e. in the circulation tank, according to the following summation equation:

$$3HClO + 3OH^- \longrightarrow ClO_3 + 2Cl^- + 3H_2O$$

Hence, the gross equation for the formation of chlorate may be expressed as follows:

$$Cl^- + 3H_2O \xrightarrow{6\,e^-} ClO_3^- + 3H_2$$

By maintaining the pH value within the range mentioned above and by limiting the residence time of electrolyte within the cell, the anodic chlorine formation, which proceeds according to the summation equation:

$$Cl^- + \tfrac{9}{2} H_2O \xrightarrow{9\,e^-} ClO_3^- + \tfrac{9}{2} H_2 + \tfrac{3}{4} O_2$$

is prevented to a large extent, the current yield of this reaction being only 66.7%, thus favouring the purely chemical formation of chloride (current yield: 100%).

Depending on the current density, the overall current yield of this process is up to 95%.

Consumption figures

For the production of chlorine dioxide with integrated $NaClO_3$ electrolysis and HCl synthesis units

per kg ClO_2 – 100 %

HCl – 100 %	0.55 kg
Soft water for ClO_2 absorption at 12 °C	0.17 m³ at 6 g ClC
Electric power (DC) for electrolysis	8.9 kWh
Steam (3 bar)	4.5 kg
Cooling water (20-40 °C)	0.44 m³
Proportionate cost of recladding anodes, per ton of Cl_2	DM 21.–

Process description

The diagram represents a chlorine dioxide facility coupled with a chlorate electrolysis unit.

The electrolysis cells (1) are equipped with activated titanium anodes and steel cathodes. The electrolyte circulation between the cells and reaction vessel (3) is promoted by the gaseous hydrogen forming at the cathodes. Electrolyte and cell gas are separated in the gas separator (2), the gas being cooled before it is sent to a hydrochloric acid synthesis unit.

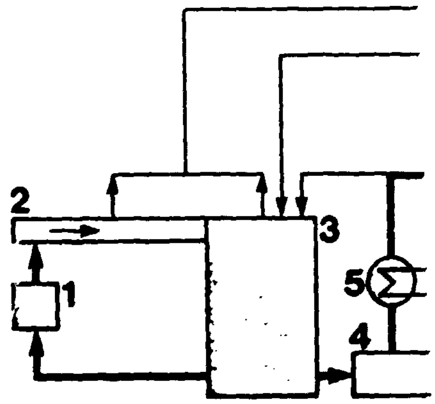
To dissipate the Joule's heat loss in the electrolysis process, a side stream of the electrolyte is fed via a filter (4) to the electrolyte cooler (5). The major portion of the cooled electrolyte is returned to the reaction vessel; the remaining minor part is sent to the chlorate solution storage tank (6). The concentrated chlorate solution is pumped from this tank via a further cooler (7) to the reaction column (10). Controlled quantities of hydrochloric acid are fed to the reaction column from the hydrochloric acid storage tank (8) via a heater (9), while air is admitted at the bottom. The column is subdivided into several stages, the lower part being heated. As a result, the water excess introduced by the reaction water and by the hydrochloric acid is evaporated and subsequently condensed. This condensate and the condensate obtained in cooling the cell gas is used as absorption water for the hydrochloric acid synthesis unit.
The residual solution in the reaction column is returned from the lowermost tray via the reaction vessel into the electrolyte cycle, thereby completely avoiding any chlorate losses.

The gas mixture that forms in the reaction column, consisting of chlorine dioxide, chlorine and air, is fed to the separation column (11) into which water is sprayed at the top.

Owing to the better solubility of chlorine dioxide in water, the chlorine and chlorine dioxide are separated. The chlorine can be burnt in the hydrochloric acid synthesis unit (12) together with the cell gas to form HCl, or it can be used for the production of bleaching liquor.

Chlorine dioxide production pro

1 Chlorate cells
2 Gas separator
3 Reaction vessel
4 Filter
5 Electrolyte cooler
6 Chlorate solution tank
7 Chlorate solution cooler
8 Hydrochloric acid tank
9 Hydrochloric acid heater
10 Reaction column
11 Separating column
12 Hydrochloric acid synthesis unit



Consumption figures

For the production of chlorine dioxide with integrated $NaClO_3$ electrolysis and HCl synthesis units

per kg ClO_2 – 100 %

HCl – 100 %	0.55 kg
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Electric power (DC) for electrolysis	8.9 kWh
Steam (3 bar)	4.5 kg
Cooling water (20-40 °C)	0.44 m^3
Proportionate cost of recladding anodes, per ton of Cl_2	DM 21.–

Product qualities

Absorption water temperature	ClO_2 content in g/l	Cl_2 content in g/l	HCl content in g/l
6 °C	9	0.8	0.6
9 °C	8	0.8	0.6
12 °C	6	0.8	0.6
20 °C	4.5	1	0.6

Personnel requirement

for the entire plant	1 man per shift

Process description

The diagram represents a chlorine dioxide facility coupled with a chlorate electrolysis unit.

The electrolysis cells (1) are equipped with activated titanium anodes and steel cathodes. The electrolyte circulation between the cells and reaction vessel (3) is promoted by the gaseous hydrogen forming at the cathodes. Electrolyte and cell gas are separated in the gas separator (2), the gas being cooled before it is sent to a hydrochloric acid synthesis unit

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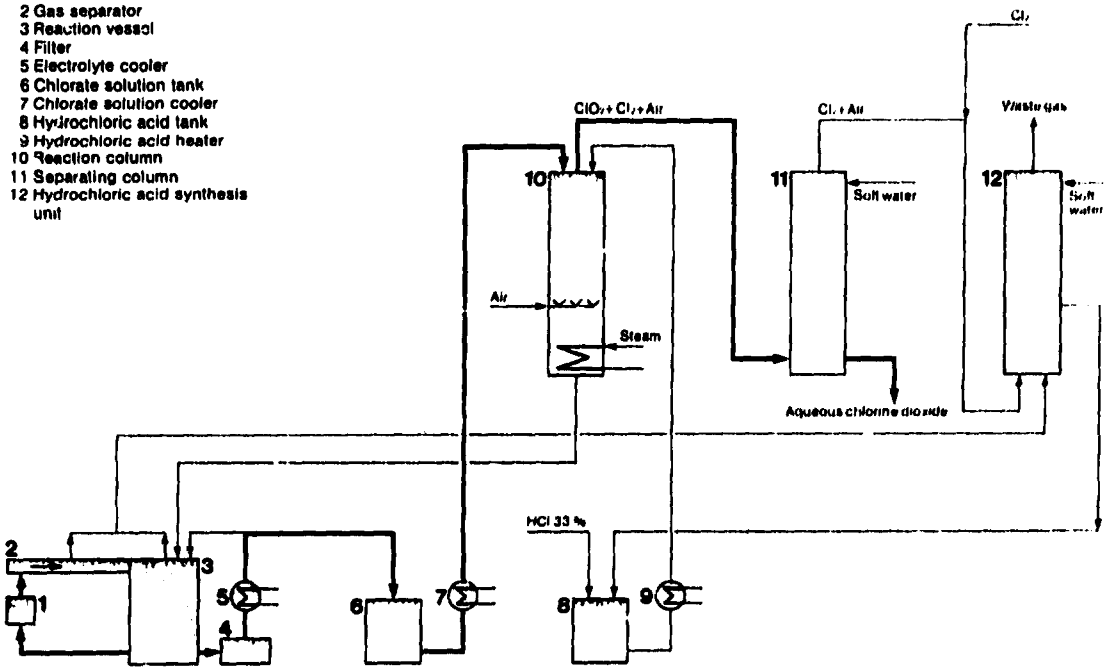
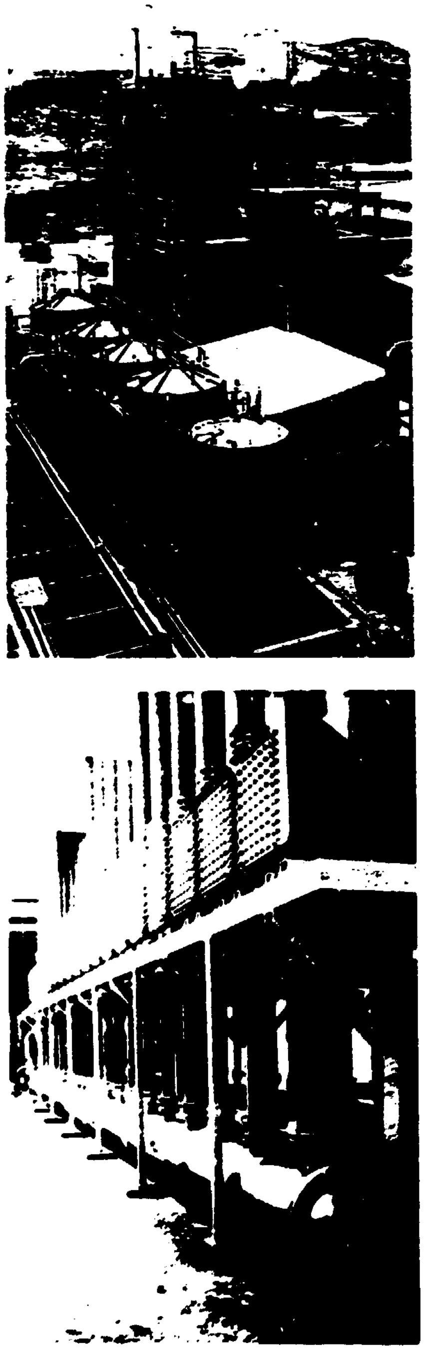
Chlorine dioxide production process

1 Chlorate cells
2 Gas separator
3 Reaction vessel
4 Filter
5 Electrolyte cooler
6 Chlorate solution tank
7 Chlorate solution cooler
8 Hydrochloric acid tank
9 Hydrochloric acid heater
10 Reaction column
11 Separating column
12 Hydrochloric acid synthesis unit





◀

Chlorine dioxide plant (top)
Row of 25-kA cells (bottom)

Advantages of the Uhde/Munich process

☐ No losses of sodium chlorate occur, as the residual solution from the chlorine dioxide unit is returned into the electrolyte cycle. In other processes, the residual solution contains unreacted chlorate which must be regarded as a loss. In view of the herbicidal action of chlorate, such residual solutions must be treated to prevent environmental pollution.

☐ The only feedstock required is hydrochloric acid. Waste acid from organic chlorination processes could be used for this purpose, because the chlorine dioxide process will accept up to 5 g/l organic impurities in the acid.
Moreover, there is no necessity to handle or store solid chlorate salts.

☐ No pollution of the environment: apart from small quantities of pure condensate, there are no byproducts or waste.

☐ Unchanging product quality: the process is continuous; the gas stream is thus constant, with the result that the aqueous chlorine dioxide solution produced always has the same chlorine dioxide and chlorine concentrations.

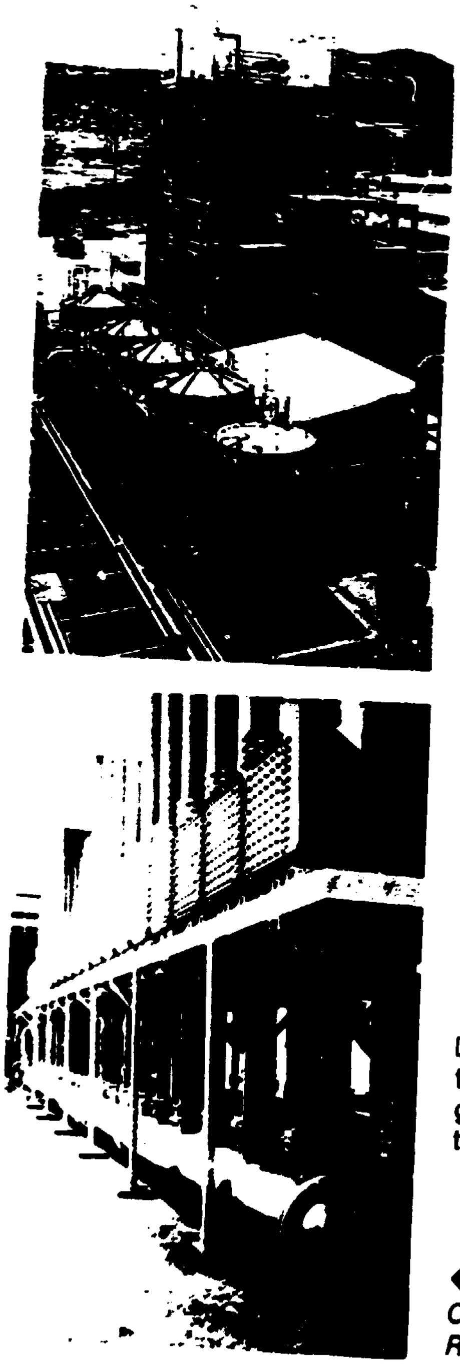
☐ Simple to operate, hence low personnel requirements: 1 man per shift is sufficient.

☐ Low maintenance costs and high on-stream factor by using corrosion-resistant and reliable materials. The titanium anode cladding only has to be renewed every 5 to 6 years.

☐ The process is well-proven, having been applied on a commercial scale in more than 20 plants. The design gives due consideration to the latest state of engineering technology and uses carefully selected materials of construction.

☐ The process is highly reliable and very stable. The low O_2 content (< 2 %) of the cell gas makes it suitable for HCl synthesis. It should be mentioned that the cells are totally filled with liquid at all times and have no gas spaces. Explosions of cell gas within the cell are thus impossible, even if the gas contains more than 4% O_2 as a result of a fault or during start-up.

☐ No chlorate-bearing residual solution: hence, there is no risk of an uncontrolled chlorine dioxide formation in the receiver for such solutions.



Chlorine dioxide plant (top)
Row of 25-kA cells (bottom)

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☐ No chlorate-bearing residual solution: hence, there is no risk of an uncontrolled chlorine dioxide formation in the receiver for such solutions.

Chlorine dioxide by the Hoechst AG process

Advantages of the Hoechst process

☐ Low capital investment costs

☐ Simple operation, high operational reliability

☐ High product quality, i.e. ClO_2 solution with low Cl_2 and HCl contents

Consumption figures

per kg ClO, 100 %

$NaClO_3$	100 %	1.69	kg
SO_2	100 %	0.63	kg
H_2SO_4	100 %	1.8–1.9	kg
Electric power for motors		0.010	kWh
Steam (3 bar)		0.5	kg
Cooling water		0.050	m^3
Soft water for ClO_2 absorption (4 °C)		0.17 m^3 at 6 g ClO_2/l	

Product qualities

Temperature of absorption water	ClO_2 content in g/l
3 °C	8
4 °C	6

Personnel requirement

for the entire plant	1 man per shift

The Hoechst AG process for the production of chlorine dioxide is based on the conversion of sodium chlorate in a sulphuric acid solution by means of sulphur dioxide according to the following gross reaction equation:

$$2NaClO_3+SO_2 \rightarrow 2ClO_2+Na_2SO_4$$

Apart from this main reaction, various side reactions take place which produce chlorine or chloride instead of chlorine dioxide and result in yield losses (chemical losses). Further losses occur due to unused chlorate leaving the system with the reaction solution (effluent losses).

With the Hoechst AG process, the reactions which have a reducing effect on the yield are suppressed to a large extent, so that, under correct operating conditions, chlorine dioxide yields of 92–94 %, referred to the total sodium chlorate input, can be achieved.

Process description

The plant mainly comprises a scrubbing vessel, a main reactor, a final reactor and a purge column.

The reactants, namely concentrated sodium chlorate solution and sulphuric acid are fed to the scrubbing vessel in order to remove the unconverted sulphur dioxide and the hydrochloric acid from the gas mixture produced in the main reactor and the final reactor. After leaving the scrubbing vessel, the reaction solution flows first into the main reactor and then into the final reactor.

A mixture of air and sulphur dioxide is fed into these two reactors in order to reduce the chlorate to chlorine dioxide. The solution from the final reactor flows to a purge column, in which dissolved chlorine dioxide and sulphur dioxide are simultaneously removed by means of air.

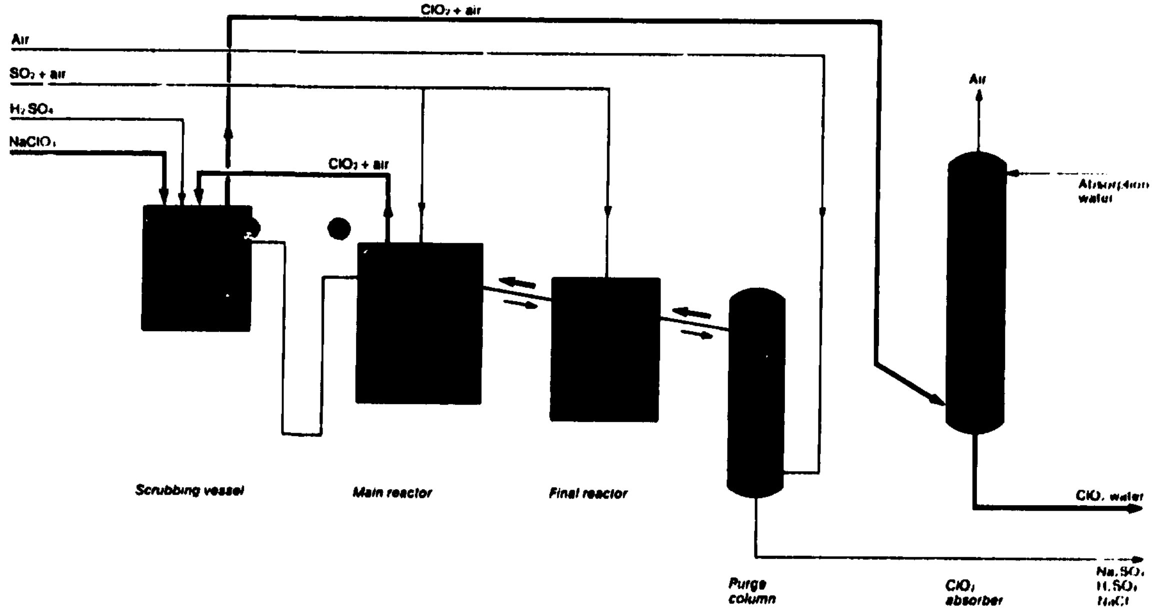
The solution leaving the purge column has the following composition:

Na_2SO_4	220	g/l
H_2SO_4	450	g/l
NaCl	3–4	g/l
$NaClO_3$	1.0	g/l

This solution can be used for the recovery of tall oil.

The air dilution rate of the gaseous SO_2 and the air feed to the purge column are adjusted such that the gaseous mixture produced contains approx. 10–12 % by vol. chlorine dioxide and 0.2–0.25 % by vol. chlorine. The gaseous mixture is fed to a spray-type absorption column. If absorption water with a temperature of 3–4 °C is used, the concentration of the chlorine dioxide solution will be 6–8 g ClO_2/l.

ClO_2 plant using the Hoechst AG process



Chlorine, sodium hydroxide, sodium hypochlorite
Uhde membrane-cell electrolysis

For membrane electrolysis plants with their various plant sections, Uhde not only has its own longstanding experience in the engineering and commissioning of alkaline chloride electrolysis plants to draw on, but also has access to the operating experience and research of Bayer AG and Hoechst AG in this field. Uhde has the following membrane cells and cation exchange membranes at its disposal.

Membrane cells:

Uhde monopolar cells (MM)
Uhde/Hoechst bipolar cells

Cation exchange membranes:

Flemion (Asahi Glass)
Nafion (Du Pont)

Bipolar cells

In bipolar cells, the power flows parallel to the cell axis, in other words the power flows from one electrode through a partition to the electrode with opposite polarity of the next element.

The Uhde/Hoechst-type cells consist of metal elements, the membrane being clamped between the cathodic and anodic half shells. The individual elements are pressed together in a frame to conduct the electric power.

Features of the Uhde/Hoechst bipolar membrane cell

☐ Available in different sizes from 1 m² to 2.8 m² per cell element (active anode surface).

☐ This cell technology was developed, starting in 1975, by Hoechst AG/Frankfurt.

☐ Anode half shell made entirely of titanium, cathode made entirely of stainless steel or nickel.

☐ No electrical connections inside the electrolytic cell.

☐ Each cell element is sealed with the aid of a separate flange, which is a special advantage compared to filter-press-type cells and this permits quick installation and reassembly of individual cell elements.

☐ In contrast to other monopolar and bipolar cells, if a membrane of one cell fails, it is not necessary to disassemble the complete cell stack. This is a unique advantage of our bipolar cell, resulting in high on-stream factors even during membrane exchange or other maintenance operations.

☐ Recoating of anodes is easily accomplished without any welding or cutting procedures.

☐ Capacity can be increased at a later date by adding cell elements.

☐ Cathodes are available with special coating.

Bipolar cells are particularly suitable for small to medium plant capacities. The low amperage of this type of cell has a favourable effect on the investments for the DC power supply system, especially in the case of low plant capacities. This type of cell is also suitable for converting older electrolysis plants, which are often supplied with power from several low-amperage rectifier units.

Advantages

Safe design:

☐ Functional components located outside reaction chamber

☐ Individual vessels, reliable leakage detection

☐ Time-proven conventional materials of construction

☐ Low risk of blockages at the inlet

High layout flexibility:

☐ Parameters:
area per element,
current density,
number of elements
per electrolyzer

☐ Capacity easily increased

Ease of operation:

☐ Simple monitoring of individual cell voltages
- by operator or
- automatically

☐ Electric contacts easily accessible

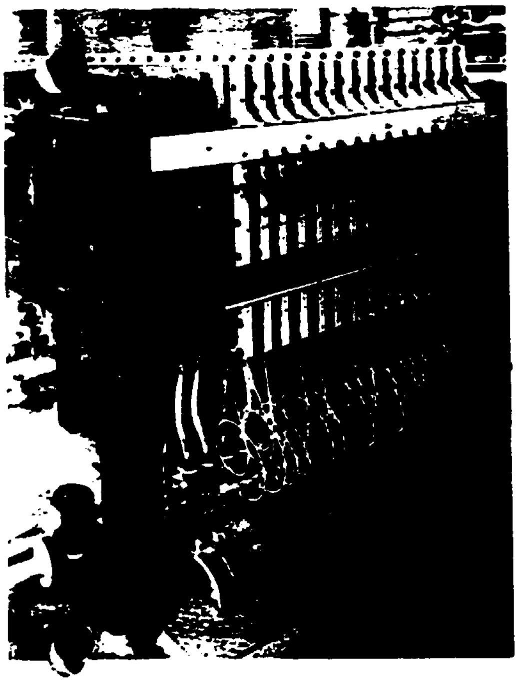
Operating data:

NaOH concentration	up to 35 % (by wt. depending on type of membrane)
Power consumption:	2100–2400 kWh/t NaOH at 3 kA/m² (depending on cathode and membrane material)
Service life of membrane:	2–3 years
Lifetime of electrode activity:	>5 years

Product quality:

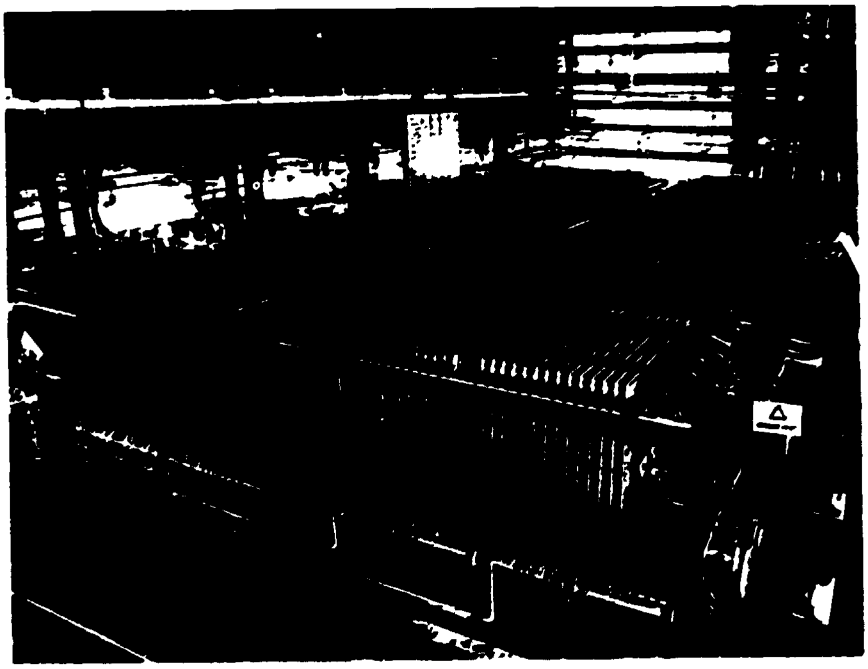
Caustic soda solution	
NaOH	up to 35 % (wt.)
NaCl	< 100 ppm (referred to 100 % NaOH)
Gaseous chlorine	
Cl_2	> 97 % (vol.)
O_2	~ 2 % (vol.)
H_2	< 0.05 % (vol.)
Hydrogen	
H_2	99.9 % (vol.)

Uhde/Hoechst bipolar membrane cell 2.7 m² (15 elements), Hoechst AG, Frankfurt



Monopolar membrane cells, ROCHE PRODUCTS/Scotland

- ☐ Few units
- ☐ Few electrolyzer blocks
- ☐ Individual cells can be replaced easily
- ☐ Low costs for spares
  - Few elements
  - Few components per unit of capacity
- ☐ Low production losses in the event of cell replacement
- ☐ No high-current switch



Bipolar membrane cells Tofte Cellulosefabrikk/Norway

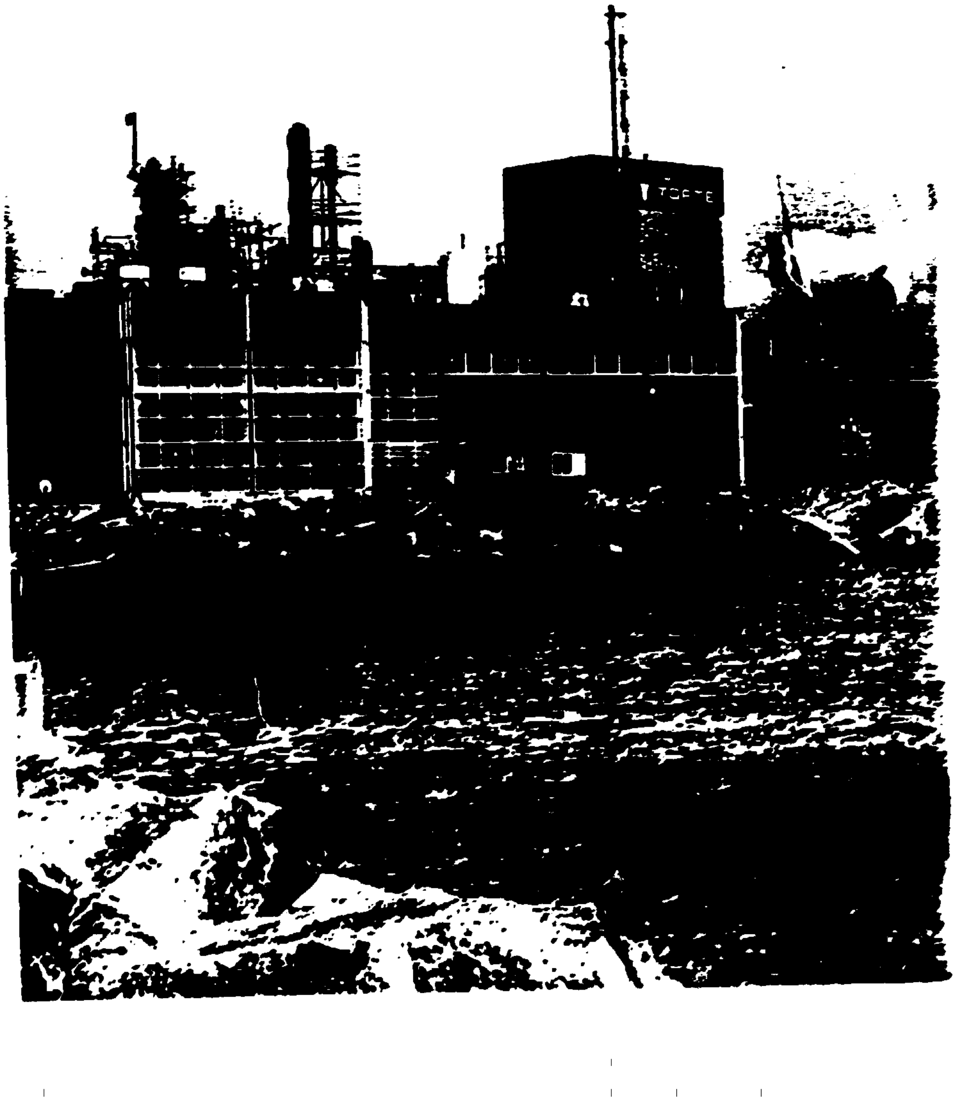
Uhde membrane electrolysis plants

□ Since 1981, Tofte Cellulosefabrikk A/S & Co. at Tofte in Norway has been operating the first complete membrane electrolysis plant to be designed and constructed by Uhde.

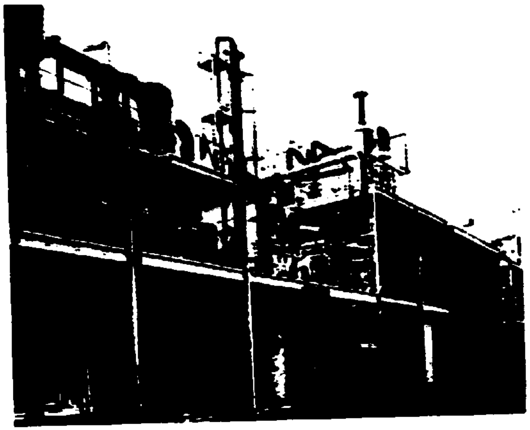
The plant has a capacity of 40 tpd chlorine and is equipped with 5 blocks of bipolar cells.

Uhde completed the plant only 13 months after signing the contract. The plant went on stream with consumption figures which are even more favourable than the guaranteed figures.

□ Uhde has designed and constructed a membrane electrolysis plant for the production of bleaching liquor for Messrs. Hoffmann-LaRoche AG. The plant, which is located at Dalry, Ayrshire/Scotland, has a capacity of about 70 tpd chlorine. It is equipped with 28 monopolar cells working at a maximum load of 80 kA. Commissioning started at the end of 1983.



View of the membrane electrolysis plant for Tofte Cellulosefabrikk in Norway



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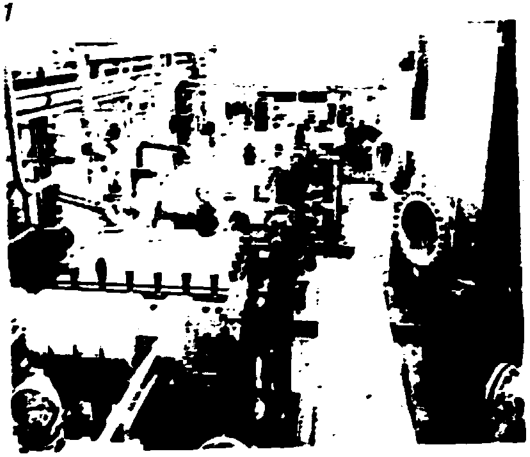

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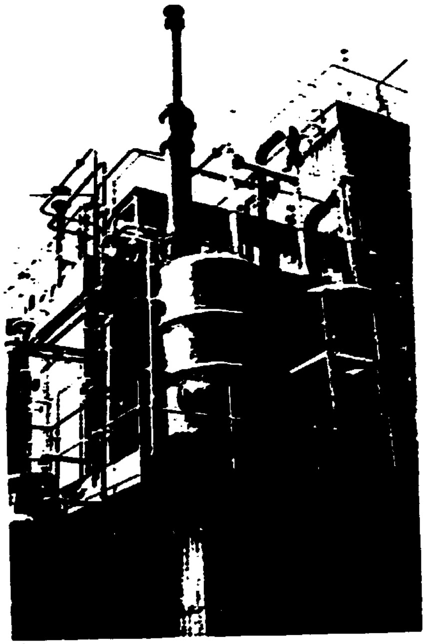

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1) Chlorine treatment and hypochlorite plant, Tessenderlo/Belgium

2) Secondary brine purification plant (filters and ion exchangers), ROCHE PRODUCTS/Scotland

3) Hypochlorite plant, SCHWEIZERHALL/Switzerland

4) Ion exchangers in a pilot plant, BAYER AG/Germany

Combination of membrane cell electrolysis and Uhde/Munich process

Chlorine dioxide, chlorine, sodium hypochlorite and sodium hydroxide, which are the most important bleaching chemicals for the cellulose industry, can be produced together very economically in a combined plant comprising an alkaline chloride electrolysis plant using the membrane process and a chlorine dioxide plant using the Uhde/Munich process. This is because some process units, for example the HCl synthesis unit and the waste gas dechlorination unit, can be used for both the chlorine dioxide plant and the alkaline chloride electrolysis plant.

The excess hydrogen can be used as fuel for generating steam.

Uhde's combined process offers the following:

☐ simultaneous production of bleaching chemicals: chlorine dioxide, chlorine, hypochlorite or caustic soda and hydrogen;

☐ the only feedstocks are common salt and electric power;

☐ it is particularly economical because some process units can be used for both processes jointly;

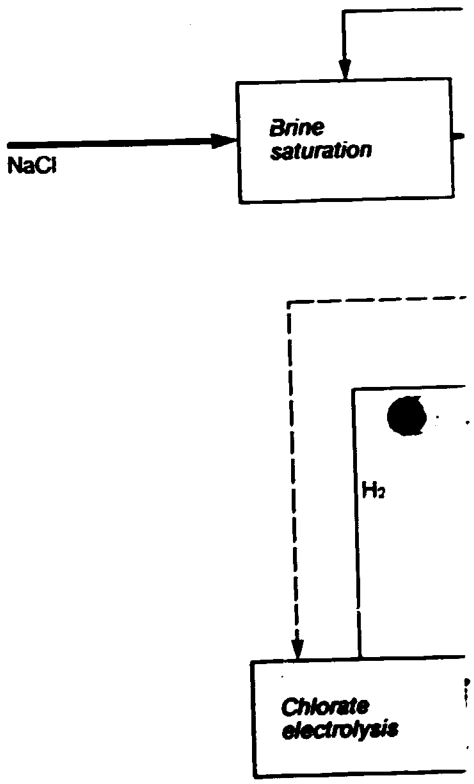
☐ high adaptability to the desired chemical balance;

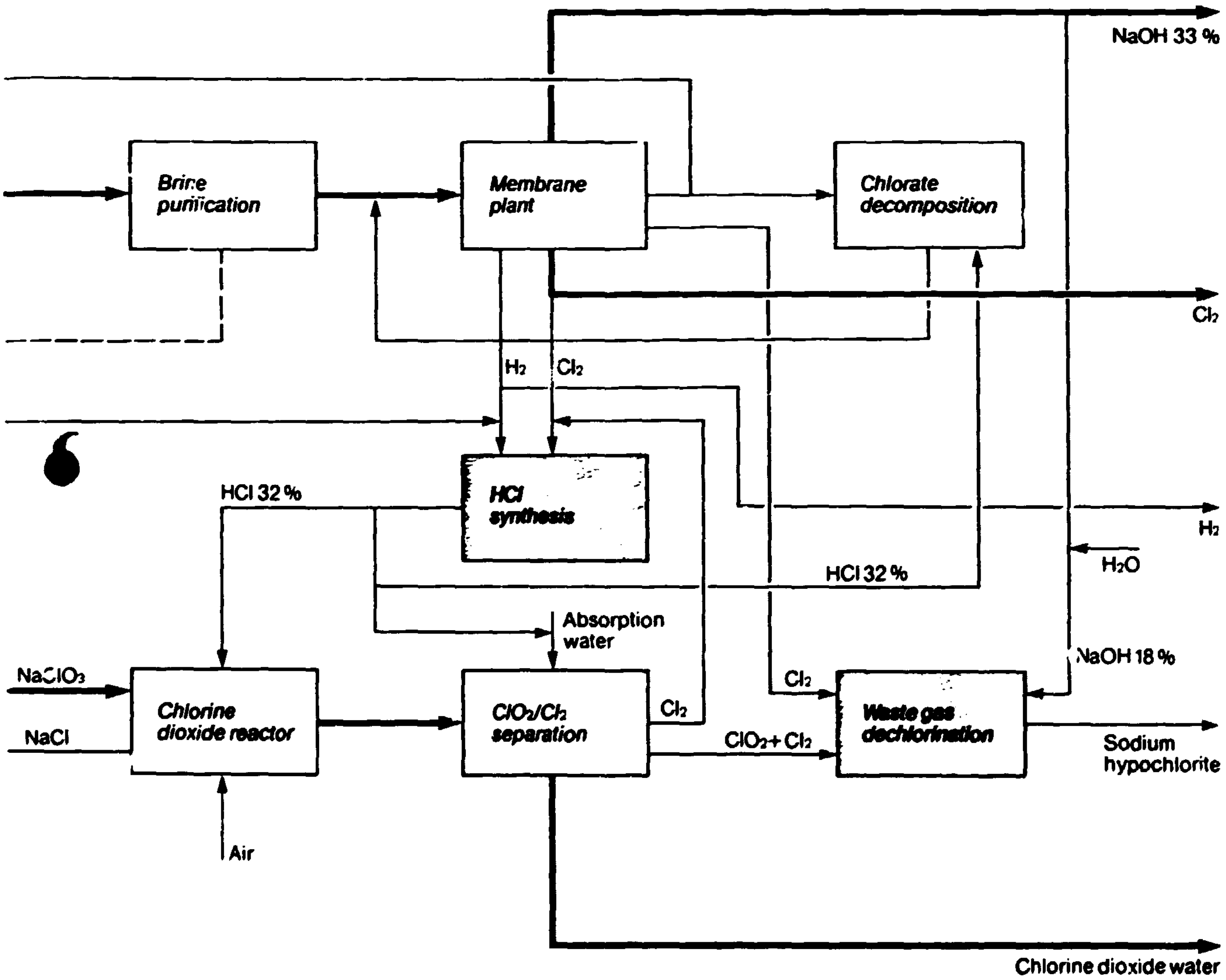
☐ no transport of hazardous and/or diluted chemicals;

☐ process well-proven in practice.

12 tpd ClO_2 plant by the Uhde/Munich process, SAPPI/South Africa

Combination of membrane cell electrolysis and Uhde/Munich process




NaOH 33 %
Brine purification
Membrane plant
Chlorate decomposition
Cl₂
H₂
Cl₂
HCl 32 %
HCl synthesis
H₂
H₂O
HCl 32 %
Absorption water
NaClO₃
NaCl
Chlorine dioxide reactor
ClO₂/Cl₂ separation
Cl₂
Cl₂
NaOH 18 %
Waste gas dechlorination
ClO₂+Cl₂
Sodium hypochlorite
Air
Chlorine dioxide water

UHDE

Design and construction
of chemical and
other industrial plants

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- Refineries
- Syngas and synthesis processes
- Gas purification
- Coal technology
- Fertilizer
- Foodstuffs
- Biotechnology
- Breweries
- Plastics
- Synthetic fibres
- Organic chemicals
- Pharmaceuticals
- Cosmetics
- Electrolysis processes
- Nuclear technology
- Electrothermal processes
- Environmental protection
- Miscellaneous processes
- Civil engineering and erection
- Energy supply systems
- Infrastructure

Uhde GmbH –
a member of the Hoechst group

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ATTACHMENT VIII

Norsk Hydro
Aluminium, Magnesium

›rsk Hydro Group companies and sales offices, ɹminium Division:

way:
sk Hydro a s Karmoy Fabrikker, Karmoy.
sk Hydro Aluminiumprofiler a.s, Magnor.
:able A'S, Havik, Karmoy.

den:
sk Hydro Sverige AB, Stockholm.
nska AB Eloxal, Tyreso.

mark:
k Hydro Danmark a s, Glostrup.
der Aluminium ApS, Tonder.

ria:
niniumwerk Nenzing GmbH, Nenzing

ermany:
Aluminium GmbH & Co., Berlin
k Hydro a s. Verkaufsorg. fur Hutten-
minium, Bad Durkheim

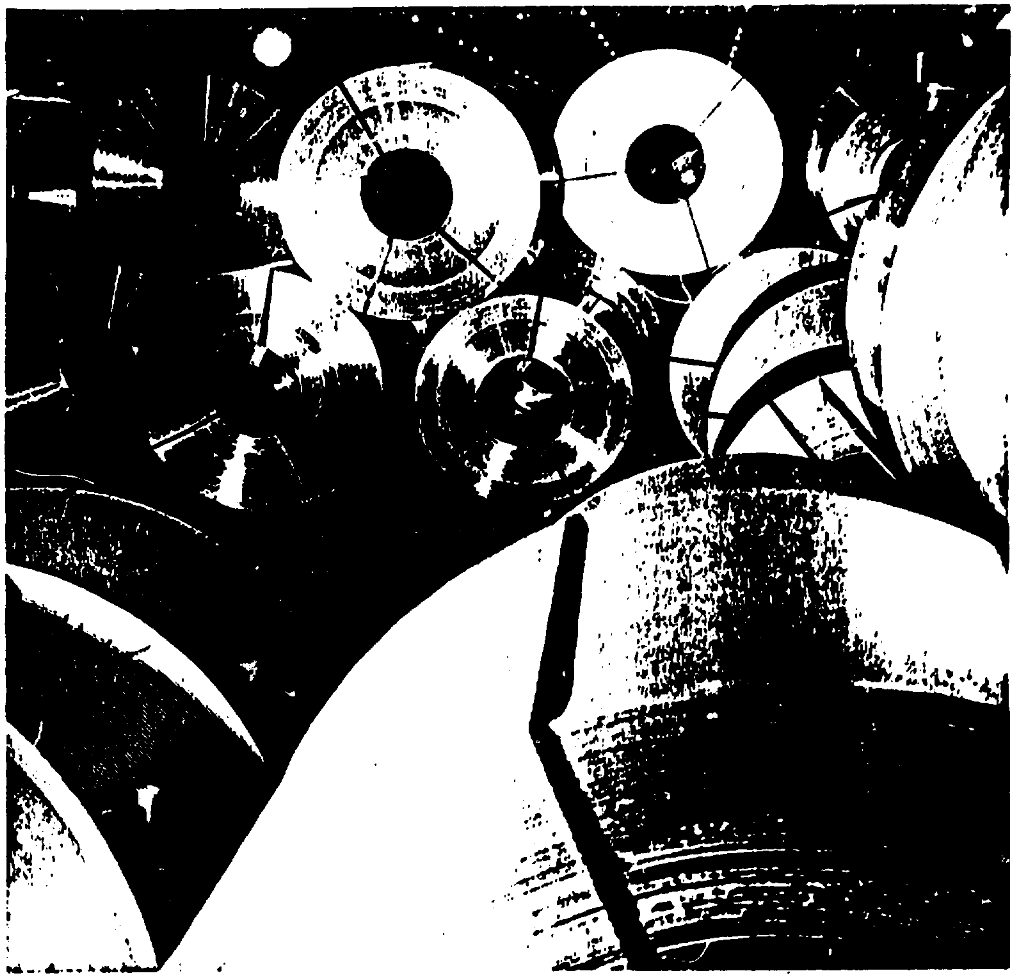
UK:
Norsk Hydro (U.K.) Ltd., Feltham, Middx.
Aluminium Precision Extruders Ltd.,
  Bedwas, Newport, Mon.
Ashley Aluminium Ltd., Winsford, Cheshire.
Alustock Ltd., Feltham, Middx.
Aluminium Packaging Ltd.,
  Blackmill, Bridgend.
Viking Alloys Ltd., Manchester.

France:
Alunord s.a., Louviers.
Alustock s.a., Le Mesnil-Longpont s/Orge.

Belgium:
Hydalu s.a., Seneffe.

Switzerland:
Noralu AG, Dübendorf.

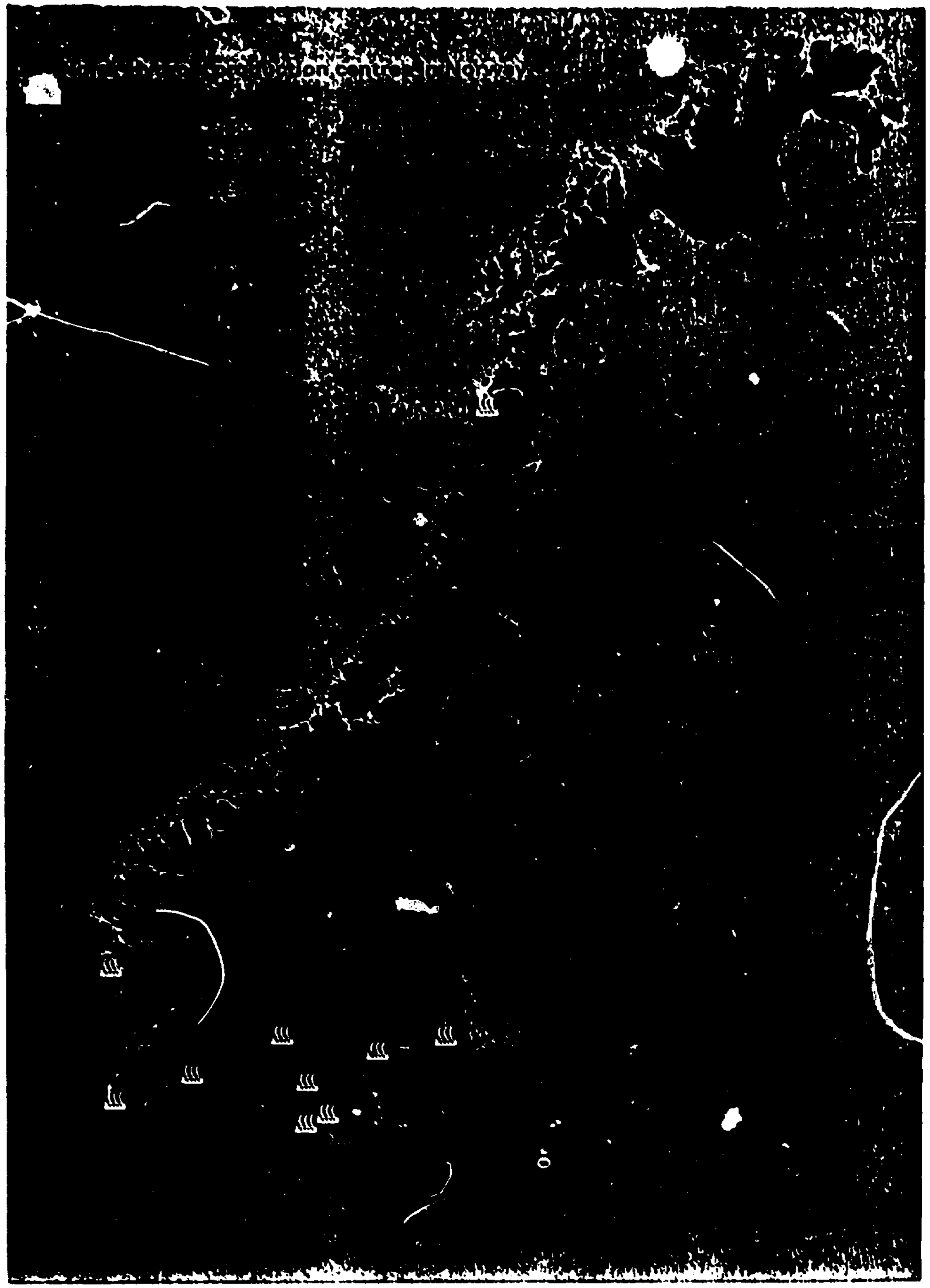
Grondahl & Son Trykkeri A s
2 77 8000

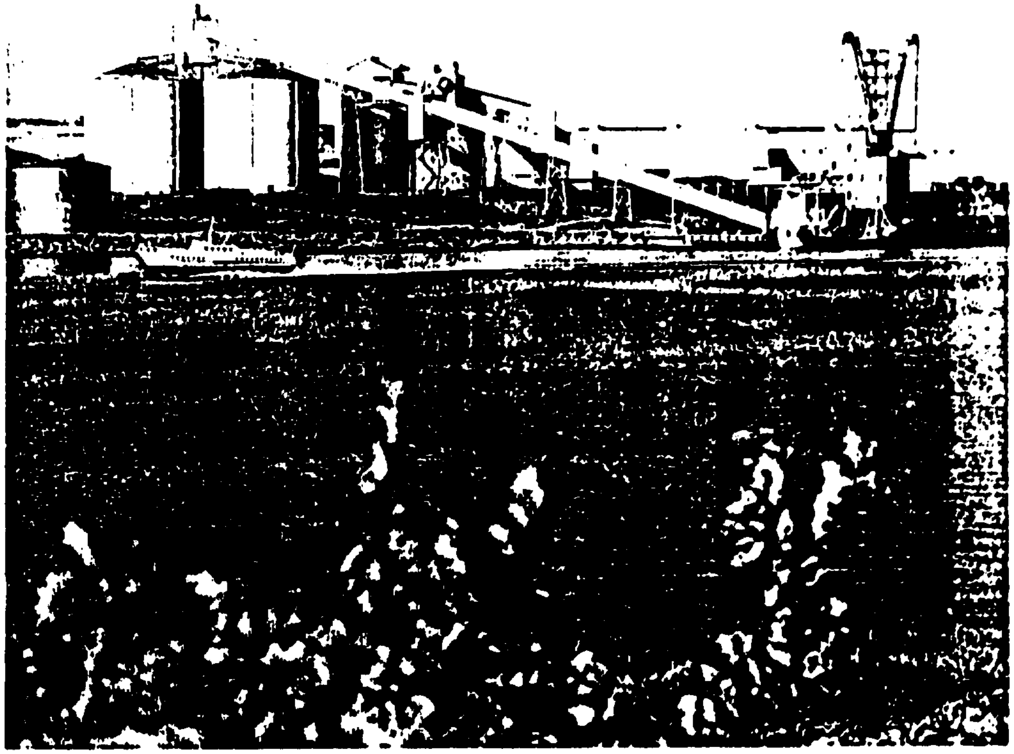


Aluminium

Attachment VIII

A Norsk Hydro Booklet





The aluminium plant at Karmoy helped to provide a broader base both for Norsk Hydro and the local community

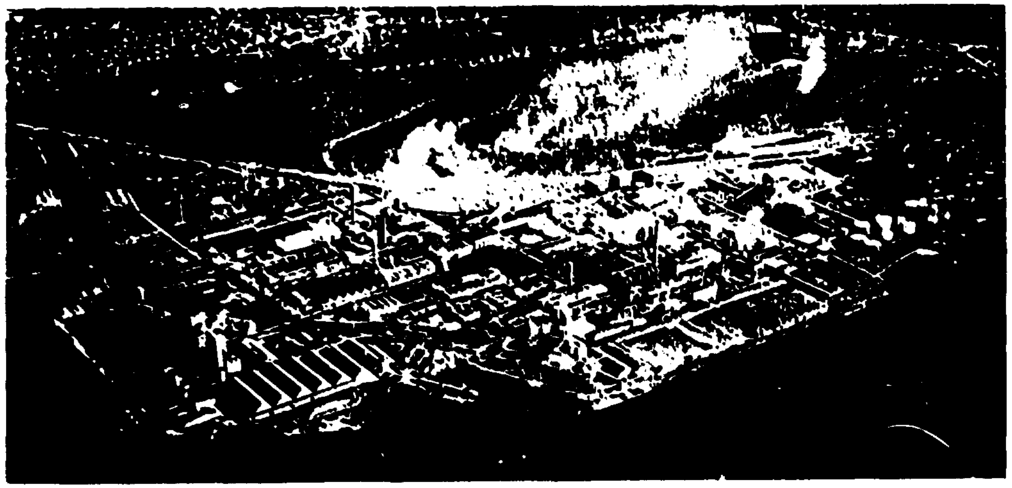
The role of aluminium in Norsk Hydro

Norsk Hydro is active in several fields of industry. The two most commonly associated with our name are fertilizers and oil, and it is often forgotten that we are also a major producer of light metals. In this booklet we describe our aluminium operations, and the part they play in relation to our other products.

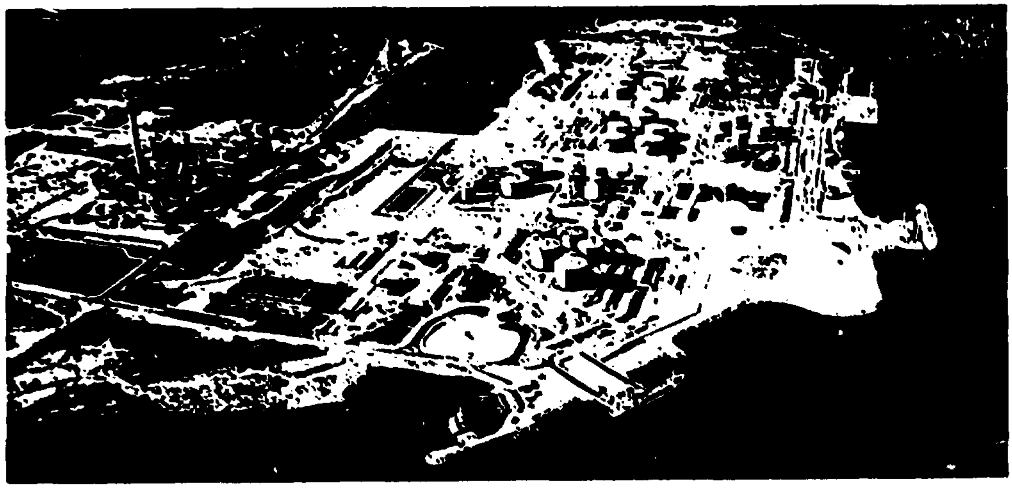
In Norsk Hydro we have sought to disversify our activities, in order to make us better able to weather the fluctuations of world trade and thus help make our operations and the jobs in our factories less vulnerable to economic pressures.

The hydro-electric power for our aluminium production has its source in the Roldal-Suldal catchment area in the counties of Hordaland and Rogaland in western Norway. In the 1960's there were few jobs available in northern Rogaland and many people were commuting seasonally, between Karmoy, a district of Rogaland, and the coastal fishing banks of the USA. What they really wanted, however, was to live and work at home in Karmoy.

Thus the interests of the region and Norsk Hydro were both served by the decision in [illegible] to build an aluminium plant at Karmoy. In [illegible] the Prime Minister at the time, Per Borten, formally switched on the power at our Karmoy plant.



At its Porsgrunn plant Norsk Hydro produces a wide range of products including fertilizers, PVC, magnesium and industrial chemicals



At Mongstad Norsk Hydro owns a 1,750 acre industrial site. The first development project, the Rafinor oil refinery, was completed in the summer of 1975

The Norsk Hydro Group

In Norway, Hydro has production plants at Karmoy, Rjukan, Notodden, Porsgrunn and Glomfjord. We also participate in the oil refinery at Mongstad and are now building a petrochemical complex at Rafnes in southern Norway in partnership with two other Norwegian companies. The Group has over 10,000 employees and makes over 50 different products. Synthetic fertilizers, oil and aluminium have already been mentioned, and to these must be added magnesium, petroleum products, the plastics raw material PVC, industrial chemicals, electric power, mechanical engineering products and laminates

Hydro at Karmøy

The Karmoy plant, with 1,200 employees, is Norsk Hydro's next largest production site.
The aluminium plant came on stream in 1967. The capacity for primary aluminium is currently 120,000 tonnes a year, most of which goes to the Group's own semi-fabricating facilities at Karmoy and elswhere in Norway and abroad.

There are today two cell buildings at Karmoy, but site preparations have already been made for the addition of two more and an expansion of our reduction capacity is being planned. This is desirable for two main reasons; it will make us more competitive in the long term and will help to safeguard jobs in the plant.

At Karmoy Norsk Hydro has an industrial site of 550 acres. The aluminium plant takes up about 175 acres.

Karmøy

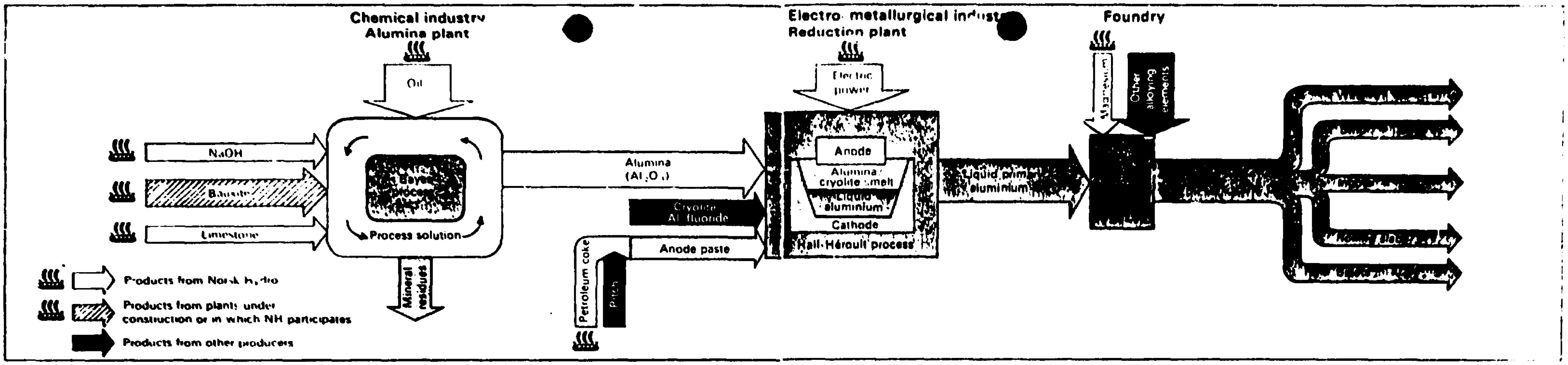
The district of Karmoy comprises both the island of Karmoy and a mainland strip on the other side of the Karmsund sound south of Haugesund. It has 30,000 inhabitants, and judged by population is the largest district of north Rogaland.

Until the mid-1960's the economic life of the community was dominated by farming, fishing and seafaring. However, structural changes led to a surplus of labour locally. The district needed new jobs and a more varied economic base.

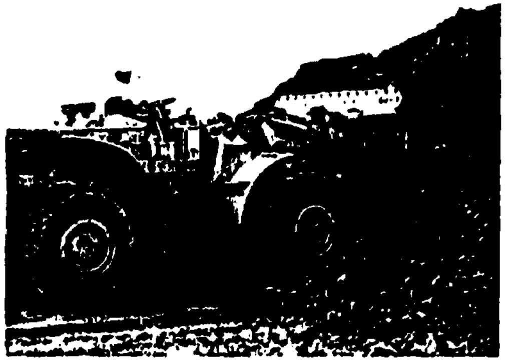
This is the background for the enthusiasm with which Norsk Hydro's plans were received in 1963 when the company announced that it had decided to build an aluminium plant at Karmoy. Several factors had influenced Hydro's choice of location.

Experience from other industrial sites in Norway indicated that it would be wise to avoid a situation where the new plant dominated the local community. This was why Hydro undertook the extra investment needed to transmit the power from the Roldal-Suldal area out to the coast where a new plant would be more easily absorbed by the surroundings without causing too great changes in the population pattern and the way of life of the inhabitants.

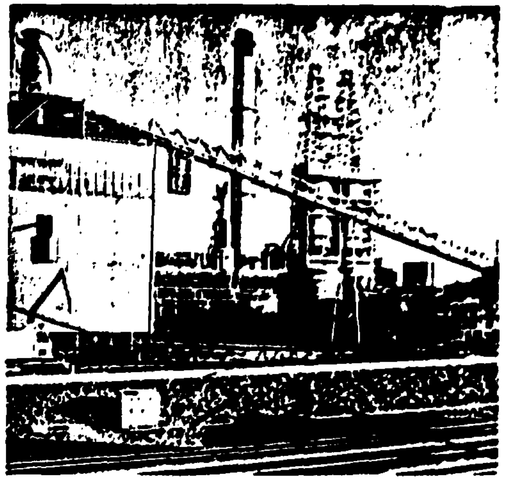
At Karmoy, moreover, labour was available, plenty of land was earmarked for industrial development, and an ice-free harbour could be built



The Roldal-Suldal project comprises five power stations. They generate each year around 2.5 thousand million kilowatt hours, st of which goes to the Karmoy plant.



Mining bauxite. Bauxite is usually found in the form of loose rock which is easy to take out.



The petroleum coker at Mongstad makes us self sufficient in this important raw material for aluminium production.

Production of aluminium

The production of aluminium takes place in several stages:

- the mining of bauxite
- the extraction of aluminium oxide
- the production of primary aluminium
- the production of semi-fabricated products
- the production of finished goods
- the remelting of aluminium scrap.

Norsk Hydro's aim is to expand its aluminium activities to include several of these steps. This will make us less dependent on others and strengthen our competitiveness.

Electric power

Norsk Hydro has always been a large manufacturer of fertilizers. Originally this production was based on hydro-electric power, and as a result Hydro's later development has been as a power-processing company. The industrial utilization of electric energy will continue in the future to be one of the mainstays of our activities.

The production of primary aluminium requires large quantities of electricity. When the method of producing ammonia for fertilizers by the electrolysis of water was superseded by petrochemically based ammonia, this freed electric power and put Hydro in a position to realise its long-standing plans to start aluminium production.

Bauxite

Bauxite is a type of clay which contains aluminium oxides. The biggest bauxite deposits are found in Africa, Australia and in Central and South America.

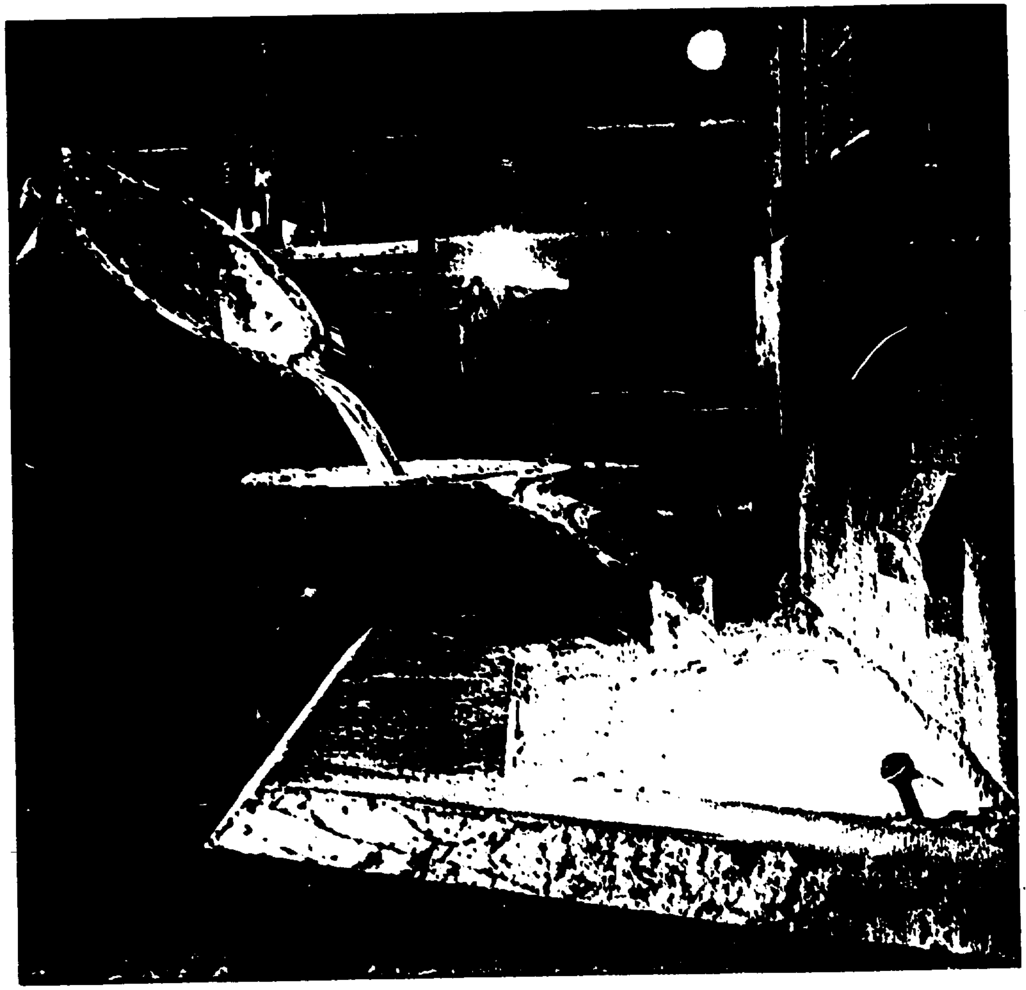
The aluminium industry is at present dependent on bauxite, which is the basis for the industrial production of the intermediate product, alumina, from which primary aluminium is obtained.

Norsk Hydro has an interest in a mining company in the Amazon region in Brazil, in an area where deposits of around 500 million tonnes of bauxite of good quality have been proven.

Petroleum coke

Petroleum coke is one of the auxiliary materials used in aluminium production. The annual consumption at Karmoy is around 55,000 tonnes, and formerly this had to be bought from abroad.

Petroleum coke is now made at the Mongstad refinery in western Norway in which Hydro has a share, and which is able to supply both the Karmoy plant and other Norwegian aluminium producers. Mongstad can produce 160 000 tonnes of petroleum coke a year.



From the electrolytic reduction cells the metal is taken in large crucibles to the foundry

Primary aluminium

Aluminium oxide, or alumina, is the most important raw material in the production of primary aluminium. The oxygen is separated from the aluminium metal in electrolytic reduction cells by a process called electrolysis. The alumina is dissolved in a bath of cryolite at a temperature of about 960°C. A strong electric current passes through the cryolite bath and splits the alumina into aluminium and oxygen.

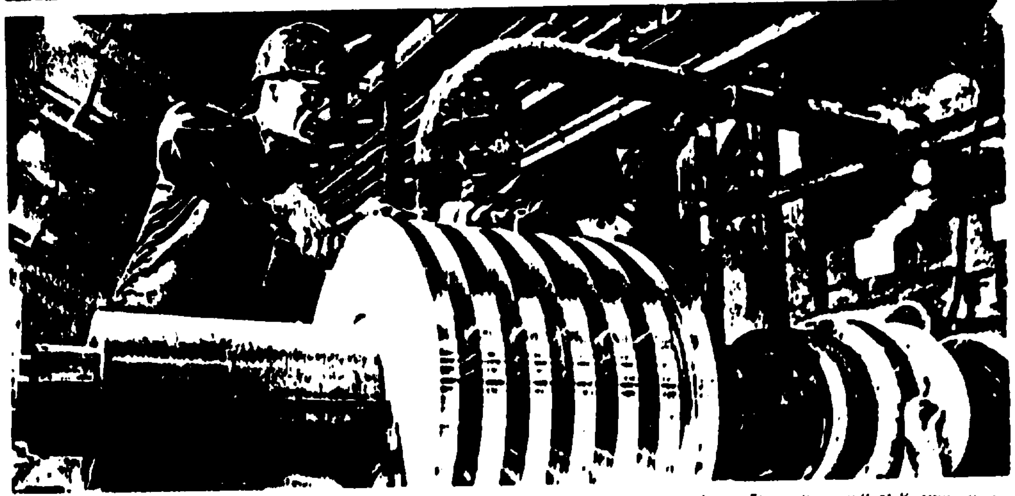
The liquid metal is tapped from the cells and taken to the foundry. To produce one kilogramme of aluminium it takes two kilogrammes of alumina, about half a kilogramme of anode paste, 70 grammes of cryolite and 70 grammes of aluminium fluoride, and 14 to 18 kilowatt hours of electric energy.

At Karmoy the electrolysis process takes place in two large buildings, each almost a kilometre in length, containing 340 cells which can produce about 300 tonnes of primary aluminium a day.

New technology

A project aimed at improving process control and cell design and output is being carried out. The project combines computer-based process simulation with external, purchased technology.

From one of the cell buildings at Karmoy. The white powder is alumina (aluminium oxide) which is dissolved in the cells and broken down into aluminium and oxygen.



Aluminium is easy to form. The rolling mill at Karmoy [illegible] sheet and strip

The foundry

In the next stage most of the liquid primary aluminium taken from the cells goes into melting furnaces in the foundry, where the metal is refined and alloying elements are added in order to achieve the desired composition. One widely used alloying element is magnesium, which is also a Hydro product.

From the melting furnaces the metal flows first to casting furnaces and then to casting machines which form it into ingots, extrusion billets, rolling slabs, wire bars and rod, and cast coils.

The foundry is also equipped with a large induction furnace for melting scrap.

The rolling mill

In the rolling mill part of the metal is made into sheet and strip in different alloys, sizes and thicknesses. The capacity is about 25 000 tonnes year, depending on the product mix.

The cast coils of 6.5 mm thick aluminium from the foundry are passed through a rolling mill and for each pass the thickness is reduced by 30 to 4 per cent. When the products have been levelled, trimmed and slit into strip or cut into sheets, they undergo a thorough quality control before being packed for transport.

The extrusion plant at Karmoy can make over 5,000 different profiles and tubes

The die opening is cut out and filed with great precision. The die workshop has its own drawing office

The extrusion plant

The raw materials for the presses are cylindrical ingots, or billets, from the foundry. These are put into the press, heated to 400-600°C, and pressed through a die opening which corresponds to the shape of the final profile or tube.

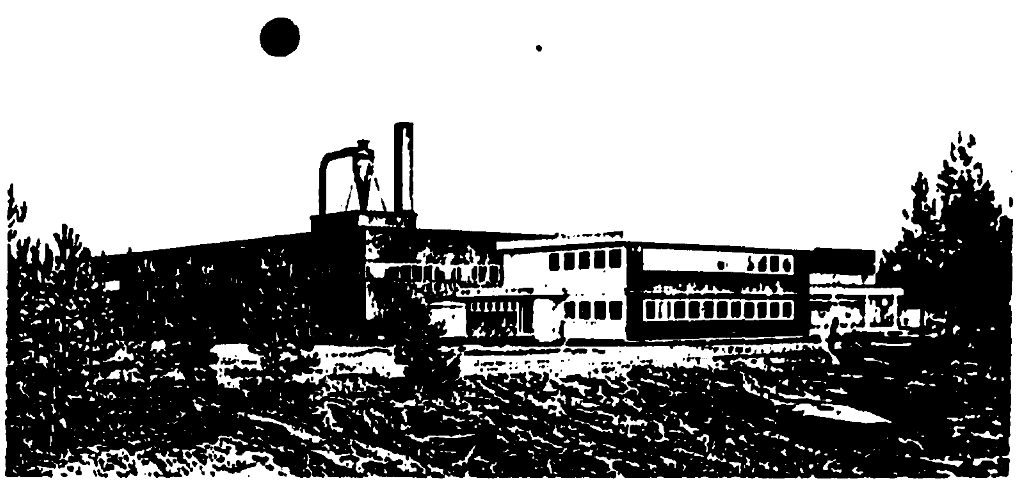
The die workshop, where the dies for the various profiles are made, is a vital part of the extrusion plant.

In full operation the plant has a capacity of around 10,000 tonnes of profiles a year.

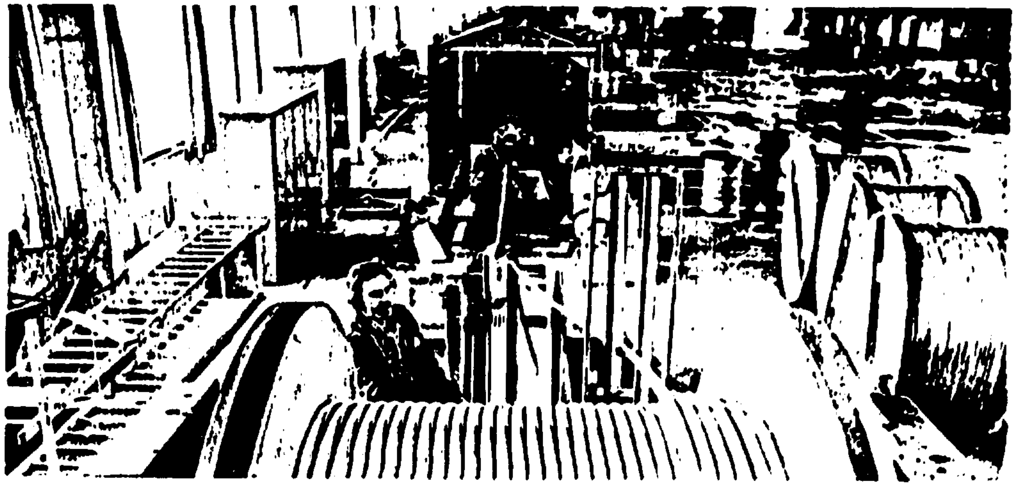
The profiles can be anodised to give them a surface coating in several colours. This is an electrochemical process and also makes the metal more corrosion resistant.

Profiles from Karmoy are mainly used in the ship-building, building and electrical industries, and in the transport sector.

Both standard and special profiles are made. The extrusion plant can supply whole systems of special profiles to meet the customers' particular requirements, and designs are developed in close co-operation with the customer.



The extrusion plant at Magnor lies close to the Swedish border. It makes aluminium profiles for the Norwegian and Swedish markets



Aluminium is a good conductor of electricity and is [illegible] power lines. Norcable at Karmoy makes both conductor [illegible] and cable cores

The extrusion plant at Magnor

Norsk Hydro Aluminiumprofiler, the extrusion plant at Magnor, supplies profiles mainly to Eastern Norway and the Swedish market. The plant was started up in 1972 with one 1,600 tonne press with a capacity of 3,500 tonnes of profiles a year. The billets which are its raw material come from Karmoy. Some of the profiles produced are put through further manufacturing processes, and anodising facilities are now being built.

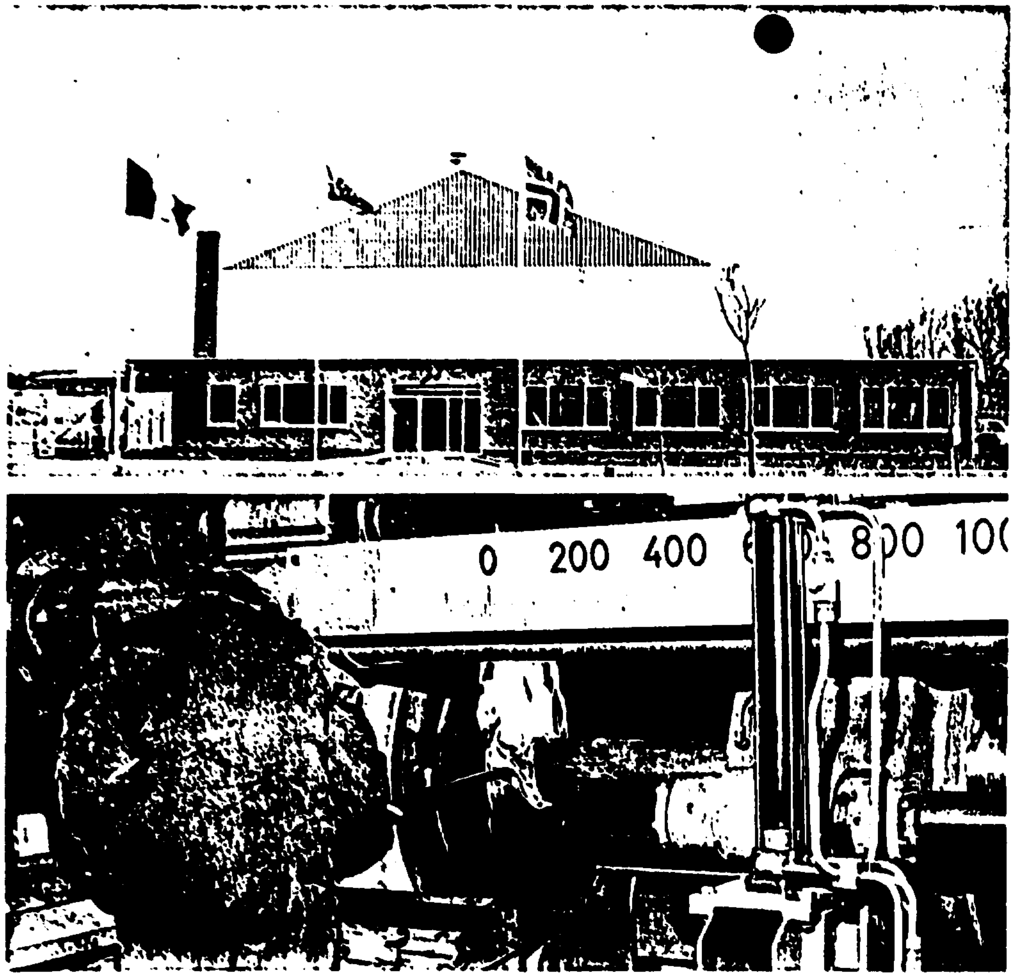
The company has about 100 employees.

Norcable

Norcable is a semi-fabricating facility adjacent to the Karmoy plant and is owned jointly by Standard Telefon og Kabelfabrik (STK), the Norwegian subsidiary of ITT, and Norsk Hydro.

The company was started in 1973 and uses wire rod from the foundry at Karmoy. Norcable has two main products: cable cores which are supplied to STK's factory in Oslo, and conductor cable for transmission lines.

Norcable has an annual capacity of about [illegible] tonnes.



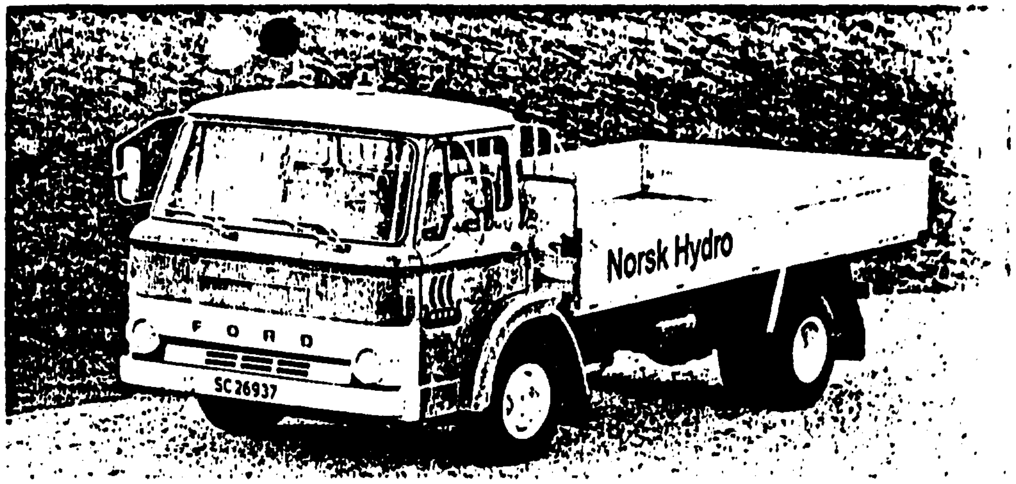
Norsk Hydro has built extrusion plants in Britain, France, Belgium, West Germany, Austria and Denmark. The pictures show Hydalu in Belgium

Semi-fabricating facilities abroad

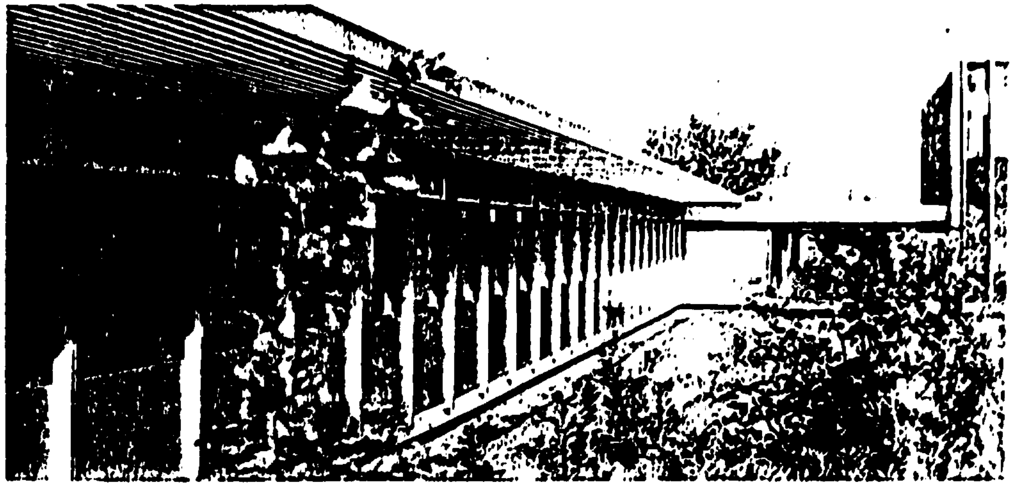
The major aluminium producers of the world are engaged in all stages of the production process. The free market for primary aluminium is therefore limited, and a producer who wants to maintain his independence and secure outlets for his products must fabricate a large part of the metal himself. From the outset Norsk Hydro planned to process its primary metal in its own semi-fabricating plants. Economic factors make it necessary to carry out some of this fabricating close to the customer. Production can then also be tailored to suit the market it will serve, and it is easier to maintain the close contact with customers needed for many semi-fabricated products.

In the United Kingdom Norsk Hydro has two extrusion plants, Aluminium Precision Extruders Ltd. near Caerphilly, and Ashley Aluminium Ltd. in Cheshire. We also have a stockist company for extruded and rolled products, Alustock Ltd., with offices and warehouses covering the whole of Britain. Hydro has a factory making foil containers for the food packaging industry, Aluminium Packaging Ltd., and an interest in Viking Alloys Ltd., which makes aluminium rod and wire. There is a sales department for aluminium products at the Norsk Hydro group office in Feltham.

In France Hydro owns Alunord s.a., an extrusion plant in Louviers, and Alustock s.a., a stockist for extruded and rolled products with warehouses outside Paris and Lyons.



The platform of this lorry is aluminium.



Aluminium is increasingly used as a building material

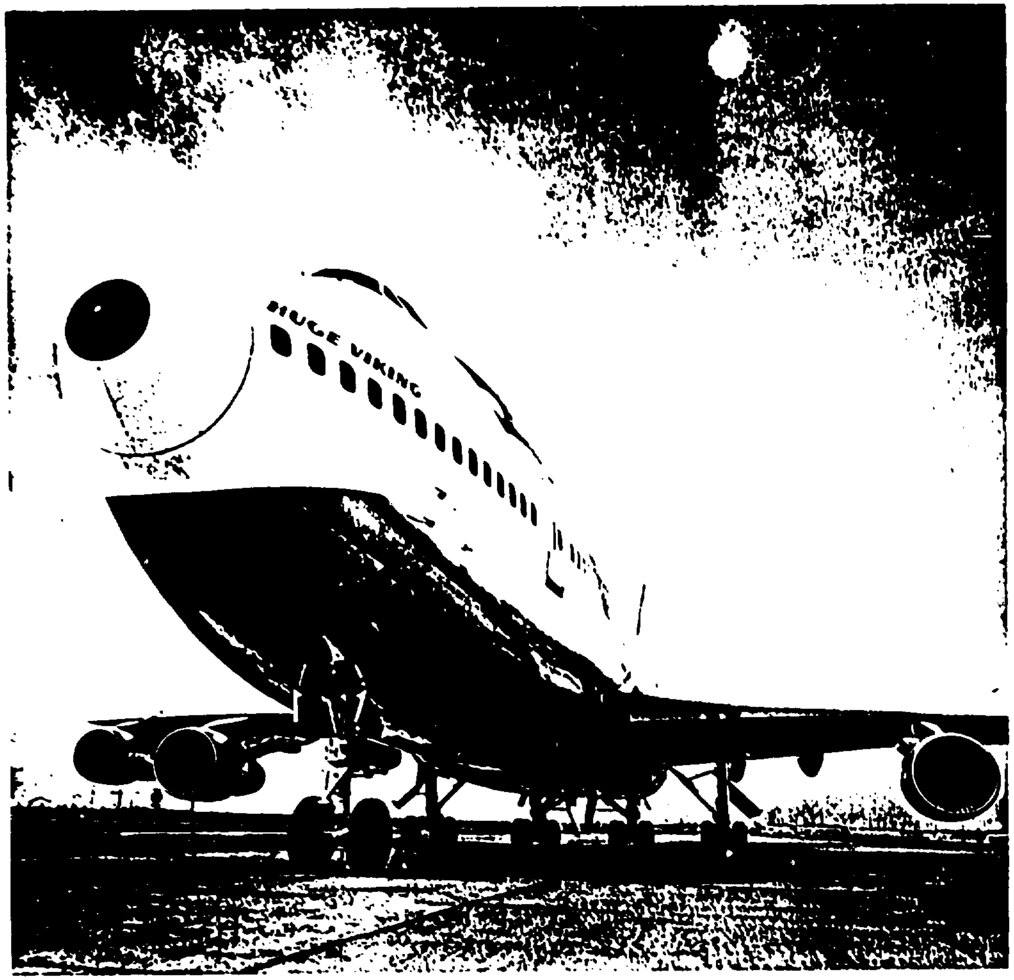
Hydro also has extrusion plants in Austria, Aluminiumwerk Nenzing GmbH, in West Germany, BAG Aluminium GmbH, in Denmark, Tonder Aluminium Aps, which specialises in making close tolerance tubes for the car industry and various other applications, and in Belgium, Hydalu s.a. which makes aluminium conductors. In addition we have sales offices in Sweden and Denmark.

All our semi-fabricating plants are backed up by the expertise and research and development facilities of the Karmoy plant and the Hydro group.

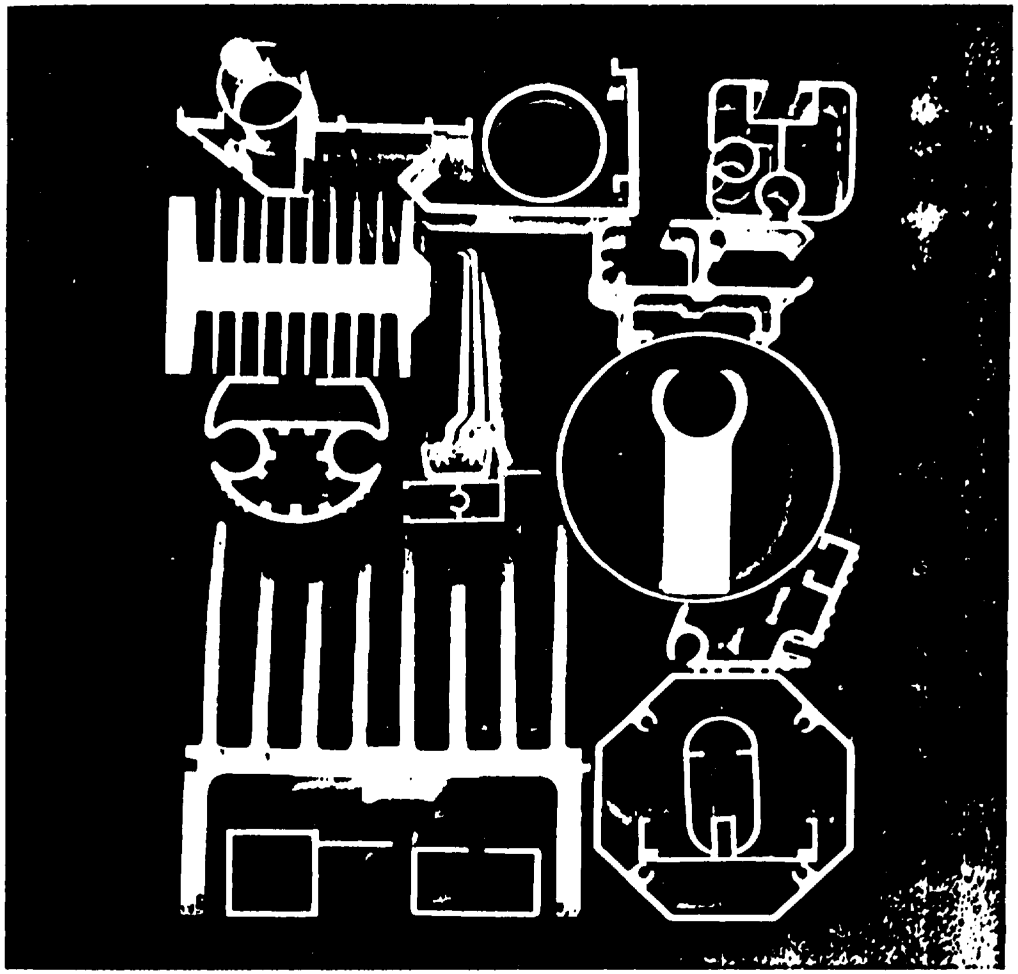
The environment

Efforts to reduce effluents and noise by improved equipment and finding better technological solutions go on continuously. Research plays an important part in these endeavours, and here it is a great advantage that we can draw on the extensive technical organisation of the Hydro group which has been active within the chemical industry for many years and has gained wide experience in dealing with environmental problems.

Our goal is to create a cleaner industrial environment and thus also make jobs in all our plants pleasanter and more satisfying.



[illegible] has made possible much of the progress made in our [illegible]



A selection of aluminium profiles made by Norsk Hydro

A versatile metal

Several factors make aluminium a metal with bright prospects. It is one of the most widespread metals in the earth's crust, and its valuable properties such as low specific weight, good conductivity, strength and high resistance to corrosion, make it suitable for many purposes.

Today it is used especially where the emphasis is on light weight and durability. Typical areas of application are in the transport sector, for instance for the bodies of lorries and buses, for LNG tanks and for containers, in the building industry for windows, ceilings, cladding and inside wall panels, in packaging for all kinds of food and drink containers, for components in electrical articles and household appliances, and as profiles which go into many different kinds of finished goods.

Research and product development are expected gradually to open up new possible fields of application, and here Hydro's Aluminium Division will be in the forefront.

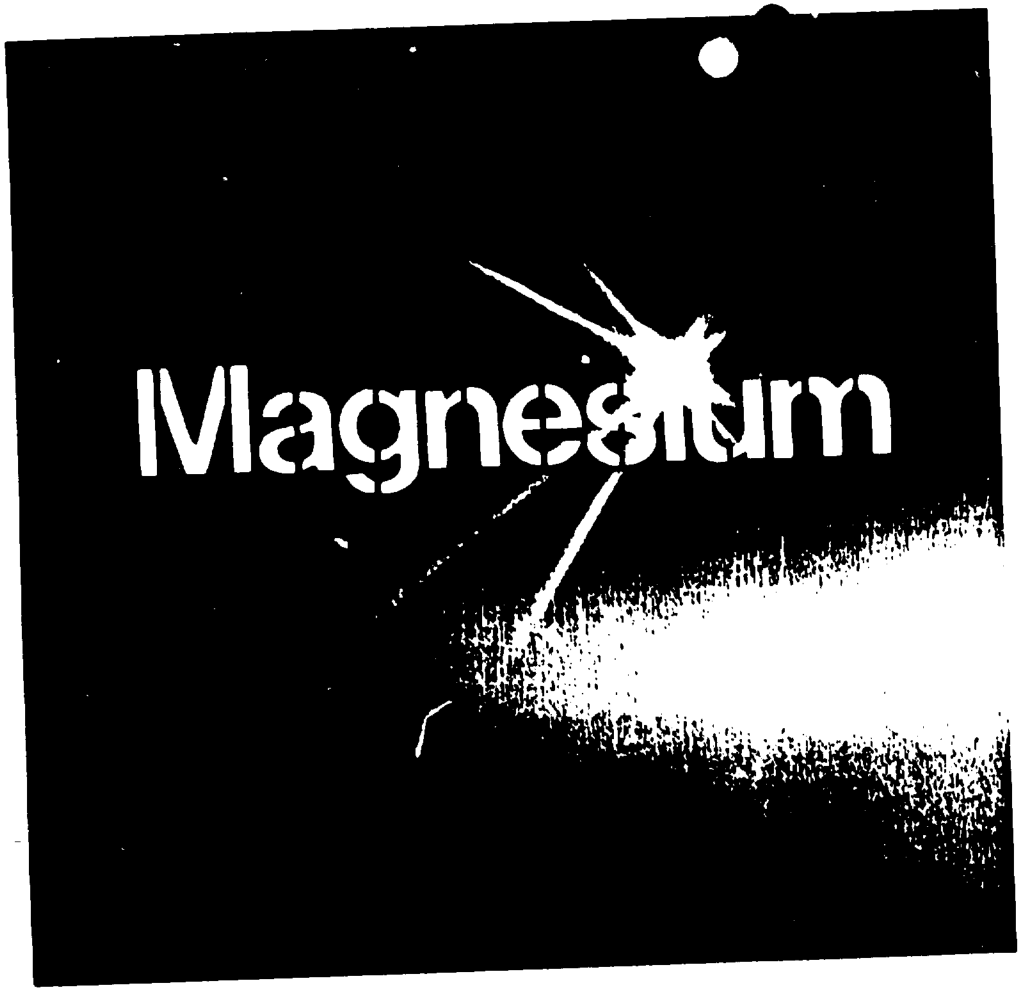
An energy-conserving metal

One of the main objectives during the production of aluminium is to get as much as possible out of the power used. Aluminium production has often been described as power intensive, but this takes into account only one phase of the whole process, namely the production of primary metal. At this stage it is correct that power consumption is higher for aluminium than at the corresponding stage for many other materials.

However, the oil crisis and the possibility of a general shortage of energy made us take a closer look at the whole picture of material selection and energy consumption. Neither bauxite mining, the production of alumina, nor the semi-fabricating of aluminium is particularly power intensive [illegible] when we consider the complete chain of [illegible] nium production processes, aluminium can [illegible] pare favourably with, for example, iron [illegible]

This is even more marked when we [illegible] der the energy consumption of the finished [illegible] duct during its lifetime. Because of its low [illegible] weight, for example, aluminium components [illegible] reduce the fuel consumption or permit a [illegible] payload for all forms of transport.

The energy consumed after the metal [illegible] scrapped must also be considered. The [illegible] and remelting of aluminium scrap [illegible] energy than for most other metals.



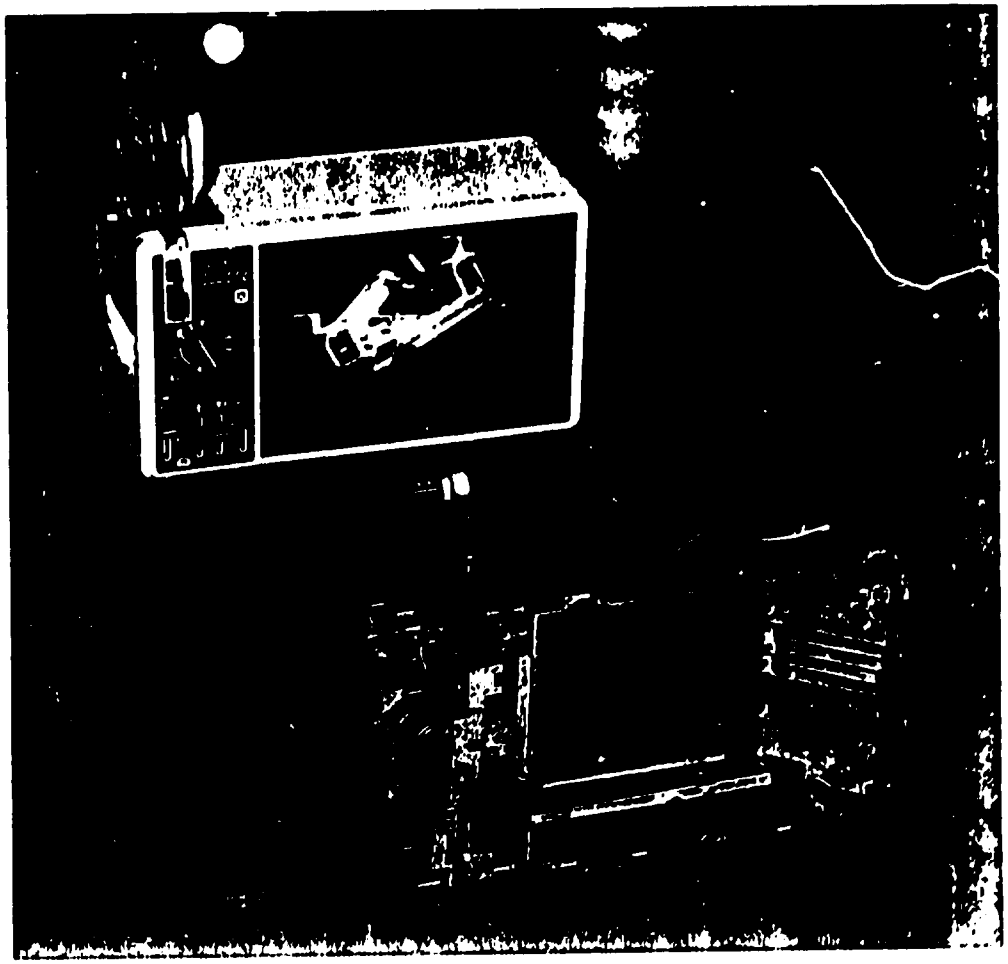
Norsk Hydro

Bygdøy allé 2, Oslo 2, Norwegen

[illegible] Offset AS 1980

Magnesium

Norsk Hydros
Mini-Broschüren



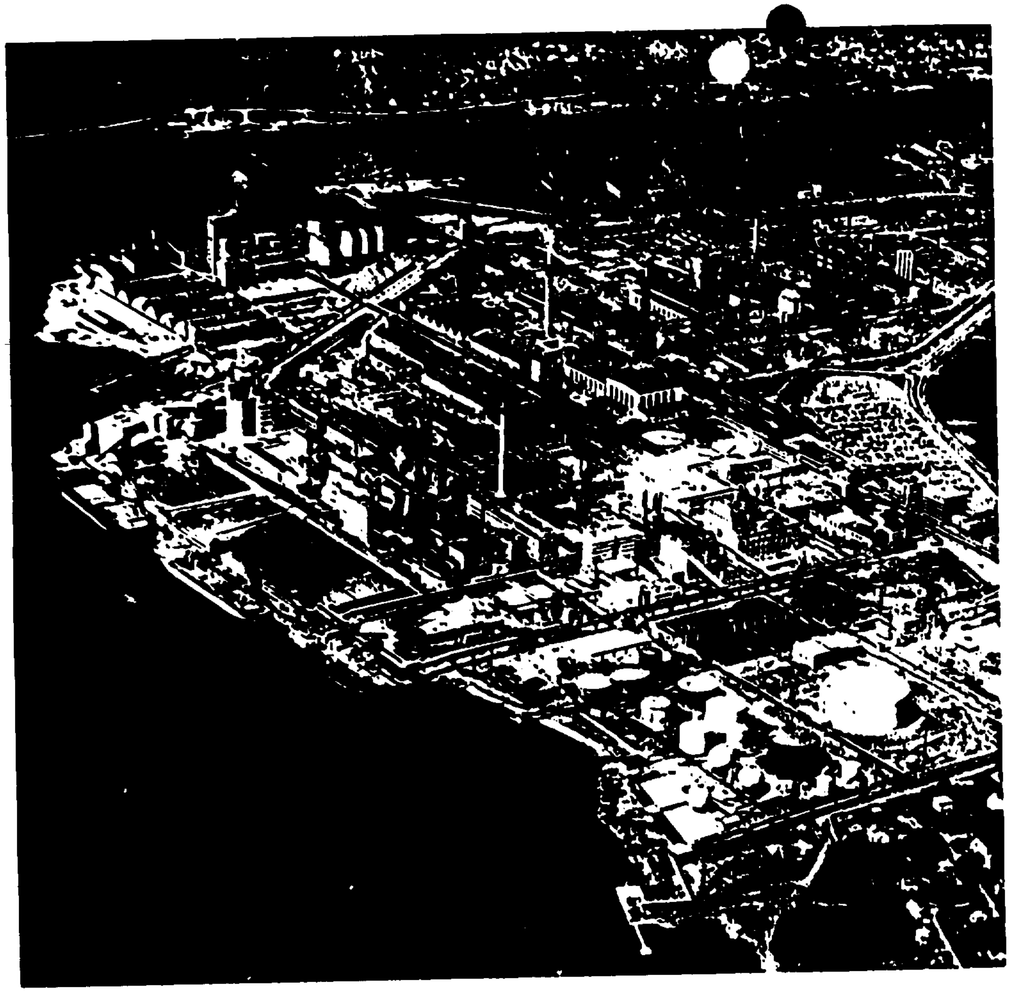
Dieser Filmprojektor ist ein Beispiel fur die vielen Verwendungsmöglichkeiten des Leichtmetalls Magnesium.

Vorgeschichte

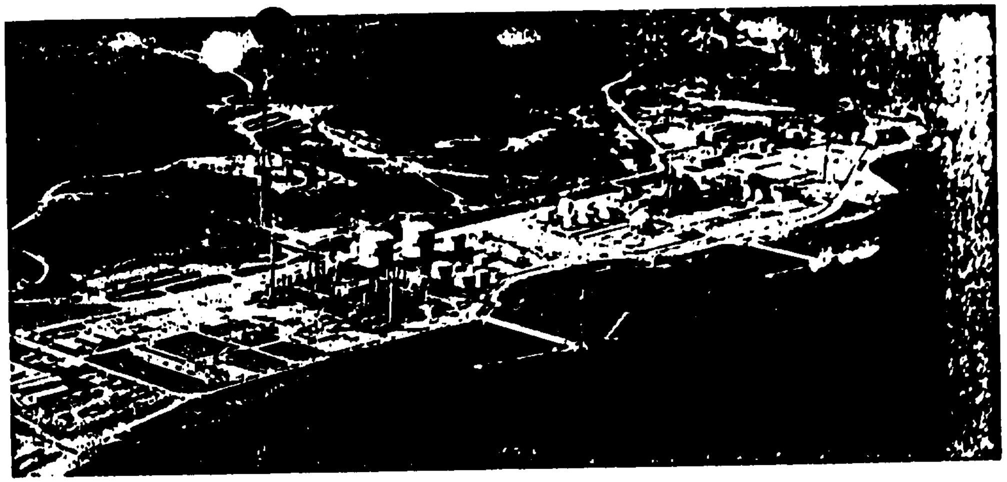
Am 1. August 1951 produzierte Norsk Hydro in Heroya die erste «norwegische» Magnesiummassel. Damit war eine alte Norsk Hydro-Idee verwirklicht worden - die Nutzung elektrischer Energie fur die Herstellung von Leichtmetallen.

Mitentscheidend fur die Errichtung einer Magnesiumhutte in Heroya waren die nahezu idealen Ortsverhaltnisse. Norsk Hydro verfugt hier uber grosse Mengen elektrischer Energie. Seewasser und Dolomitgestein gibt es in unerschopflichen Mengen, und daruber hinaus konnen auch Nebenerzeugnisse anderer Produktionszweige in Heroya fur die Magnesiumherstellung genutzt werden.

Die erste Jahresproduktion von nur 2[illegible] t [illegible] wurde in den folgenden Jahren immer [illegible] gesteigert. Durch standige Erweiterungen, M[illegible]sierungen, Neuanlagen und nicht zuletzt [illegible] den hervorragenden Einsatz aller Mitarbeiter [illegible] die Kapazitat jetzt 50 000 Tonnen jahrlich [illegible]. Vor allem brachten die intensiven Forsch[illegible] und Entwicklungsarbeiten produktionstech[illegible] Kenntnisse, uber die neben Norsk Hydro [illegible] derer Hersteller verfugt.



Mit rund 4 600 Mitarbeitern ist Porsgrunn Fabrikker die grösste Arbeitsstätte in Norwegen



Das Aluminiumwerk auf Karmøy hat eine jährliche Kapazität von 110.000 Tonnen Hütten-Aluminium. Ungefähr die Hälfte wird im Werk weiterverarbeitet.

Oben: Auf Rafnes produziert Hydro Äthylen, Vinylchlorid und Chlor

Norsk Hydro

Schon seit der Gründung beschäftigt sich die Norsk Hydro vorwiegend mit energieveredelnden Produktionsprozessen. Das erste Kraftwerk – Svaelgfossen bei Notodden – wurde 1907 gebaut. Es war damals das grösste in Europa und diente als Energiequelle für die Kunstdünger-Produktion.

Heute verfügt Norsk Hydro über zahlreiche Produktionsstätten in Norwegen. Das grösste Werk befindet sich in Heroya bei Porsgrunn. Es ist mit 4 600 Beschäftigten der grösste Industriebetrieb Norwegens. Hier werden Kunstdünger, Magnesium, PVC und andere Industrie-Chemikalien produziert.

Das Werk Rjukan stellt Kunstdünger, schweres Wasser und Aluminiumguss her. Angeschlossen ist ein Maschinen- und Apparatebau.

Notodden ist die älteste Produktionsstätte des Konzerns. Laminate, Verpackungsmaterialien, Elektrolyseure und Verbrennungsanlagen sind hier die Produktionsschwerpunkte.

Auf der Insel Karmoy betreibt Norsk Hydro eine Aluminiumhütte, die neben Hüttenaluminium auch Halbzeuge liefert.

Das nördlichste Werk liegt in Glomfjord. Die Produktionskapazität dieses Werkes deckt den gesamten norwegischen Bedarf an Kunstdünger.

Mit Besitzanteilen der bedeutendsten Ölfundstellen im norwegischen Schelf, unter anderen Ekofisk und Frigg, ist Hydro seit 1963 in erheblichem Umfang an der Nordsee-Ölgewinnung beteiligt.

Eine Ölraffinerie, die seit 1975 in Mongstad produziert, wurde unter Norsk Hydro-Regie errichtet. Ebenso betreibt Norsk Hydro petrochemische Anlagen – ein Äthylenwerk, eine Vinylchlorid- und eine Chlorfabrik – auf Rafnes in Bamble, die Rohstoffe aus dem Ekofisk-Feld verarbeiten.

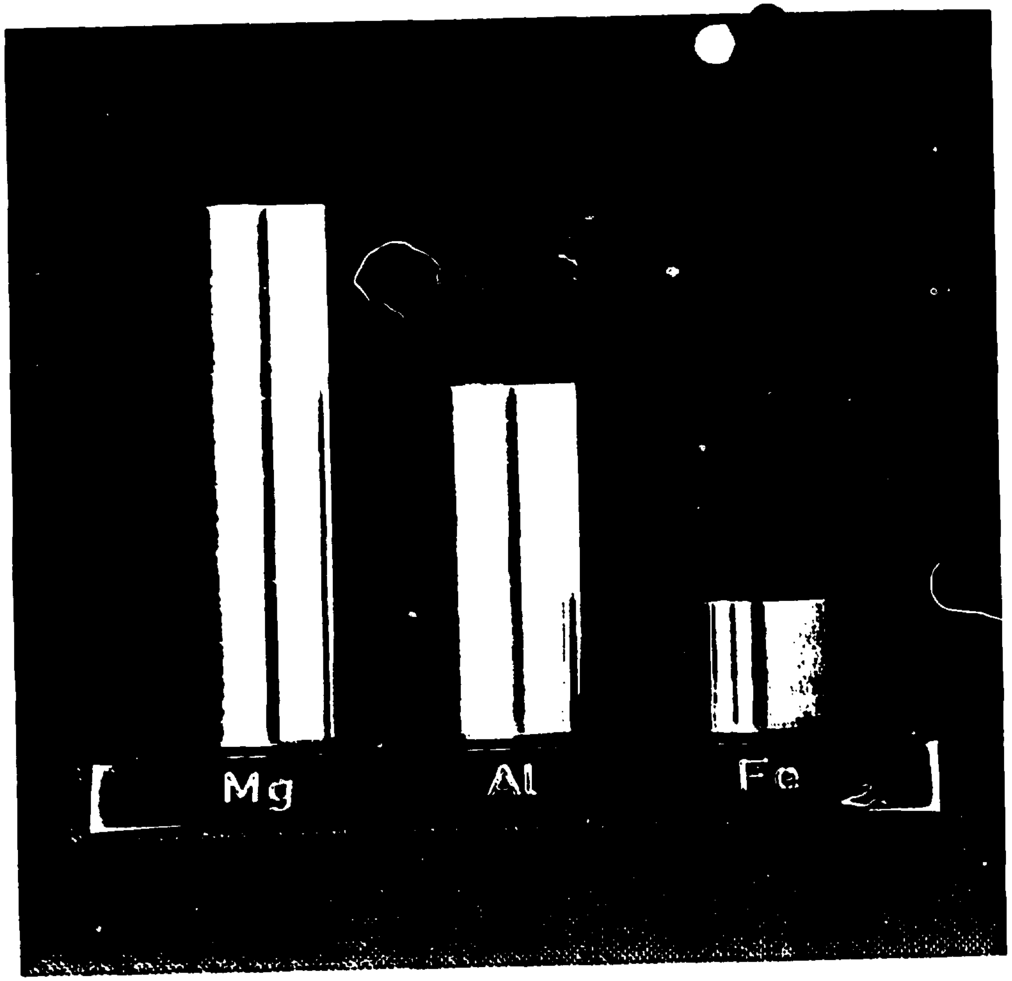
Ungefähr Dreiviertel der Produktion dieser Unternehmen wird exportiert. Vorwiegend nach Schweden, Dänemark, Grossbritannien, in die EWG-Länder, die USA und nach Fernost.

Norsk Hydro produziert in vielen Ländern der Erde. Im Emirat Qatar im Mittleren Osten werden Ammoniak- und Harnstofffabriken betrieben.

Norsk Hydro besitzt in Holland die NSM (Nederlandse Stikstof Maatschappij), die Kunstd[illegible] mittel herstellt, und 1 200 Personen beschäftigt.

Aluminium wird in eigenen Presswerken in Grossbritannien, Frankreich, Westdeutschland, [illegible] Österreich, Belgien, Dänemark und in einem Anodisierwerk in Schweden weiterverarbeitet.

Auch in Deutschland verfügt Norsk Hydro über ein Vertriebs- und Weiterverarbeitungsunternehmen für Magnesium.



Die drei Metallstucke aus Magnesium, Aluminium und Eisen wiegen gleich viel und illustrieren das niedrige spezifische Gewicht des Magnesiums

Was ist Magnesium?

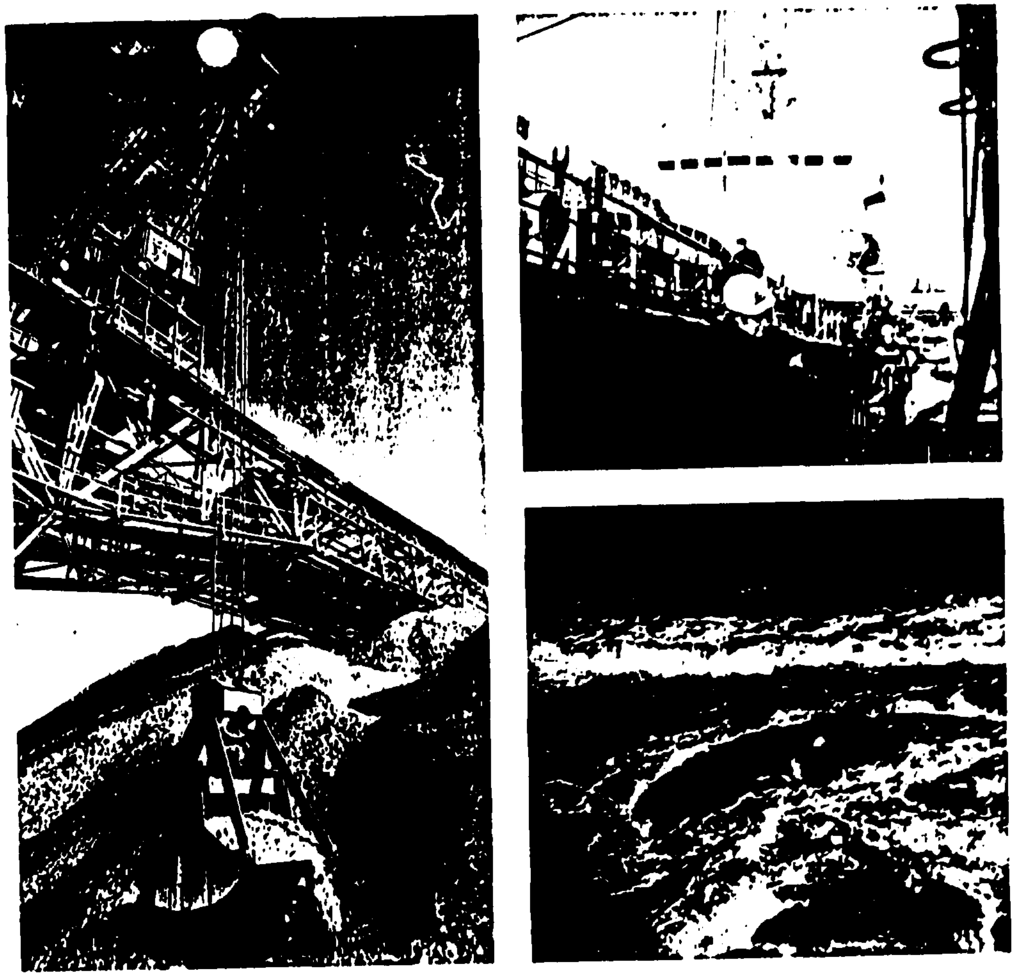
Magnesium kommt in der Natur in reiner Form nicht vor. Es ist ein Erdalkalimetall, das zwar in grossen Mengen, aber nur als chemisches Element in Abraumsalzen, im Meerwasser und in verschiedenen Gesteinen gebunden vorkommt

Reines Magnesium ist das leichteste Industriemetall. Im Vergleich der spezifischen Gewichte ist Aluminium anderthalbmal und Stahl viereinhalbmal schwerer als Magnesium. Doch im Verhaltnis von Festigkeit zu Gewicht kann Magnesium durchaus mit diesen Metallen verglichen werden

Das geringe spezifische Gewicht und die hervorragenden chemischen und mechanischen Eigenschaften haben dem Magnesium standig neue und grossere Anwendungsgebiete erschlossen

Als Legierungsbestandteil anderer Industriemetalle verbessert Magnesium wesentlich deren Festigkeit und Korrosionsbestandigkeit

Wegen seiner chemischen Reaktionsfahigkeit benutzt man Magnesium auch, um Verunreinigungen beispielsweise aus Eisen, Stahl, Blei und Kupfer zu entfernen. Es wird zur Herstellung neuer Metalle und zur Gewinnung einer Reihe verschiedener chemischer Verbindungen eingesetzt. Und als Anodenmaterial schutzt es Eisen und Stahl gegen Korrosion

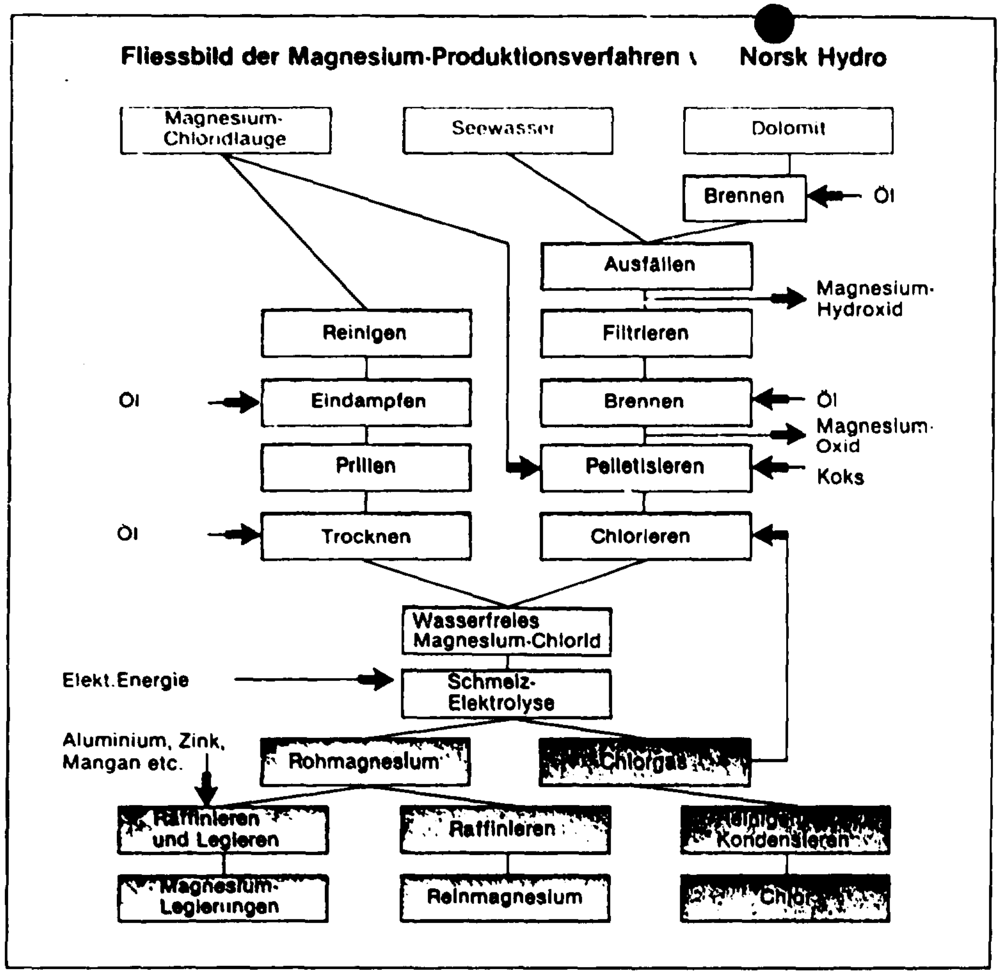


Die Rohstoffe in der Magnesiumproduktion sind Dolomit aus Sørfold in Nordland, Magnesiumchloridlauge aus Deutschland, und Meerwasser aus Frierfjorden.

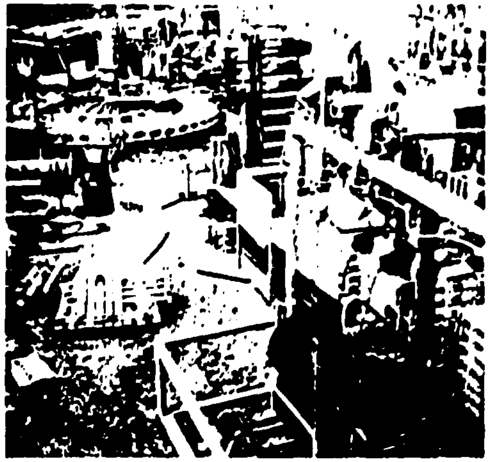
Rohstoffe

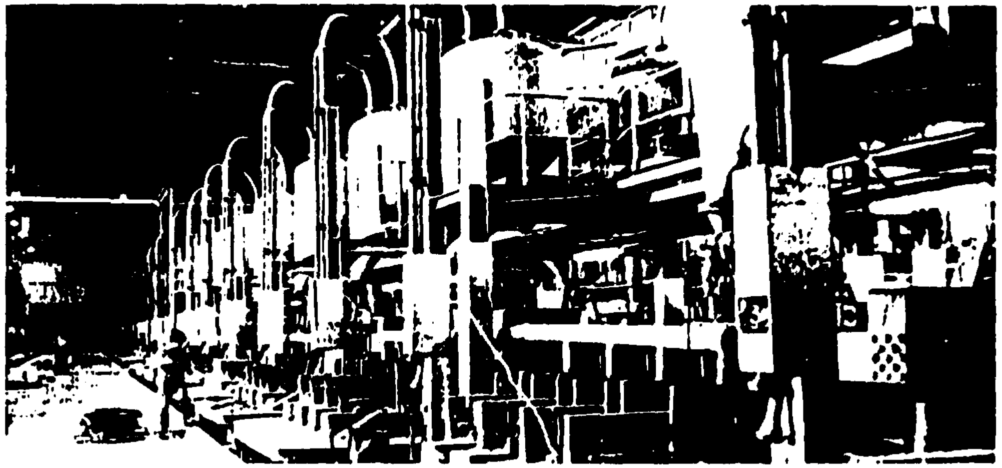
Norsk Hydro produziert Magnesium aus Dolomitgestein, Magnesium-Chloridlauge und Meerwasser. Von diesen Rohstoffen gibt es grosse Vorrate, und das Seewasser ist nahezu unerschopflich. Mit Dolomit versorgt sich Norsk Hydro von Sørfold in Nord-Norwegen, wo die Vorkommen sich durch hohe Reinheit auszeichnen. Das Meerwasser wird aus Frierfjorden vor Herøya hochgepumpt. (Ein Kubikmeter Seewasser enthalt etwa 1,3 kg Magnesium). Die Magnesium-Chloridlauge kommt aus Westdeutschland

Die fur den Herstellungsprozess von Magnesium notigen Energiemengen – Elektrizitat, Ol und Gas – bezieht Norsk Hydro aus eigenen Quellen. Allerdings tragt hier die intensiv betriebene [illegible] Forschung dazu bei, dass sich der Energieverbrauch pro Tonne Metall standig verringert



Norsk Hydro produziert Magnesium nach zwei verschiedenen Herstellungsverfahren mit einzelnden gemeinschaftlichen Eigenschaften





Von der Anlage ganz oben links wird wasserfreies Magnesiumchlorid zu den Elektrolysezellen (unten) geleitet, wo flussiges Roh-Magnesium gewonnen, raffiniert und daraus in der Magnesiumgiesserei (oben rechts) Masseln und andere Produkte hergestellt werden

Herstellung von Magnesium

Norsk Hydro benutzt fur die Magnesium-Herstellung das schmelzelektrolytische Verfahren, wobei Magnesium-Chlorid mit Hilfe von Elektrizitat in Magnesium und Chlor zerlegt wird

Magnesium-Chlorid wird heute in Heroya in zwei Fabriken auf unterschiedliche Weise hergestellt Das Verfahren, das Norsk Hydro seit dem Start 1951 anwendet, geht von Dolomit und Meerwasser aus Zerkleinerter Dolomit wird in Drehrohrofen gebrannt Das gebrannte Produkt wird mit Meerwasser vermischt, in grosse Behalter gefullt und dann das Magnesium-Hydroxid ausgefallt Es wird getrocknet und zu Magnesium-Oxid gebrannt

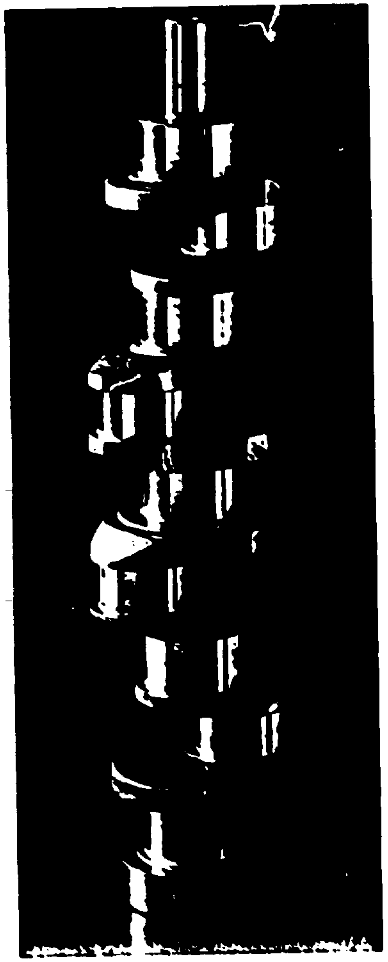
Ein Teil des Magnesium-Oxids, das in verschiedenen Industriezweigen fur die unterschiedlichsten Zwecke verwendet wird, geht in den Verkauf

Der grosste Teil wird jedoch fur die Metallherstellung genutzt. Dabei wird das Oxid mittels Chlorgas und Kohle in wasserfreies Magnesium-Chlorid umgesetzt. Anschliessend wird es in Elektrolysebadern in Chlorgas und flussiges Magnesium-Metall gespalten. Das Chlorgas geht in den Prozess zuruck.

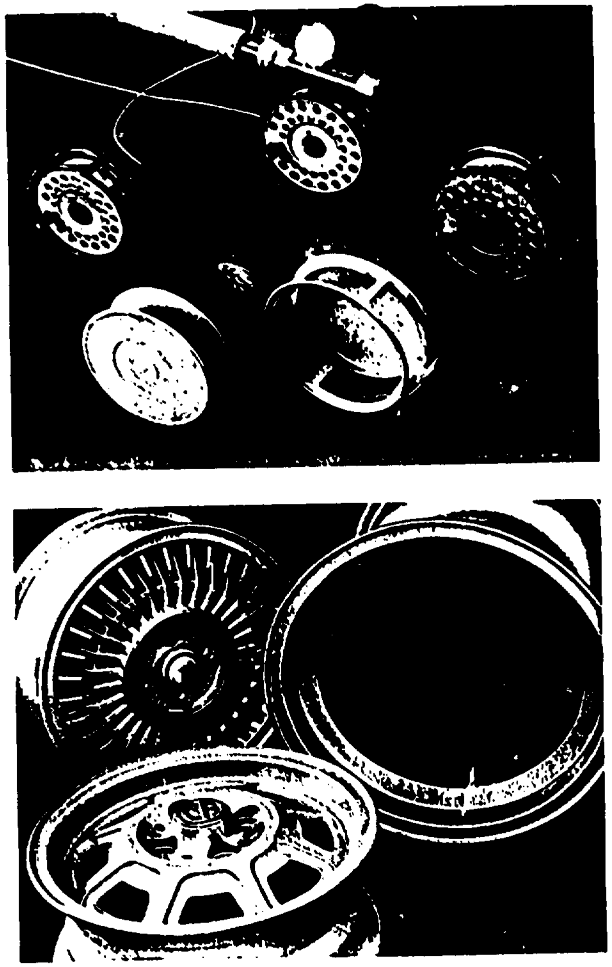
Neue Technologie

Als Abschluss eines der grossten Norsk Hydro-Entwicklungsprojekte wurde jetzt eine neue Anlage zur Herstellung von wasserfreiem Magnesium-Chlorid in Betrieb genommen. Diese Anlage arbeitet wirtschaftlicher und umweltfreundlicher.

Der Rohstoff, der hier verarbeitet wird, ist eine Magnesium-Chloridlauge, die mehr als 30 Prozent Magnesium-Chlorid, aber auch Verunreinigungen wie Schwefel und Bor enthalt, die in der ersten Stufe des Produktionsprozesses ausgeschieden werden. Danach wird das Wasser zunachst durch Eindampfen der Lauge entfernt Diese wird dann in einen Spruhkristallisationsturm geleitet, wo sie zu einem festen gekornten Stoff erstarrt Warmluft und Salzsauregas treiben das restliche Wasser vollkommen aus Das wasserfreie Magnesium-Chlorid wird in Elektrolysebadern in Chlorgas und flussiges Magnesiummetall gespalten und das Metall schliesslich zu Masseln und Bolzen gegossen Als Nebenprodukt entstehen mit jeder Tonne Magnesium ungefahr drei Tonnen Chlorgas, ein wertvoller Rohstoff fur die petrochemischen Werke in Rafnes



Diese Kurbelwelle ist aus Sphäroguss, der durch Magnesium-Behandlung des Gusseisens entsteht.



Magnesium in Hobby-Ausrüstung und für Autos.

Geräte mit niedrigem Gewicht erleichtern die Arbeit.

Produkte und Verwendungen

Unlegiertes Magnesium

Norsk Hydro verkauft unlegiertes oder reines Magnesium grosstenteils an die Aluminiumindustrie in Norwegen und im Ausland. Durch Magnesium als Legierungszusatz gewinnt das Aluminium bestimmte physikalische Eigenschaften.

Das Ende der 40er Jahre entwickelte Gusseisen mit Kugelgraphit gilt als einer der bedeutendsten Fortschritte auf dem metallurgischen Gebiet. Es wird mittels Magnesium in reiner Form oder mittels Ferrosilizium hergestellt. Der Magnesiumverbrauch für die Erzeugung von Gusseisen mit Kugelgraphit nimmt ständig zu.

Neue Technologien fordern bessere Stahlqualitäten. Magnesium wird deshalb zur Entschwefelung von Eisen und Stahl eingesetzt.

Die chemische Industrie nutzt Magnesium-Späne für organische Synthesen. Und bei der Herstellung von Titan, Zirkon, Uran und anderen Metallen wird Magnesium als Reduktionsmittel verwendet.

Legiertes Magnesium

Mit Aluminium und Zink legiert, erhält Magnesium hervorragende Gebrauchseigenschaften. Magnesium-Legierungen lassen sich weiterverarbeiten durch Giessen, Walzen, Pressen und Schmieden.

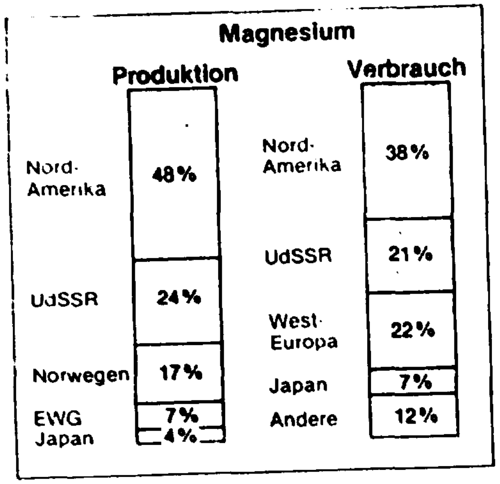
Magnesium ist leicht zu verarbeiten, und die Kombination des niedrigen Gewichts mit hoher Festigkeit erschliesst diesem Metall ständig neue Verwendungsmöglichkeiten.

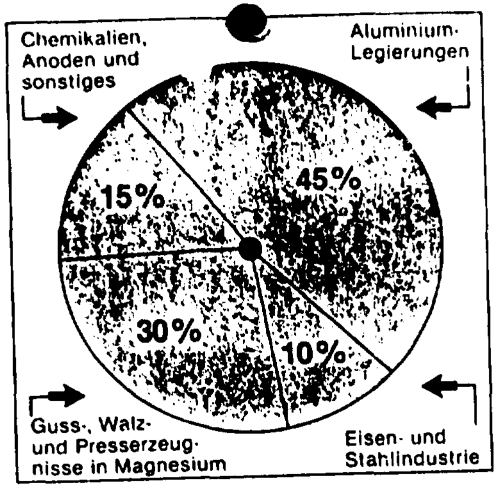
Magnesium findet man heute in industriell genutzten Produkten genauso wie in Gegenständen des täglichen Bedarfs: In Flugzeugen, Motorsägen, Kameras, Rasenmähern, Motorblöcken, Autofelgen, Getriebegehäusen und Campingausrüstungen.

Speziell im Transportsektor werden durch die Verwendung leichtgewichtiger Magnesium-Legierungen bedeutende Energieeinsparungen erzielt. Die hier möglichen Brennstoffeinsparungen betragen ein Vielfaches der für die Herstellung von Magnesium aufgewendeten Energiemengen.

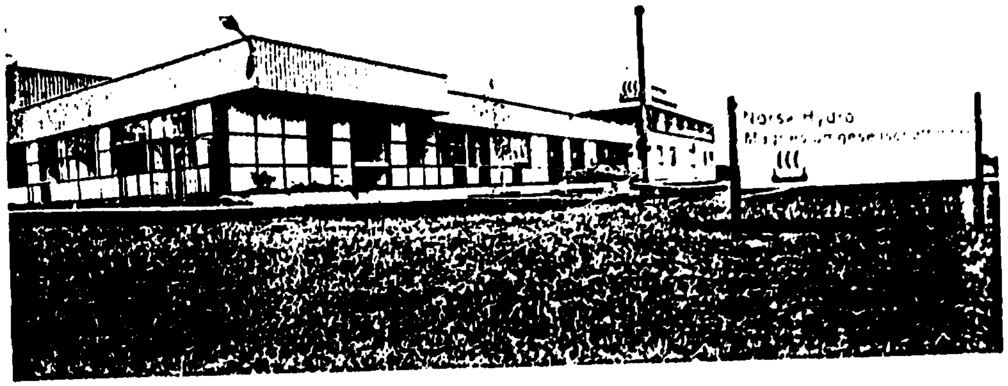
Magnesium-Oxid

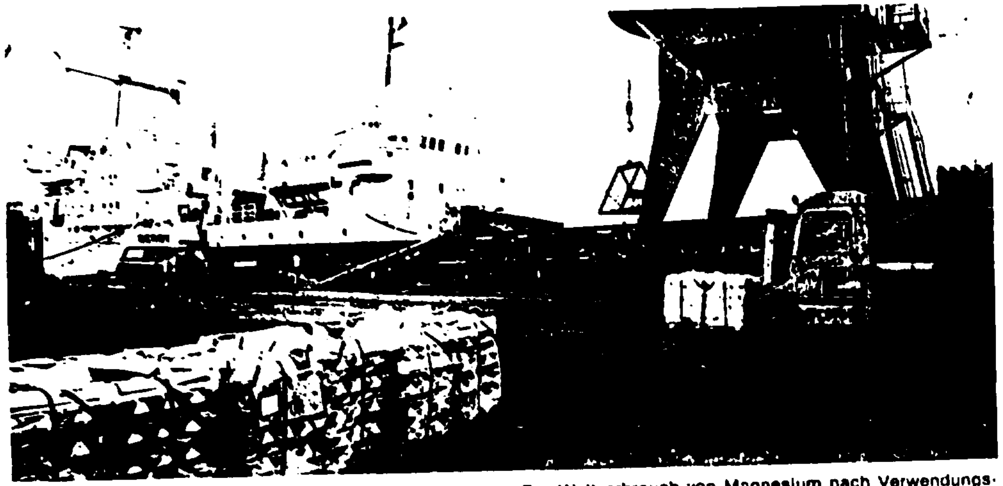
Magnesium-Oxid entsteht als Zwischenerzeugnis bei der Metallherstellung von Norsk Hydro. Hauptabnehmer ist die Zelluloseindustrie, die das Magnesium-Oxid als Base der Kochflüssigkeit einsetzt. Die Betriebe können umweltfreundlicher und wirtschaftlicher produzieren. Magnesium-Oxid wird auch als Zusatz zum Viehfutter, für [illegible] werke und in der chemischen und pharmazeutischen Industrie verwendet.



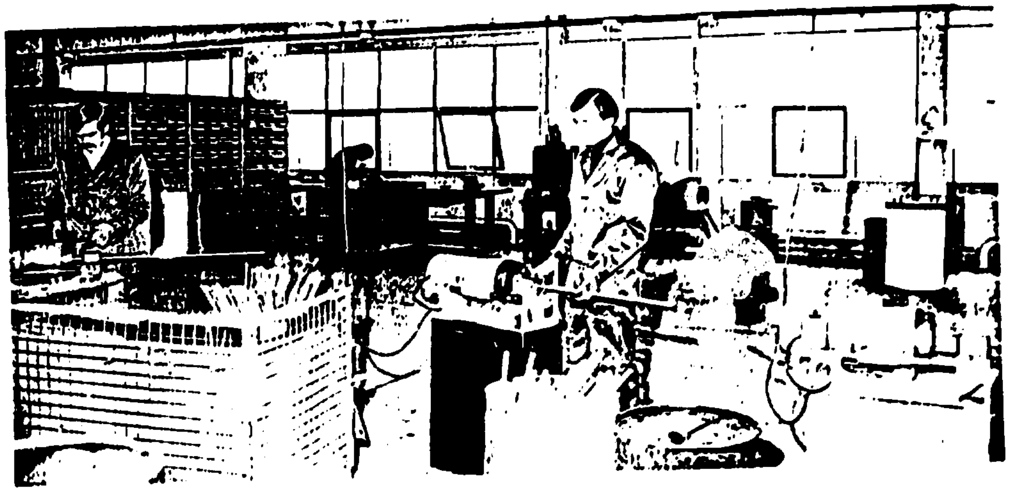


Der Weltverbrauch von Magnesium nach Verwendungsgebieten.





Norsk Hydro hat einen bedeutenden Anteil an der Weltproduktion von Magnesium. Uber 90% werden exportiert.



Die Produktionsanlage der Norsk Hydro Magnesiumgesellschaft für Anoden, Spane und Umschmelz-Legierungen in Bottrop (Westdeutschland).

Verkauf und Märkte

Auf dem Magnesium-Markt gehort Norsk Hydro zu den fuhrenden Unternehmen. Das Magnesium aus Heroya – international unter dem Handelsnamen NORMAG (R) bekannt – deckt ungefahr ein Sechstel des heutigen Weltverbrauchs

Die weltumspannende Norsk Hydro-Verkaufs- und Beratungsorganisation pflegt den standigen Kontakt und Erfahrungsaustausch mit Abnehmern auf allen Markten

Uber 90 Prozent der Magnesium-Produktion wird exportiert, hauptsachlich nach West-Europa

Zu den grossten Magnesium-Verbrauchern ausserhalb West-Europas und den USA gehoren die UdSSR, Japan, Brasilien und Kanada. Die Schautafeln oben zeigen die geographische Verteilung von Magnesium-Produktion und -Verbrauch in der Welt, aufgegliedert nach Verwendungsgebieten. Diese Zahlen geben einen Überblick der heutigen Situation, die jedoch im Hinblick auf die standige technische und wirtschaftliche Weiterentwicklung immer wieder Veränderungen unterworfen sind.

Auf dem skandinavischen Markt fur leichtgebranntes Magnesium-Oxid deckt Norsk Hydro uber 90 Prozent des Gesamtbedarfs der Zelluloseindustrie in Norwegen und Schweden

Norsk Hydro Magnesiumgesellschaft

Grosse Mengen norwegischen Magnesiums werden nach Westdeutschland und Osterreich exportiert. Importeur ist die Norsk Hydro Magnesiumgesellschaft mbH in Essen, die auch Sekundar-Magnesium-Legierungen produziert, Magnesium-Anoden fur den kathodischen Korrosionsschutz herstellt und die chemische Industrie mit Magnesium-Spanen beliefert. Auf dem Anodensektor ist die deutsche Norsk Hydro-Tochter ein fuhrendes Unternehmen

Mit modernen Produktionsanlagen in einer 1975 errichteten Betriebsstatte besitzt die Norsk Hydro Magnesiumgesellschaft eine solide Basis fur die industrielle Nutzung ihrer Kenntnisse und jahrzehntelangen Erfahrungen mit dem leichten Nutzmetall Magnesium

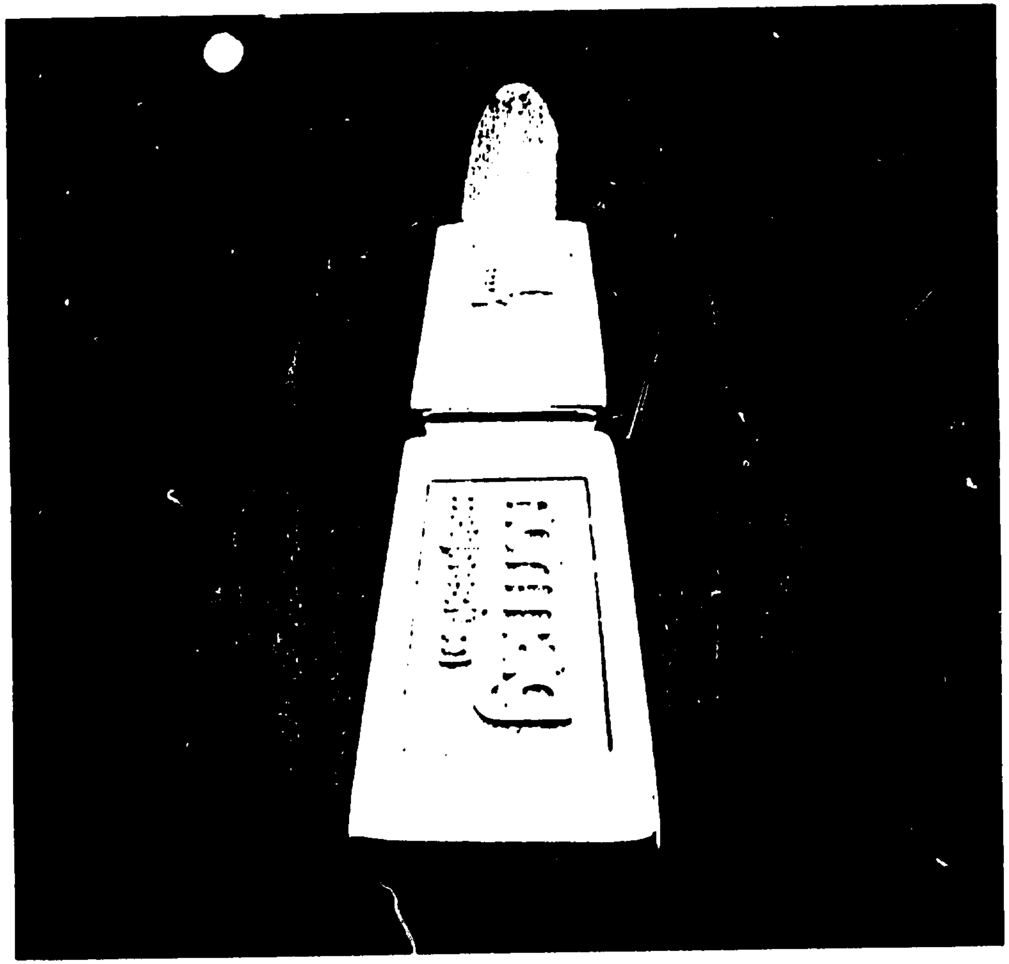
Norsk Hydro setzt grosse Mittel in der Forschung für die Produktions- und Anwendungs-Technik von Magnesium ein

Forschung

Als Grossproduzent mit hohem technologischem Niveau verfugt Norsk Hydro uber ein entsprechendes Forschungs- und Entwicklungspotential. Die Norsk Hydro-Forschung konzentriert sich vorrangig auf drei Gebiete

- die Verfahrenstechnik, die standig zu verbessern ist und fur die immer wieder neue Methoden entwickelt werden mussen,
- die Anwendungstechnik, mit der dem Magnesium neue interessante Einsatzgebiete zu entwickeln und zu erschliessen sind,
- den Umweltschutz, in dessem Interesse die Produktionsprozesse auf geringstmögliche Umweltbelastung zu gestalten sind.

Ein aktuelles Beispiel fur die intensiven Norsk Hydro-Forschungsaktivitaten ist das in jahrelanger Arbeit entwickelte neue Verfahren fur die Herstellung von wasserfreiem Magnesium-Chlorid, durch das die Umweltbedingungen entscheidend verbessert wurden.



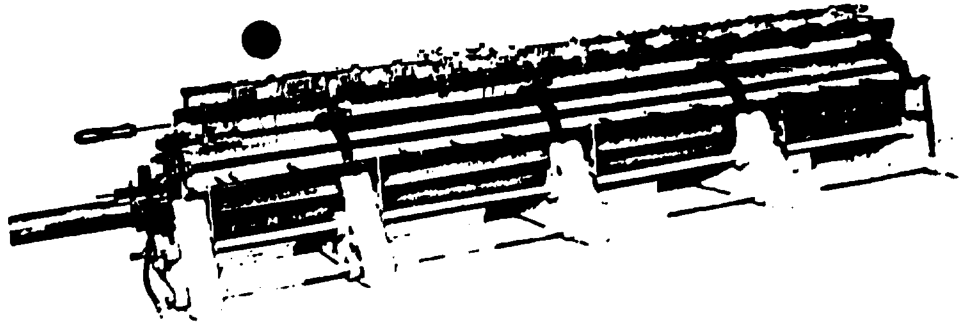
Magnesium in der Zukunft

Magnesium ist einer der meist verbreiteten Grundstoffe auf der Erdoberflache. Trotzdem wurde es erst spat als Gebrauchsmetall genutzt, weil der lange und komplizierte Produktionsprozess erst im modernen Industriezeitalter entwickelt werden konnte. Magnesium ist ein junges Metall; es spielt erst eine bescheidene Rolle in der Metallwirtschaft der Welt. Aber gerade darin sieht Norsk Hydro grosse Chancen fur die Zukunft des Magnesiums.

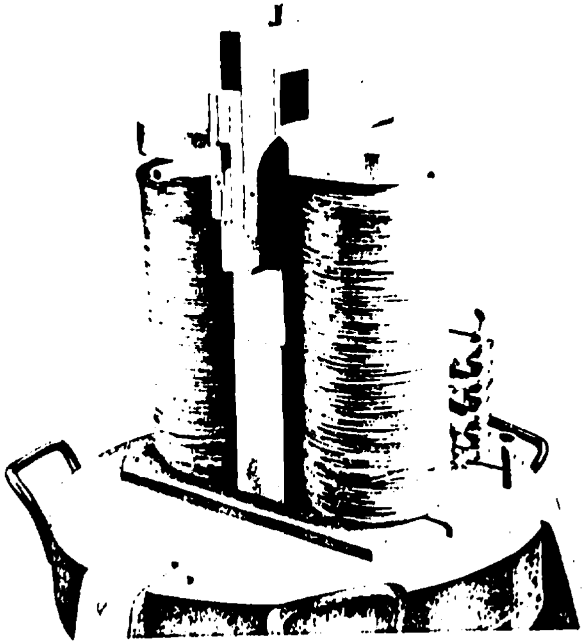
Das niedrige spezifische Gewicht, verbunden mit guten physikalischen und chemischen Eigenschaften, werden diesem hervorragenden Werkstoff weitere Einsatzmoglichkeiten auf vielen Gebieten erschliessen. Die Verwendung von Magnesium beim Bau von Verkehrsmitteln, bei der Eisen- und Stahlzherstellung und in der chemischen Industrie nimmt standig zu. Aber vor allem sichert die Unerschopflichkeit seiner Vorstoffe dem Magnesium eine expansive Zukunft. Es wird uber seine heutige Stellung als Konstruktionswerkstoff, Legierungselement und Chemikalie hinaus weiter an Bedeutung gewinnen.

Sam Eyde

Kristian Birkeland



Birkelands elektrische Kanone



Der erste experimentielle Lichtbogenofen

Die Ideen hinter Norsk Hydro

Wie kann die Lebensmittelproduktion im Einklang mit dem Bevölkerungszuwachs gesteigert werden?

Diese Frage ist in den letzten Jahrhunderten ständig gestellt worden, und viele haben den Versuch gemacht, das Problem zu lösen.

In der ersten Hälfte des 16. Jahrhunderts haben die Forscher eingesehen, dass man nicht damit fortfahren konnte, die Erde durch Ernten auszubeuten, ohne mehr dafür zu tun als etwas Naturdünger. Der Erde musste ausserdem eine Reihe von Planzennährstoffen zugeführt werden, besonders Stickstoff, Phosphor und Kalium. Die natürlichen und nutzbaren Vorkommen von Phosphor und Kalium waren reichlich, während die Stickstoffvorräte (Salpeterfelder in Chile) nur für eine begrenzten Zeit ausreichen konnten.

Daher fing man an, sich für Luft zu interessieren, die ja 80 % Stickstoff enthält. Die Aufgabe war, den Luftstickstoff in eine Verbindung überzuführen, die von den Planzen verwertet werden konnte. – Die Wissenschaftler hatten festgestellt, dass dies durch elektrische Entladungen bei hoher Temperatur möglich wurde. Sollte dies aber industriell ausgenutzt werden, so würde es nach den damaligen Verhältnissen enorme Energiemengen erfordern

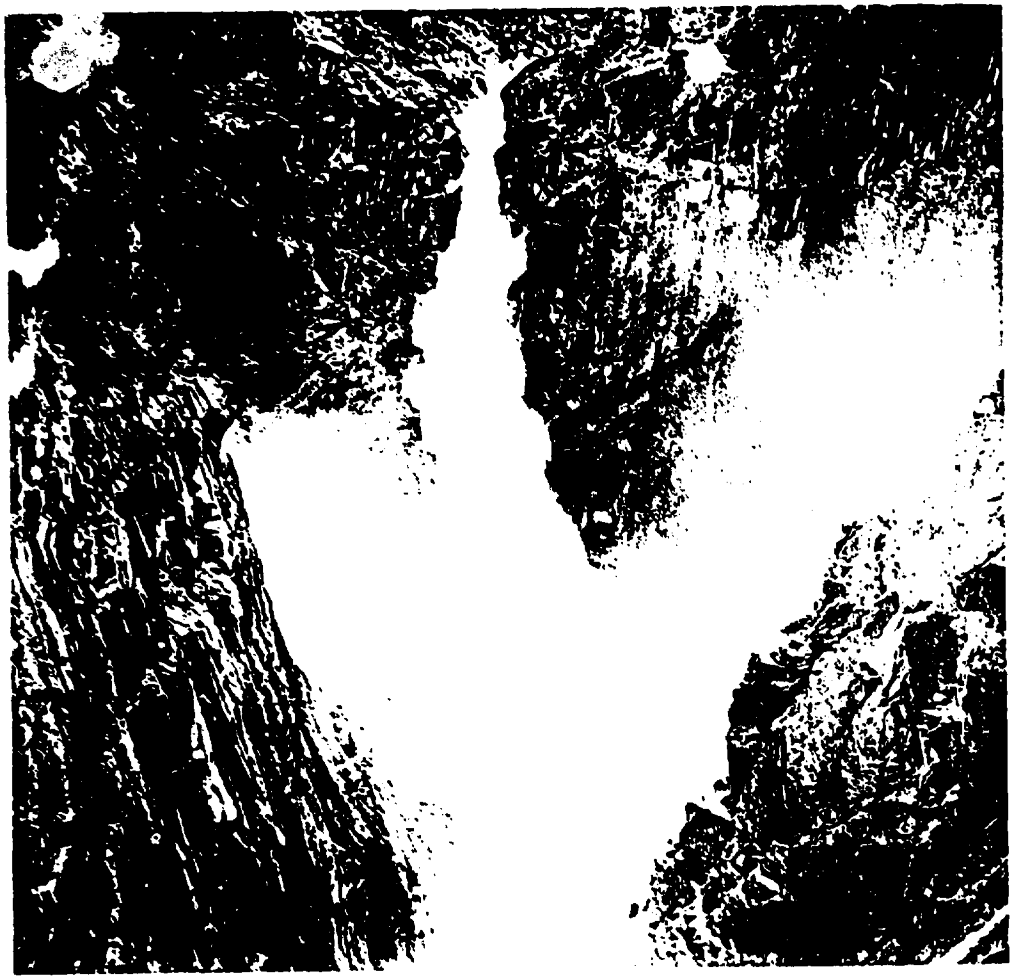
Hier kamen die Wasserfälle zur Anwendung. Ab Ende des vorigen Jahrhunderts war man sich über die Möglichkeiten klar geworden, die in der Ausnutzung der Wasserfälle für de Herstellung von Elektrizität lagen.

Mit solchen Problemen befasste sich Ingenieur Sam Eyde, als er dem Wissenschaftler Kristian Birkeland in einer Gesellschaft bei dem damaligen Staatsminister Gunnar Knudsen begegnete. Es war am Freitag, dem 13. Februar 1903. Eyde erzählte Birkeland über seine Pläne, und sagte, dass er eine kräftige elektrische Entladung mit sehr hoher Temperatur benötigte, um Luft-Stickstoff zu binden

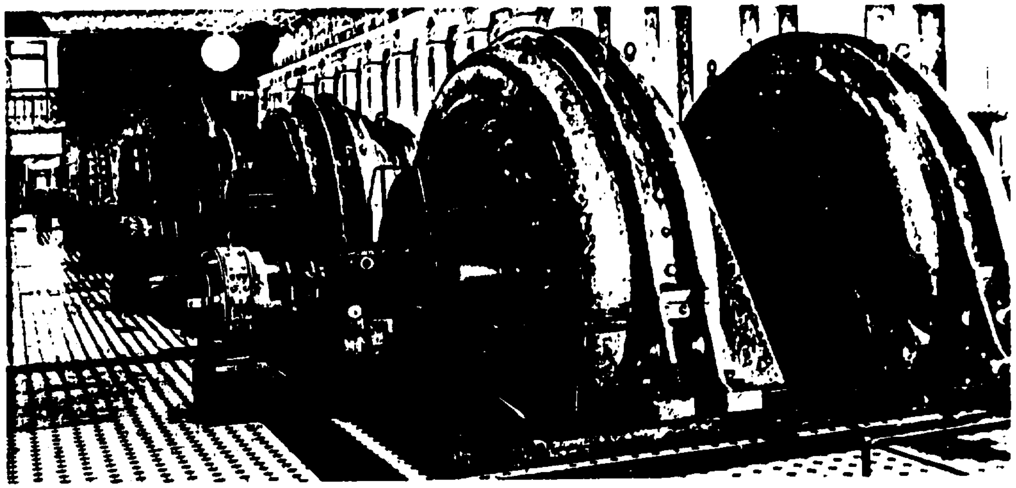
Birkeland war einer der führenden und originalsten Wissenschaftler von Norwegen. Ihm fehlte aber das Geld, um wissenschaftliche Experimente betreiben zu können.

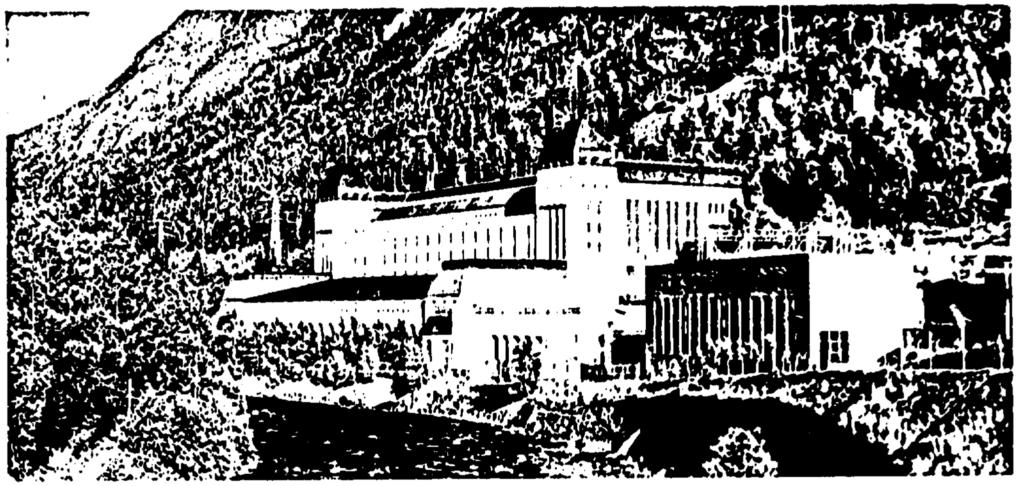
Daher hatte er einige Projekte in Angriff genommen, die er gedachte, industriell auszunutzen und sich damit das notwendige Kapital zu beschaffen. Eines von diesen Projekten war eine elektrische Kanone, die er soeben einem auserwählten Publikum im Festsaal der Universität vorgeführt hatte.

Die Demonstration war gelinde gesagt misslungen. Eine kräftige elektrische Entladung hatte einen Kurzschluss in der ganzen Kanone [illegible]



Der Wasserfall Rjukanfossen, wie er sich immer in besonders wasserreichen Jahren zeigt





Inneres des Såheim-Kraftwerks im Jahre 1926.

Såheim Kraftwerk, auch «die Oper von Rjukan» genannt

grossen Radau verursacht. Vielleicht war diese Entladung der Funke, nach dem Sam Eyde suchte.

Damit begannen der Ingenieur und Wissenschaftler eine erfolgreiche Zusammenarbeit. Diese resultierte in dem Lichtbogenofen, genannt Birkeland-Eyde-Ofen, und ergab die erste Fabrik der Welt für Herstellung von Stickstoffdünger, die auf Notodden am 2. Mai 1905 in Gang kam.

Durch Mitwirkung des schwedischen Finanzmannes Wallenberg wurde das notwendige Kapital beschafft, und am 2. Dezember 1905 wurde Norsk Hydro gegründet mit Marcus Wallenberg als Präsident und Sam Eyde als erster Generaldirektor.

Norsk Hydro wird gegründet

Norsk Hy[illegible]-Ele[illegible]risk Kvælstofaktieselskab (... Stickst[illegible]ie die Gesellschaft damals hiess, wurd[illegible] um «Wasserkräfte zu erwerben [illegible]utzen, natürliche und künstlich ausgebau[illegible]owie «alle industriellen Anlagen zu erwerben, zu bauen und zu betreiben ... zur Herstellung von Salpetersäure und allen anderen Arten stickstoffhaltiger Produkte ...»

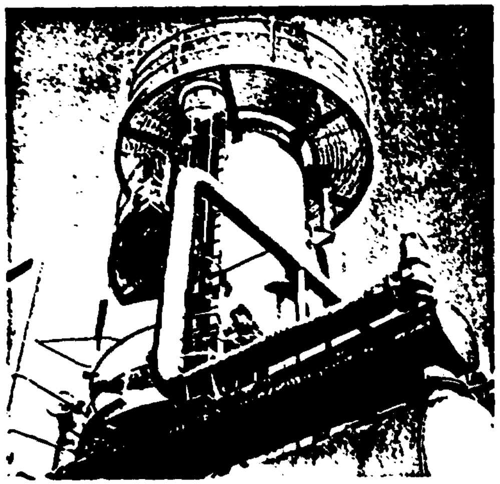
Die erste Zeit hindurch geht die Entwicklung der Gesellschaft parallel mit dem Wasserfallausbau in Telemark. Die Produktion benötigte grosse Mengen elektrischer Energie, und die Wasserläufe im östlichen Telemark, Tinnelven mit Svælgfossen und den Flüssen Måna mit Rjukanfossen, wurden die Kraftquellen des Unternehmens.

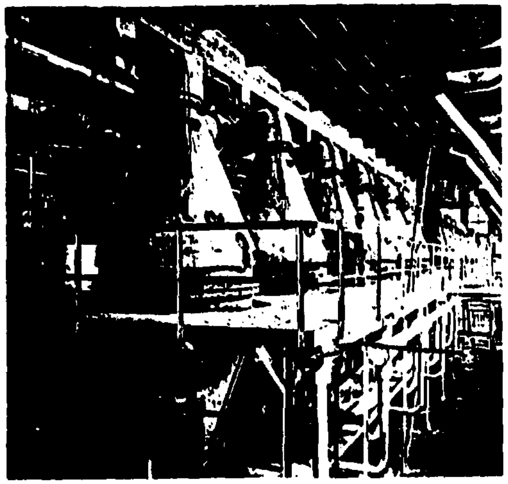
Die erste bescheidene Produktion bei Notodden Fabrikker erforderte 1800 kW. (Heute verfügt Norsk Hydro über eine Maximalkapazität von nahezu 1,6 Millionen kW). Ohne vor technischen Schwierigkeiten zurückzuschrecken, wurde damit begonnen, den Wasserfall Svælgfossen bei Notodden auszubauen. Dieses Kraftwerk war das grösste in Europa, als es 1907 in Betrieb genommen wurde.

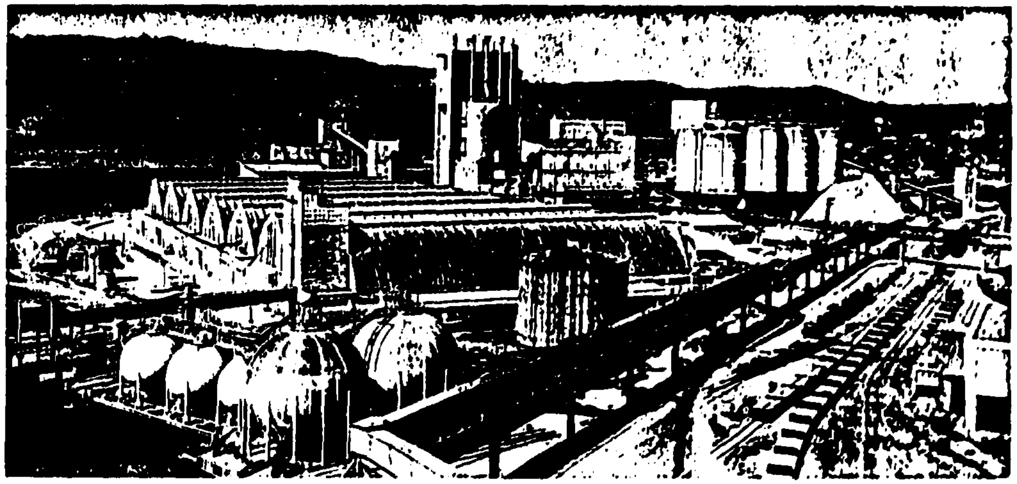
Bald wurde beschlossen, neue Fabriken zu bauen, und schon 1911 stand das Vemork-Kraftwerk fertig.

Die Technik von damals kannte keine Möglichkeiten zur elektrischen Kraftübertragung über grössere Entfernungen. Die zweite nächste Fabrik der Gesellschaft, Rjukan Fabrikker, ist daher in dem engen und nahezu unbewohnten Tal Vestfjorddalen entstanden, wo sich nach und nach eine kleine Stadtgemeinde entwickelte.

Rjukan war mehrere Jahre hindurch Zentrum für Norsk Hydros Salpeterproduktion. Von hier aus, und von Notodden, wurde Norgesalpeter, und später Kalksalpeter in grosse Teile der Welt exportiert.







Stammbaum der Verarbeitung von Erdöl zum fertigen Volldünger. Hydro bietet Beratung und Werkshilfe über die ganze Welt an

Anlagen zur Verbrennung von Ammoniak zu Stickoxid

Volldüngerfabrik III, Herøya, mit Lagerhallen und Schüttgüter

Aus der Ammoniakfabrik

Änderungen des Verfahrens

Bis zum Ende der 20er Jahre betrieb die Gesellschaft ihre Salpeterproduktion nach dem Birkeland/Eyde-Verfahren. In 1927/28 erfolgte eine durchgreifende Änderung. Die Produktion wurde auf das Haber/Bosch-Verfahren umgestellt, wo der Weg zur Salpetersäuregewinnung über Ammoniak führte. Mit demselben Stromverbrauch ergab das Ammoniakverfahren eine etwa viermal höhere Ausbeute als das Birkeland/Eyde-Verfahren.

Die Fabriken auf Rjukan und Notodden wurden jetzt nach und nach auf Ammoniakgewinnung umgestellt, und eine neue Fabrik wurde auf Herøya bei Porsgrunn gebaut. Hier sollte das Ammoniak aus Rjukan und Notodden zu fertigem Salpeter verarbeitet werden. Binnen kurzer Zeit wurde die Produktion verdreifacht, und neue Produkte wurden in das Produktionsprogramm aufgenommen.

Dann brach 1940 der Krieg aus. Bomben und Sabotage verursachten grosse Zerstörungen auch an mehreren Fabrikanlagen von Norsk Hydro. Aber bereits das erste Jahr nach der Befreiung arbeiteten die Fabriken wieder voll und ganz. Allmählich wurde es auch möglich, Erweiterungen vorzunehmen. Neue Kraftwerke wurden in Betrieb genommen, und in 1949 wurden dann Glomfjord Fabriker in Nordland in Betrieb gesetzt.

Neue Produkte und Rohstoffe

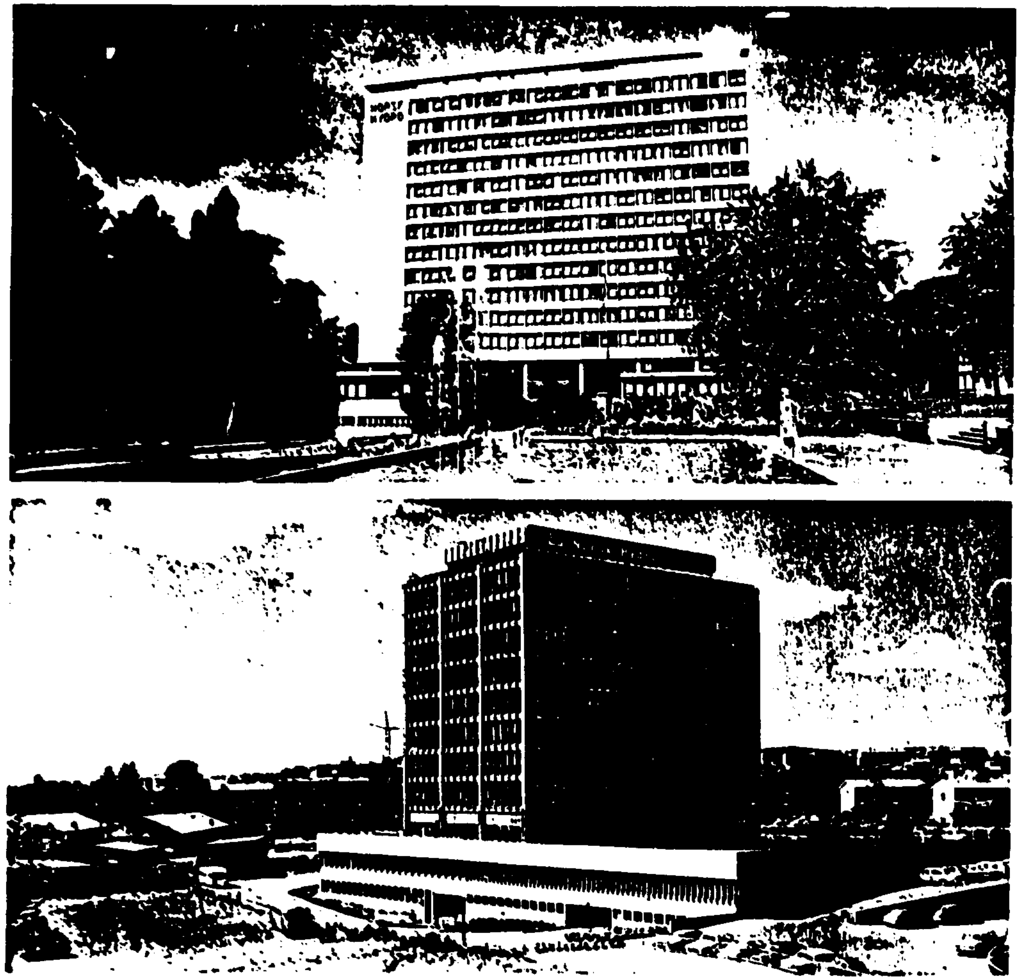
Nach 1945 hat sich Norsk Hydro in starker Expansion befunden, mit grossen Investitionen in Erweiterungen und Neu-Anlagen.

Das Produktionsvolumen für die Stickstoffprodukte wurde verfünffacht, und gleichzeitig sind neue techno- und petrochemische Produkte wie Aluminium, Magnesium und Kunststoffrohstoff hinzugekommen.

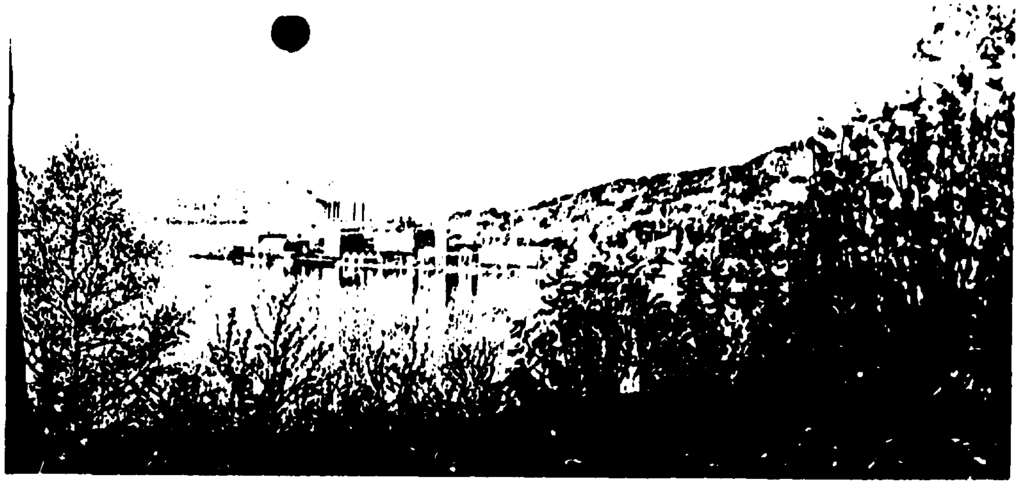
Ab Mitte der 60er Jahre sind ausserdem entscheidende Änderungen in der Rohstoff- und Energiegrundlage für Stickstoffdünger eingetreten, der immer noch die wichtigste Produktgruppe des Unternehmens ist. Die Fertigung wurde auf Öl umgestellt. Während der Wasserstoff für Ammoniak früher durch Elektrolyse von Wasser hergestellt wurde, wird er jetzt durch Spaltung von Öl oder Öldestillaten und Wasser in einem petrochemischen Verfahren hergestellt. Damit ist die Zeit vorbei, wo man von grossen Mengen elektrischer Energie zur Herstellung von Kunstdünger abhängig war.

Die Wasserkraft konnte demzufolge für andere und höherwertige Produkte freigemacht werden.

Norsk Hydro baute als Konsequenz der Entwicklung zwei grosse neue Ammoniakfabriken auf Herøya, auf der Basis von Schweröl und dem Öl-Destillat Naphtha als Rohstoff.



Norsk Hydros Hauptverwaltung in Bygdoy allé im Zentrum von Oslo und Lørenfaret 3 in Oslo/Økern



Norsk Hydro Notodden Fabrikker liegt an dem Binnensee Heddalsvannet

Schweissarbeiten in der Zentralwerkstatt

Von der Sackfabrik

Die Hauptverwaltung

Die Hauptverwaltung des Konzerns liegt in Bygdoy allé 2 in Oslo. Das Gebäude wurde von dem Architekten Erling Viksjo entworfen, und wurde im Dezember 1960 bezogen. Um das Gebäude herum hat die Gesellschaft einen 12.000 m² grossen Park angelegt

Der Kunstmaler Jakob Weidemann hat die grossen Wandflächen des Vestibüls dekoriert.

Der grosste Teil von Hydros Hauptverwaltung ist in diesem Gebäude konzentriert, und von hier aus wird die weltumspannende Tätigkeit der Gesellschaft gesteuert.

Seitdem die Büroräume im Jahre 1960 bezogen wurden, hat sich die Anzahl der Mitarbeiter verdoppelt. Dies hat dazu geführt, dass die Gesellschaft in 1975 ein grösseres Bürogebäude auf Økern/Oslo gekauft hat, wo u.a. die Engineering-Division und verwandte Tätigkeiten ihren Sitz haben. Die eigene Versicherungsgesellschaft der Norsk Hydro, Industriforsikring A/S, ist ebenfalls dort untergebracht. Im ganzen arbeiten ca. 300 Personen in Økern, während rund 500 ihren Arbeitsplatz in Bygdoy allé haben.

Die Abteilung der Öl-Division für Erforschung und Produktion hat ihren Sitz in Sandvika in der Nähe von Oslo mit ca. 100 Angestellten.

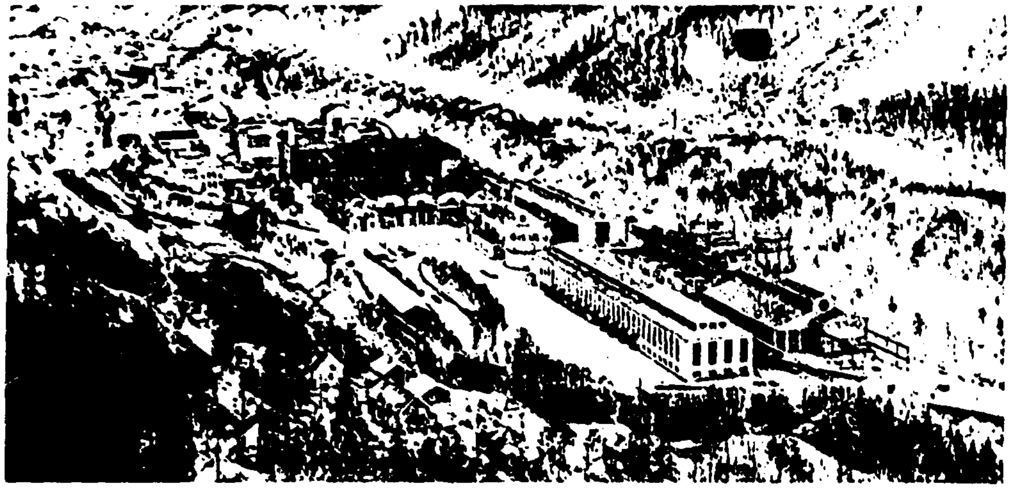
Notodden Fabrikker

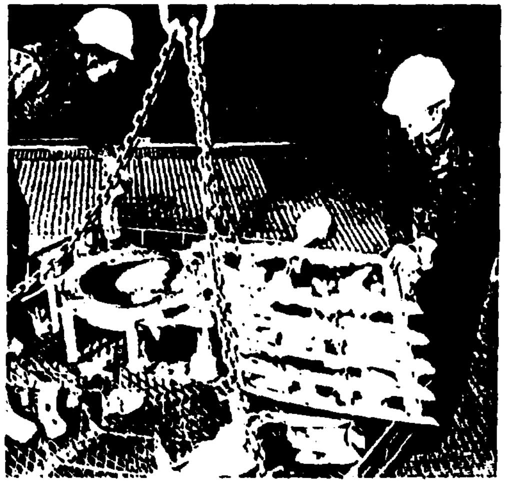
Die erste Fabrikanlage von 1905, Notodden Fabrikker, hat im Laufe der Jahre erhebliche Veränderungen erfahren. Die Salpeterproduktion, die die Grundlage für Norsk Hydros weitere Entwicklung und Wachstum geschaffen hat, begann bereits Ende der zwanziger Jahre nachzulassen, da Ammoniak das wichtigste Produkt wurde. Aber auch Ammoniak fiel weg beim Übergang zur petrochemischen Herstellung auf Heroya Ende der sechziger Jahre. Stattdessen wurden jetzt in Notodden Fabrikker mehrere interne Hilfsbetriebe der Gesellschaft eingerichtet

Eine Verpackungsfabrik wurde bereits 1935 erstellt, eine Anlage fur Vernickelung von Elektrolyseuren kam hinzu, und 1957 wurde die Zentralwerkstatt der Gesellschaft nach Notodden verlegt

Diese Tätigkeiten haben sich mit der Zeit zu selbständigen Produktionseinheiten entwickelt. Die Zentralwerkstatt hat sich auf Maschinen- und Anlagenbau spezialisiert, und die Verpackungsfabrik produziert Kunststoff- und Papiersäcke mit einer jährlichen Kapazität von uber 50 Millionen.

Ein ganz neuer Produktionszweig, der 1968 aufgenommen wurde, umfasst die Herstellung der Laminate Respatox und Respalit sowie [illegible] platten und Einrichtungen aus Laminaten

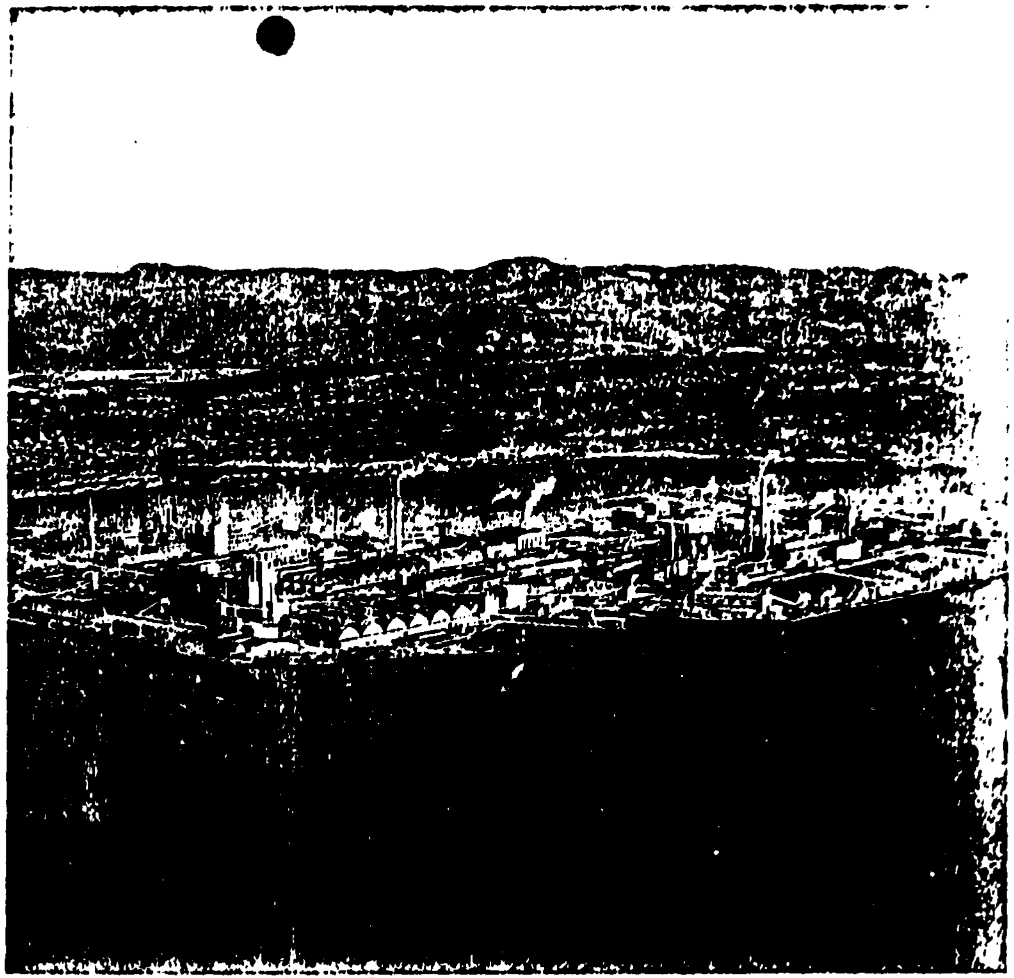




Norsk Hydro Rjukan Fabrikker liegt in Vestfjorddalen

Sandgiessen in der Leichtmetallgiesserei

Industriegase werden in Flaschen und Fassern geliefert



Der grosste Arbeitsplatz Norwegens, Porsgrunn Fabrikker auf Heroya

Rjukan Fabrikker

Rjukan Fabrikker ist seit 1911 in Betrieb und war nach der Produktionsumstellung Ende der 20er Jahre der grosste Lieferant der Gesellschaft von Ammoniak. Wegen hoher Frachtkosten und Ubergang zur billigeren Ammoniakproduktion auf Ölbasis in Heroya wurde Norsk Hydro in den 60er Jahren gezwungen, die Produktion auf Rjukan umzustellen und den Stromüberschuss nach Heroya zu leiten, wo er sich besser ausnutzen liess.

Ausser Ammoniak auf Elektrolysebasis, produzieren Rjukan Fabrikker heute verschiedene Sorten Dungemittel, Industriechemikalien, Edelgase und Schwerwasser (Deuteriumoxid). Die funf Kraftwerke der Fabrik in Vestfjorddalen haben eine installierte Leistung von 423.000 kW, die ca. 35 Prozent des Gesamtbedarfs des Unternehmens decken.

Nach der Umstellung wurde seitens Norsk Hydro intensiv daran gearbeitet, Rjukan neue Industrien zuzuführen, teilweise auch mit anderen Firmen.

Eigenerseits hat der Konzern die Norsk Hydro Verksteder Rjukan gegründet, als Produktionsstatte mit drei Fertigungszweigen: Leichtmetallgiesserei, Ventilfabrik und Produktionsabteilung fur Fernsteuerungen fur Ventile und für den Schiffbau

Porsgrunn Fabrikker

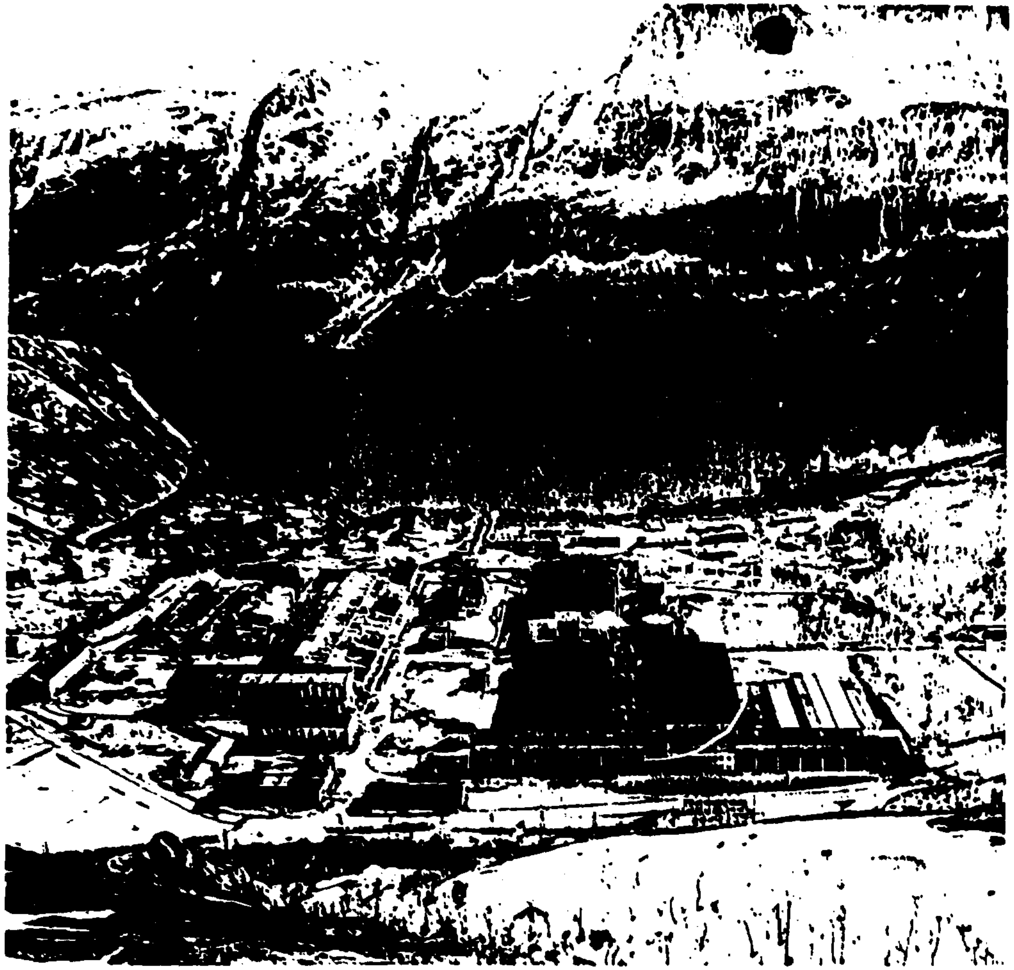
Der Aufbau von Porsgrunn Fabrikker in 1928 leitete eine kräftige Expansionsperiode für Norsk Hydro ein. Die technische Entwicklung ermoglichte jetzt die Übertragung von Strom über weitere Entfernungen, und die Gesellschaft konnte daher ihre neue Produktionsstätte an den Versandhafen legen. Die Fabrik wurde auf Heroya in Eidanger gebaut und entwickelte sich rasch zum grossten Produktionsbetrieb der Gesellschaft.

Die Hauptprodukte sind Volldünger, Kalksalpeter, Ammoniak und Harnstoff, mit zuhörigen chemischen Nebenprodukten, insgesamt mehr als 30 an der Zahl.

Die Magnesiumfabriken sind die zweitgrösste in der westlichen Welt. Hier werden Magnesiumoxid und -Metall sowie das wertvolle Nebenprodukt Chlor erzeugt. In der Kunststoffabteilung, dient eine Fabrik zur Herstellung von Kunststoffrohstoffen (Norvinyl PVC), Natronlauge und Chlor.

Das Forschungszentrum der Norsk Hydro liegt hier in direktem Kontakt mit der Industrieumwelt und umfasst eines der produktivsten Zentren für die praktische und technische naturwissenschaftliche Forschung des Landes.

Porsgrunn Fabrikker ist mit ihren ca. [illegible] Angestellten der grosste Arbeitsplatz Norwegens.



Norsk Hydro Glomfjord Fabrikker liegt in Nordland, 8 Kilometer südlich von Bodo

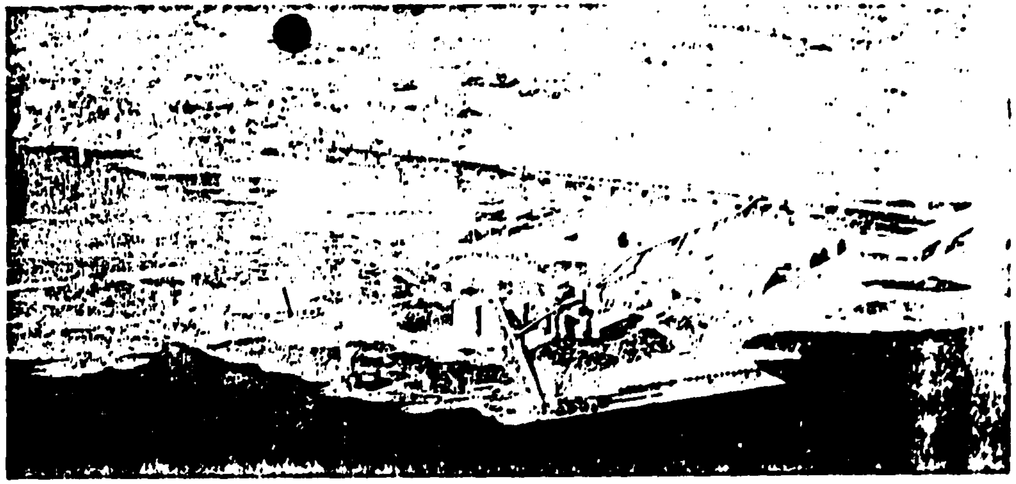
Glomfjord Fabrikker

Glomfjord Fabrikker ist die nördlichste von Norsk Hydros Produktionsstätten.

Die Tätigkeit begann hier am 1. Juli 1949, nachdem Staat und Gemeinde es hier mit Zink- und später Aluminiumproduktion versucht hatten. Glomfjord Fabrikker wurde zunächst gebaut für die Produktion von Ammoniak zur Weiterveredelung in den Anlagen der Gesellschaft auf Heroya. 1955 jedoch bekam Glomfjord eigene Fabriken zur Herstellung von Volldünger und Kalksalpeter, und ist seitdem der Hauptlieferant von Handelsdünger für die norwegische Landwirtschaft geworden.

Die Produktionskapazität für Endprodukte stieg in 1972 um 50 Prozent, und insgesamt produzieren Glomfjord Fabrikker jetzt rund 600.000 Tonnen jährlich, auf eigener Ammoniakbasis mit einigen Zulieferungen von aussen. Die Fabrik erzeugt auch Schwerwasser.

Glomfjord ist heute eine gesunde Industriegemeinde von ca. 2000 Einwohnern. Es ist viel getan worden, damit die Einwohner sich wohl fühlen sollen, und Norsk Hydro hat grosse Beträge für den Wohnungsbau investiert und mit zum Bau einer Kirche, eines Restaurants, Hotels und Sportanlagen beigetragen. Eine Drahtseilbahn führt die Leute in das schönste Gebirgsgelände hinauf.



Norsk Hydro Karmøy Fabrikker.

Flussiges Aluminium wird in Formen gegossen.

Transport von flussigem Metall von der Elektrolysehalle zur Giesserei

Karmøy Fabrikker

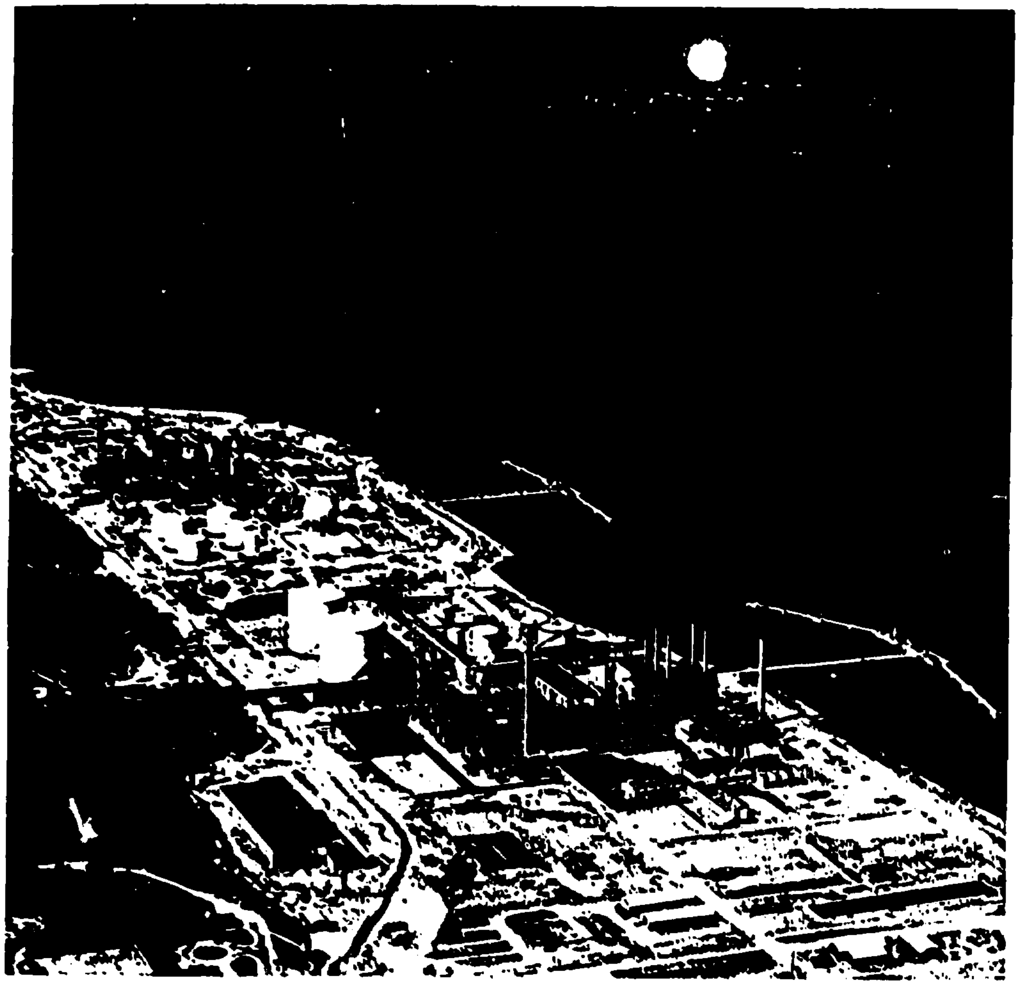
Karmøy Fabrikker bei Karmsundet gleich südlich von Haugesund ist mit ihren gegen 1300 Angestellten die zweitgrösste Arbeitsstätte der Gesellschaft.

Die beiden Elektrolysehallen wurden 1967 in Betrieb genommen. Im Oktober 1969 war die ganze erste Baustufe fertig mit Elektrolyse, Giesserei, Walzwerk, Grobdrahtwerk und Presswerk. Die Elektrolysekapazität wurde in 1971 um 25 Prozent erweitert.

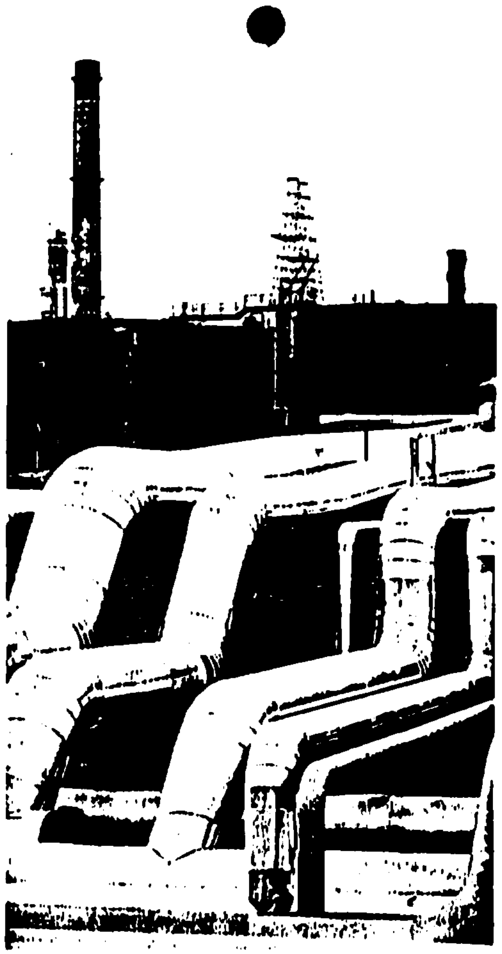
Karmoy Fabrikker wurde ein zu 100 Prozent norwegischer Betrieb, als Norsk Hydro in 1973 das gesamte Aktienkapital der Alnor Aluminium Norway A/S übernahm, von dem sie bereits 51 Prozent seit Gründung der Gesellschaft in 1963 in ihrem Besitz hatte.

Die Lage in Karmoy erlaubt es, die Produktionskapazität stufenweise auf 200 000 Tonnen Hüttenaluminium oder mehr pro Jahr zu steigern.

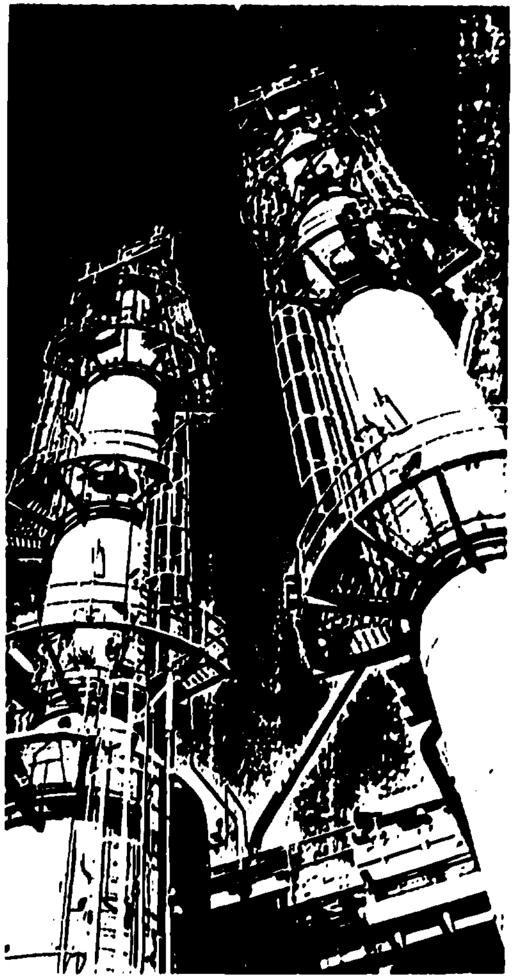
Schon von Anfang an wurde ein bedeutender Teil der Produktion an Ort und Stelle veredelt. Ausser in Norwegen besitzt die Gesellschaft Veredelungsbetriebe und Verkaufsbüros in Belgien, Dänemark, Frankreich, Grossbritannien, der Schweiz, Schweden, West Deutschland und Österreich.



Der Rafneskomplex umfasst je eine Fabrik für Vinylchlorid und Chlor



Norsk Hydro war der Bauherr für die Mongstadraffinerie Rafinor



Aus der Raffinerie

Rafnes

Rafnes in Bamble, auf der Westseite des Frierfjords direkt gegenuber von Porsgrunn Fabrikker, wurde in 1967 von Norsk Hydro als Industriegebiet fur die Erweiterung ihrer Tätigkeiten eingekauft.

Dieser Komplex mit petrochemischen Fabriken ist das bisher grösste Industrieprojekt in Norwegen Hydro war Planer und Bauherr fur die Anlagen von denen ihr die Vinylchloridfabrik zu 100 %, die Athylenfabrik zu 51 %, und die Chlorfabrik zu 50 % gehören, ausserdem leitet Hydro den Betrieb aller drei Fabriken.

Die Athylenfabrik ist der Kern des Komplexes, und soll aus Feuchtgas von Ekofisk 300 000 Tonnen Athylen und 70 000 Tonnen Propylen im Jahr erzeugen. Diese Produkte sind Rohstoffbasis für die übrigen Anlagen auf Rafnes und für die neuen Polyolefinfabriken auf Rønningen in unmittelbarer Nähe.

Die Vinylchloridfabrik veredelt Äthylen und Chlor weiter zum Zwischenprodukt Vinylchlorid, das Rohstoff für die PVC-Herstellung auf Heroya ist. Die Jahreskapazität beträgt 300.000 Tonnen.

Die Chloridfabrik produziert Chlor für die Vinylchloridproduktion, und Natronlauge, die in der Holzveredelung und in anderen chemischen Industrien verwendet wird.

Mongstad

Norsk Hydro übernahm 1971 ein 7.000.000 m² grosses Ausbaugebiet auf der Mongstad-Halbinsel 60 km nördlich der Stadt Bergen.

Nordhordland ist lange ein Notstandsgebiet mit grossem Mangel an Arbeitsplätzen gewesen, und es war für die örtlichen Behörden von grosser Bedeutung, diesen Zustand zu ändern.

Als erste Stufe in Norsk Hydros Industrieplan für Mongstad hat die Gesellschaft die Ölraffinerie Rafinor errichtet. Die Raffinerie kam im Frühjahr 1975 in Betrieb mit einer Produktionskapazität von vier Millionen Tonnen Öl im Jahr

Die Produktion umfasst Raffinerieerzeugnisse wie Heizol, Benzin, Naphtha Autodiesel Paraffin usw Ausserdem werden rund 160 000 Tonnen Petroleumkoks produziert, welcher ein wichtiger Hilfsstoff fur die Aluminiumproduktion ist und der früher vollständig importiert werden musste Die Mongstad-Raffinerie ist die einzigste in Skandinavien, die Anlagen fur eine solche Koksproduktion besitzt.

Norsk Hydro beteiligt sich mit 30 Prozent an der Raffinerie. Rafinor hat dem Bezirk 350 Dauerarbeitsplätze gebracht

Norsk Hydro betrachtet Mongstad als ein wichtiges Erweiterungsgebiet fur die Zukunft

ATTACHMENT IX

Calciumcarbide Technology

UHDE

Calcium carbide technology

ATTACHMENT IX

based on the know how of
Hoechst AG/Knapsack works,
SKW Trostberg AG
and Uhde GmbH

1.0 Introduction

Table of contents

1.1 Old and new fields of application for calcium carbide

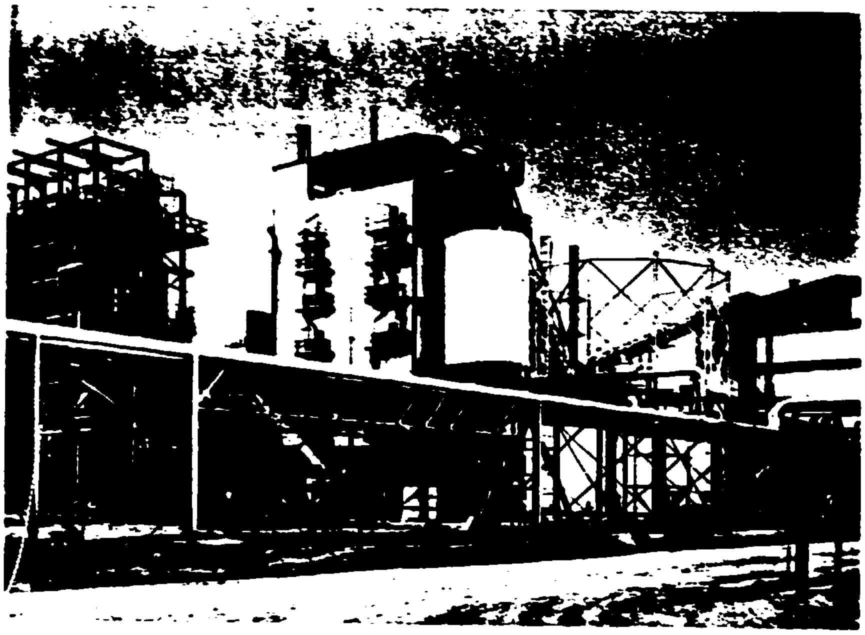
The world production of calcium carbide, which reached its peak in about 1960, suffered a drastic decline of some 40% in the course of the following 20 years. This decline was mainly due to two reasons: firstly, the switch from acetylene to ethylene as a starting material for virtually all organic bulk products and, secondly, the fact that calcium cyanamide was largely superseded by other synthetic fertilizers.

The spectacular rise in the price of crude oil in recent years is likely to improve the competitive position of acetylene as a chemical starting material in those countries where lime, coke or other carbonaceous materials and electric power are available at relatively low cost.

The further processing of acetylene to important derivatives in large-scale plants is gaining significance.

The "family tree" illustrated on page 3 shows the various fields of application of carbide. Uhde can offer the know-how required for all these processes.

Carbide plant with acetylene generator



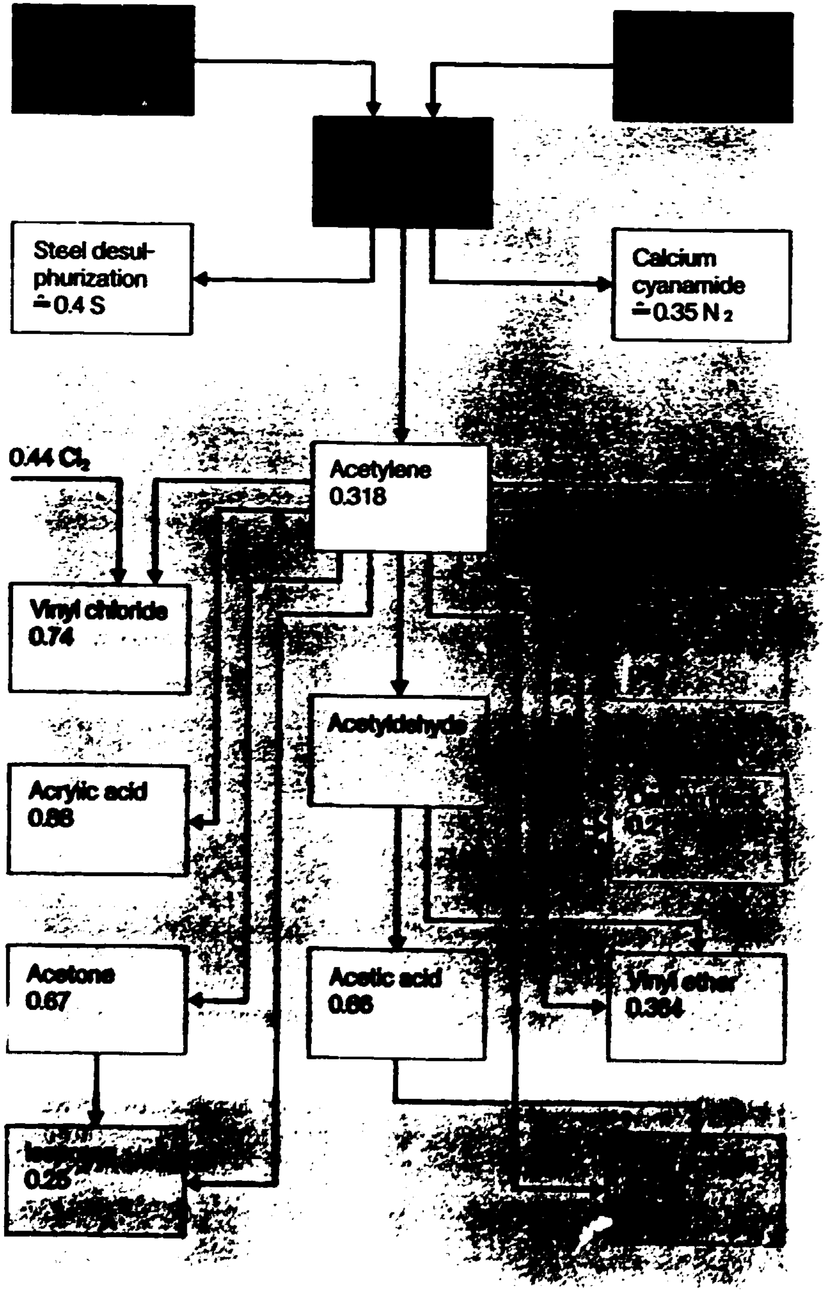
1.2 The Uhde know-how

The design and construction of plants for the production and further processing of calcium carbide is one of Uhde's many fields of activity. Well-proven processes are available for processing calcium carbide to acetylene, calcium cyanamide, carbon black and organic products, such as polyvinyl chloride and vinyl acetate.

Acetylene is also a suitable starting material for the production of synthetic rubber (polyisoprene) as well as acrylonitrile, acrylic acid and butindiol.

Knapsack, an affiliate of Hoechst AG, and SKW Trostberg AG are mass producers of carbide and a number of derivatives. They have acquired a wealth of operating experience over 70 years and this is incorporated into Uhde's engineering work. Each project handled by Uhde therefore corresponds to the latest state of technology and ensures maximum profitability.

The high degree of cooperation between Hoechst, SKW and Uhde permits a constant and speedy feedback of experience between plant operators, process engineers and design engineers.



"Family tree" for carbide. The figures in tons refer to 80% calcium carbide.

2.0 Criteria for the design of a carbide plant

The reference list documents Uhde's broad spectrum of know-how in the field of electrothermal processes (production of carbide, phosphorus, etc.) gained from the design of commercial plants, including civil works, erection and commissioning.

All this experience has been used to develop the plant components which form the basis of modern carbide technology.

☐ Closed type of furnace

☐ Hollow electrode system

☐ Dry purification of the hot furnace gases

☐ Manufacture and application of Soederberg electrodes

☐ Dry gasification of carbide and purification of the acetylene

☐ Recycling of lime from the carbide gasification unit

☐ Continuous nitrification of carbide to produce calcium cyanamide

2.1 Plant size and selection of location

The selction of the location is mainly governed by the size of the plant and the intended application for the carbide.

Carbide furnaces are operated at powers of 4 to 60 MW in all parts of the world (approx. 10000 to 15000 tpa).

However, further processing to acetylene derivatives is only interesting from the economic point of view for plants with furnace ratings of approx. 20 MW and above. In this case a well-established infrastructure is also necessary.

Smaller plants rated between roughly 10 and 20 MW can only cover a limited market for the production of welding gas or calcium cyanamide.

Another criterion for the selection of the location is the availability of the feedstocks and electric power.

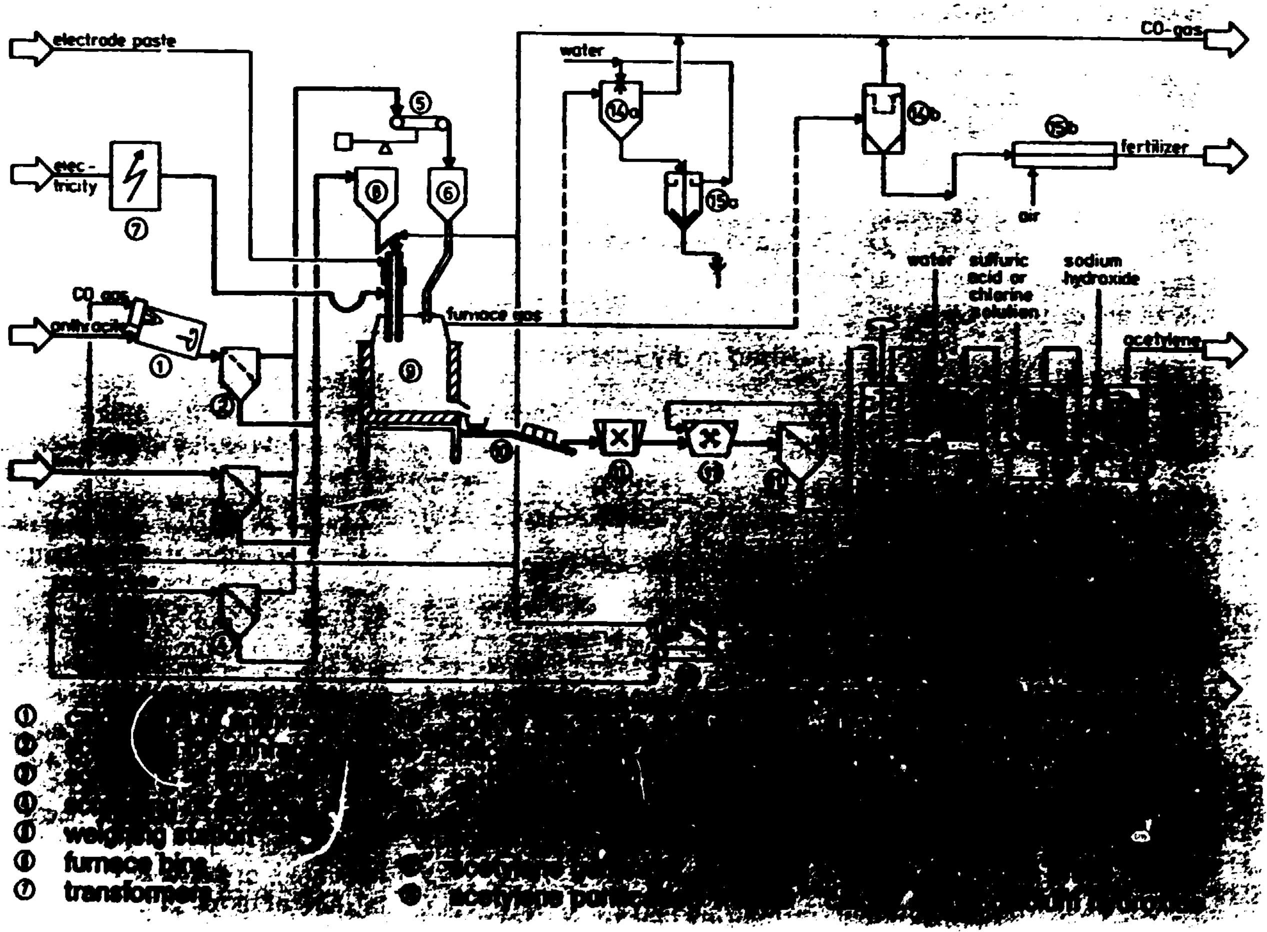
Large-scale furnaces are dependent on a reliable supply grid.

Developments such as the hollow electrode system, the dry purification and utilization of the furnace gas as an energy carrier and the use of the screened fines as the burden are of interest for furnace ratings of 10 MW and above.

In addition, lime recycling, the closed type of furnace and computer control of the furnace are of importance for the economical operation of large-scale furnaces.

The next diagram gives a general idea of the process configuration of a carbide plant with hollow electrode system, acetylene generation and lime recycling.

Flowsheet
carbide / acetylene complex


electrode paste
elec-tricity
⑦
CO gas
anthracite
①
②
⑤
⑥
⑥
⑨
furnace gas
water
⑭a
⑮a
CO-gas
⑭b
⑮b
fertilizer
air
water
sulfuric acid or chlorine solution
sodium hydroxide
acetylene
①
②
③
④
⑤ weighing station
⑥ furnace bins
⑦ transformers
acetylene puri

2.2 Feedstocks

The feedstocks have a decisive influence on the quality of the product and the economical utilization of electric power as well as on the smooth running of the furnace.
It is therefore essential that they comply with certain requirements in respect of composition, physical properties and grain size distribution.

The following data are of decisive importance:

☐ electric conductivity and reactivity of the carbonaceous material

☐ grain size, abrasion resistance, compressive strength of carbonaceous material and lime

☐ softening point of the Soederberg paste

☐ grain size distribution.

In order to ensure smooth operation of the furnace, the coarse burden must not contain any appreciable quantity of fines below 6 mm. A reasonably uniform grain size distribution will counteract dissociation phenomena and improve the operating characteristics of the furnace.

The application of hollow electrodes permits the use of inexpensive fines below 6 mm at a rate of up to 20% of the total feedstock.
It also facilitates intervention by plant personnel and reduces the electrode consumption rate.

The upper limit for the grain size of the carbonaceous material depends on the reactivity. The portion below 6 mm should be kept as low as possible.

☐ Analysis

Lime (referred to dry substance)

CaO:	92–95%
CO_2:	1– 3%
$Fe_2O_3 + Al_2O_3 + SiO_2$:	max. 3%
MgO:	max. 2%
P_2O_5 and SO_2:	as low as possible

Carbonaceous material
(referred to dry substance)

Example	Coke	Anthracite
C:	> 85%	> 80%
Ash:	max. 12%	max. 8%
S:	max. 1.3%	max. 1%
P:	max. 0.05%	max. 0.05%

Volatile matter:	1–2%
Total ash content of burden:	max. 15%
Recycled lime:	max. 50%

If all or some of the calcium carbide is intended to be converted to acetylene in dry generators in the vicinity of the carbide furnace unit, it is possible to recycle the calcium hydroxide at a rate of up to 50% of the total lime required for the furnace operation. The accumulation of impurities prohibits a higher recycle rate. The surplus calcium hydroxide can be used in the building trade or as fertilizer. No further treatment is required because of the low residual moisture.

The recycling of the calcium hydroxide basically comprises a briquetting and a calcining step, for which carbide furnace gas can be used as fuel gas.

Various types of carbonaceous material, for example metallurgical coke, petrol coke, charcoal and anthracite, etc., are suitable for the carbide production process.

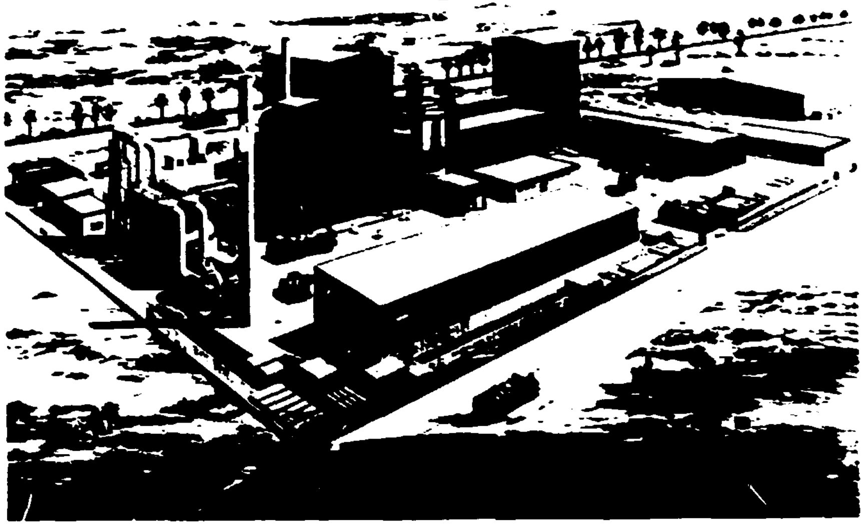
Carbonaceous materials with a high content of volatile matter, e.g. anthracite, can only be used to a limited extent in closed furnaces or must undergo previous calcination.

Assessment of the proposed carbonaceous material with regard to its suitability in a closed carbide furnace is one of the main tasks of the licensor and the project engineer. In many cases, final data cannot be elaborated until large-scale tests have been performed at Knapsack or SKW.

In some cases, an optimum furnace burden can be obtained by blending different carbonaceous materials.

The Soederberg electrode paste is manufactured from coke, calcined anthracite or petrol coke, and a mixture of tar/pitch of suitable quality and grain size. The mixture must satisfy the stringent requirements imposed on electrode compounds for modern electric furnaces with regard to the composition, mechanical and electrical properties.

Carbide plant with acetylene generator / Saudi Arabia
Top photo: plant model
Bottom photo: during erection



The consumption of Soederberg electrodes is 10 to 17 kg per ton of carbide for hollow electrodes in closed furnaces and well above 20 kg per ton of carbon for solid electrodes.

In open furnaces, the electrodes are subject to a higher burn-up rate due to the presence of air.

The specific electric power requirement of a carbide furnace mainly depends on the quality of the raw materials (ash content) and on the size and type of the furnace. Under favourable conditions, requirements of little more than 3000 kWh per ton of carbide (standard quality) may be expected. For smaller open furnaces fed with raw materials of varying quality, specific energy requirements of 3000 to 3600 kWh per ton of carbide are realistic figures.

Approx. 0.9 to 1 ton of CaO and approx. 0.5 to 0.6 tons of fixed carbon are required to produce one ton of carbide.

2.3 Product shipment

The location of a chemical plant mainly depends on the following criteria:

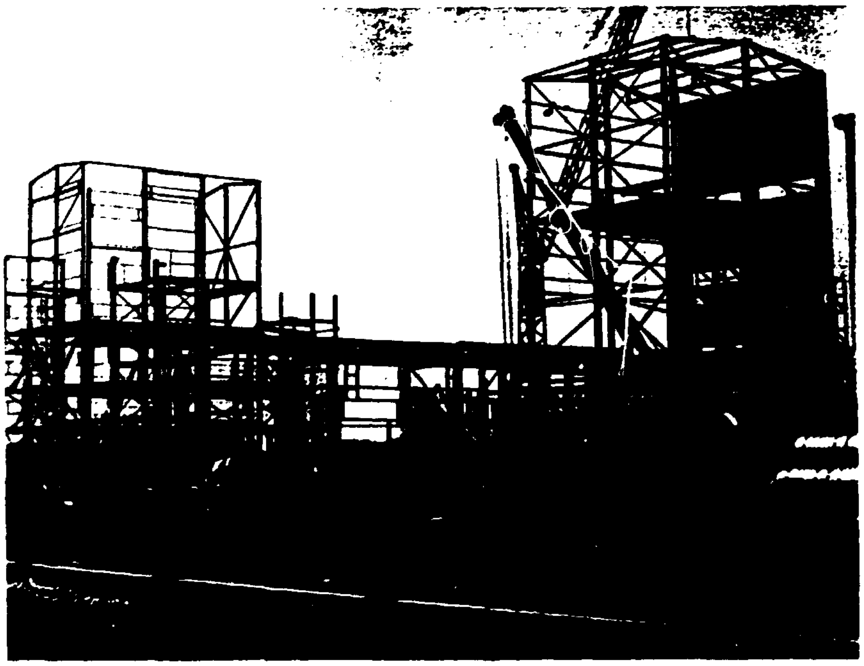
a) cost-effective raw material and energy supplies;

b) distribution of the product within the sales region

For a carbide furnace, the emphasis is on the availability of low-priced lime, carbonaceous material and electric power. Short distances to these resources are of particular advantage.

Calcium carbide, which is a valuable and energy-intensive product, can easily be transported over long distances (energy transportation). Drums with a capacity of 100 to 250 kg, small containers for one ton and large containers for up to 20 tons are recommended types of packing.

The particular requirements for transporting the product are satisfied by special containers which are also part of the know-how of Hoechst and Uhde. They can be used both for land and maritime transport.



3.0 Principal characteristics of carbide plants designed by Uhde

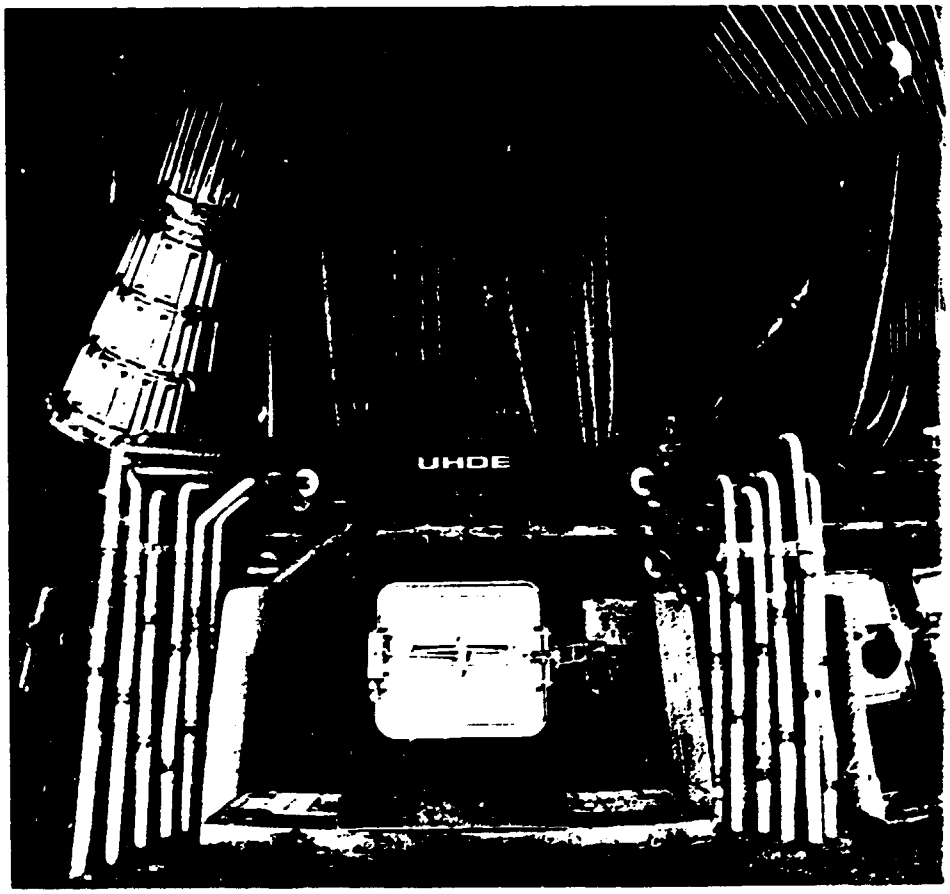
3.1 Furnace design

The furnace may be of the open, semi-closed or closed type, depending on the capacity of the furnace and the intended applications of the furnace gas.

An open furnace with a suction hood is suitable for low capacities and requires lower capital investment costs compared with the semi- or totally-closed types. In this case the energy is not recovered from the furnace gas.

With the aid of additional suction funnels which extend into the furnace burden, part of the unburnt furnace gas can be withdrawn. This will reduce the quantity of exhaust gas and lower the heat load on the electrode components. This is a semi-closed furnace. Up to 80% of the furnace gas can be recovered and used for heating purposes, for example.

Open furnaces designed and constructed by Uhde can be equipped with hoods or retrofitted for use as semi-closed furnaces.



Closed furnace designed by Hoechst-Knapsack

A closed furnace ensures complete recovery and treatment of the carbide furnace gas. This type of construction is mainly suitable for high furnace ratings. Uhde offers carbide furnaces rated up to 70 MW, which are capable of producing more than 170000 tons of carbide per year, provided that a continuous power supply and good raw material qualities are available.

3.2 Treatment of the furnace gas

The furnace gas burnt with a high excess of combustion air in the open furnace is withdrawn and passed through a jet filter. The exhaust gas treated in this way is discharged with a dust content of approx. 50 mg/m_n^3.

On the other hand, semi-closed furnaces operate much more efficiently, because a large amount of the energy from the furnace gas can be recovered. In this case as well, the gas is passed though a filter.

However, because the temperature is much higher, ceramic filter cartridges are used. The greater portion of the hydrocarbons is condensed by means of indirect cooling, the condensate also being used for heating purposes.

The dust retained in dry state mainly consists of calcium oxide and magnesium oxide. It can be used as fertilizer after the noxious substances have been incinerated.

As an alternative to the dry purification process described above, Uhde can also offer a wet purification process. The furnace gas is scrubbed with recycle water which is treated for re-use in a separate unit. The scrubbing efficiency can be adjusted to meet different gas purity requirements which affect the capital investment and operating costs. The treatment of the scrubbing water involves relatively high operating costs, particularly in the case of small carbide plants. The amount of consequential capital investment costs depends on the requirements with regard to the waste water and on the extent of available treatment facilities.

The comments made with regard to closed furnaces also apply to semi-closed furnaces.

As the two latter-mentioned types of furnace are usually designed for higher capacities, it is recommendable to integrate them with lime recycling or anthracite calcining facilities or the hollow electrode system or a combination of these. Furnace gas is required for all these auxiliary installations.

3.3 Design of the electrode system

The electrodes used by Uhde are of the self-baking, continuously-operated Soederberg type. They are the most economical type for furnaces with ratings from about 10 MW upwards.

Electrode compound can often be procured from other manufacturers (aluminium or phosphate manufacturers). Electrode shells can be fabricated in a workshop equipped for this purpose. For large production units, in-plant manufacture of electrode compound and shells is worth considerating for economic reasons.

Installation of a central pipe in the Soederberg electrode permits the introduction of fines directly into the furnace hearth at a rate of up to 20% of the total feed, which greatly reduces the raw material costs and lowers the electrode consumption. As a rule, carbide furnaces with a rating higher than 30 MW should be equipped with hollow electrodes. Moreover, hollow electrodes are a prerequisite if a process computer is to be used for furnace control.

The electrodes are normally supplied with power via three single-phase transformers. It is also possible to use a single three-phase transformer in the case of smaller furnace ratings or if it is important to minimize capital investment costs. However, the alternative involving three single-phase transformers offers the following advantages:

☐ Symmetrical load of furnace and power mains.

☐ All three secondary power lines are short with consequent reduced electrical losses and uniform phase load.

☐ The weight of each transformer is relatively low and facilitates transportation; this also simplifies the design of the load-bearing structural members.

☐ In case of failure of one transformer, the furnace can continue to be operated at reduced output if the unbalanced load is acceptable for the mains.

Adjustment of the electrodes as a function of consumption and the raising and lowering to permit electric control of the furnace are effected fully automatically by means of a hydraulic system (illustrated).

Hydraulic system for electrodes

3.4 Dry acetelene generators

Wet acetylene generators are suitable for converting calcium carbide to acetylene where small quantities of acetylene are needed for use as welding or flame-cutting gas or as fuel gas in steel processing shops and in cylinder filling stations. For large volumes of acetylene, preference should be given to special dry generators, which have already proved their merits in decades of operation.

The special design of the dry acetylene generator permits a near-stoichiometric conversion of carbide and water to acetylene so that the residual calcium hydroxide has a moisture content of only 1–4%. Compared with an aqueous calcium hydroxide suspension, this offers a number of advantages which contribute to the economy of the process:

a) Fabrication of briquettes for the lime recycling mentioned above (refer to Section 3.3).

b) Utilization of calcium hydroxide in the building trade, chemical industry, for waste-water treatment and agricultural purposes, etc.

c) Easier handling if the calcium hydroxide has to be dumped for lack of markets.

The acetylene yield is approx. 98%; carbide consumption figures are based on a specific yield of 280 litres of acetylene per kg of calcium carbide.

Scrubbing with lime water and a chlorine solution are the only operations required before the acetylene can be used as welding or flame-cutting gas or as fuel gas.

The acetylene must be subjected to chemical purification if it is intended to be used as a feedstock for the synthesis of higher molecular compounds.

3.5 On-stream time, flexibility of carbide production

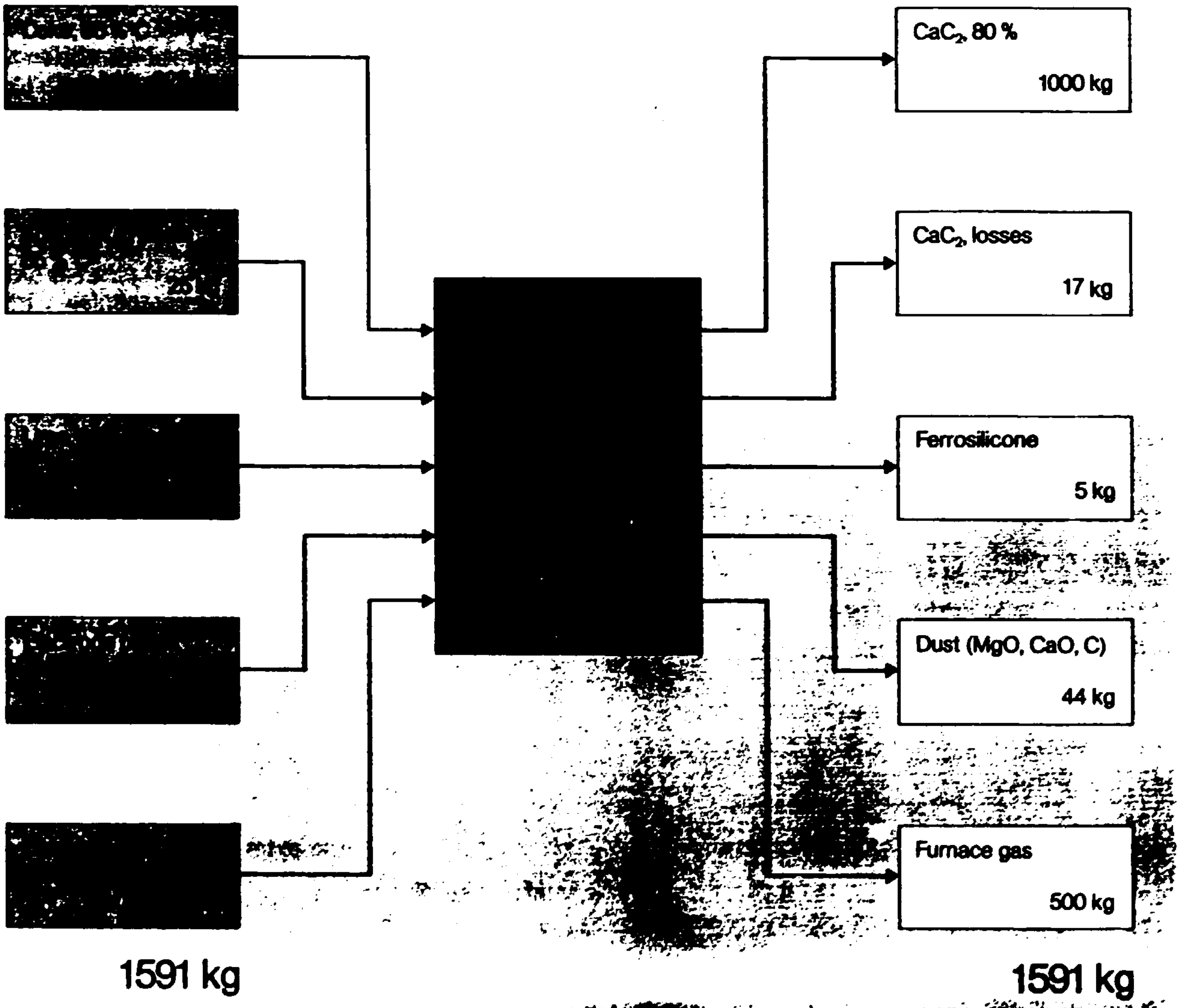
Carbide furnaces designed according to the know-how of Hoechst, SKW and Uhde are backed up by technological features proven in decades of operation and have evidenced high on-stream time and profitability. This puts the plant user in a favourable position for negotiating electric power supplies at special rates with the public utilities companies. Carbide furnaces of this type are capable of ensuring a constant basic load and can be operated along an individual power supply schedule to benefit from special rates.

It is this flexibility that is likely to yield a substantial cost advantage through preferential power prices because electric power is generally the major item for the plant operating costs.

This is bound to reduce the yield per unit of time, referred to full-load conditions, and must be compensated by a higher capacity of the production unit.

The extra costs will be quickly absorbed even if the power price reductions are only low.

4.0 Material balance for the production of carbide



5.0 Conclusion

Calcium carbide is gaining increasing significance as a starting material for the production of plastics and other organic products. The main reason is the rise in crude oil prices. For countries without appreciable national oil resources, this offers a possibility for setting up or expanding industrial facilities for the production of organic chemical products on the basis of alternative starting materials and energies derived from acetylene. Where raw materials available from domestic sources, markets and sales prices are substantially shielded from external influences.

Well-established technologies are applied for the electrothermal carbide process to meet the standards of modern chemical plants.

These technologies are applied for the electrothermal carbide process to meet the standards of modern chemical plants.

These technologies are available to Uhde. A careful analysis and a comparison of cost calculations on the basis of different raw materials ensure an optimized plant concept for each project.

In making a decision on the location of the plant, particular attention should be paid to the transportation of utilities, raw materials and products. In this respect Uhde can give expert advice by proposing different handling concepts, some of which are novel. Large-scale carbide furnace units may nowadays be built even in places which are remote from consumer markets. For these large-size furnace units, all process modifications outlined in this review provide significant improvements with regard to the economics and operating characteristics of the plant.

Uhde also has a broad spectrum of technologies for the production of acetylene from carbide, ethylene from crude oil, and their derivatives.

6.0 References
Calcium carbide and acetylene plants

Order date	Customer	Location	Products	Capacity	Type of plant	Process
1952	Imperial Chem. Industries	Melbourne Australia	Acetylene	2 x 750 m$_n^3$/hour	Dry acetylene generation	Knapsack/ Uhde
1958	Jugohrom	Skopje Yugoslavia	Granulated calcium cyanamide	30 000 tons/year (2 rotary furnaces)	Carbide preparation, furnace plant, bagging facilities	Knapsack
1960	Dynamit Nobel AG	Lülsdorf Fed. Rep. of Germany	Acetylene	400 m$_n^3$/hour	Dry acetylene generation, chemical gas purification	Knapsack/ Uhde
1960	N.V. Elektro-Zuur- en Waaterstoffabriek	Amsterdam The Netherlands	Acetylene	1050 tons/year	Dry acetylene generation, chemical gas purification	Knapsack/ Uhde
1960	Komplex	Budapest Hungary	Acetylene	2 x 400 m$_n^3$/hour	Wet acetylene generation, chemical gas purification	Knapsack/ Uhde
1960	Pechiney Compagnie des Produits chimiques et électro-métallurgiques	St. Auban France	Calcium carbide	100 000 tons/year (1 furnace, 42 MW)	Furnace plant, carbide cooling, crushing and screening facilities	Knapsac[illegible] Uhde
1963	Holland Elektro Chemical Industries	Ballengeich South Africa	Calcium carbide	24 000 tons/year (1 furnace, 10 MW)	Furnace plant, carbide cooling	Knapsack/ Uhde
1964	Dynamit Nobel AG	Lülsdorf Fed. Rep. of Germany	Acetylene	Expansion to 750 m$_n^3$/hour	Dry acetylene generation, chemical gas purification	Knapsack/ Uhde
1971	Lonza Werke GmbH	Waldshut Fed. Rep. of Germany	Calcium carbide	35 MW furnace capacity	Hollow electrode sytem	Knapsack/ UCC
1971	Zaklady Azotowe	Chorzow Poland	CO gas for org. synth.	6 x 20 (22) MW furnace capacity	Furnace gas dry purification system	SKW
1975	AECI Ltd	Sasolburg South Africa	Acetylene	5 700 m$_n^3$/hour	Carbide preparation, acetylene generation and purification	Hoechst-Knapsack, Linde, Uhde

Order date	Customer	Location	Products	Capacity	Type of plant	Process
1977	US Government	USA	Calcium cyanamide	15 000 tons/year	Carbide preparation, furnace plant, bagging facilities	Hoechst
1978*	Zaklady Azotowe	Chorzow Poland		3 x 18 t/h	Carbide classification and bagging facilities	Uhde
1980	Sentrachem Development and Technical Services	Newcastle South Africa	Carbide + acetylene	36 000 tons/year acetylene	Anthracite calcining, burden proportioning, hollow electrode, carbide furnace 50 MW, carbide cooling and crushing, acetylene generation + purification, lime recycling	Hoechst-Knapsack, Linde, Uhde
1981	Saudi Calcium Carbide Factory	Riyadh Saudi Arabia	Calcium carbide	10 MW furnace	Burden proportioning, carbide furnace 10 MW, carbide cooling, crushing and filling, drum manufacturing	SKW

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* Engineering

UHDE

Design and construction
of chemical and
other industrial plants

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Major fields of activity

- Refineries
- Syngas and synthesis processes
- Gas purification
- Coal technology
- Fertilizers
- Foodstuffs
- Breweries
- Biotechnology
- Plastics
- Synthetic fibres
- Organic chemicals
- Pharmaceuticals
- Cosmetics
- Electrolysis processes
- Nuclear technology
- Electrothermal processes
- Environmental pollution control
- Miscellaneous processes
- Civil engineering and erection
- Energy supply systems
- Infrastructure

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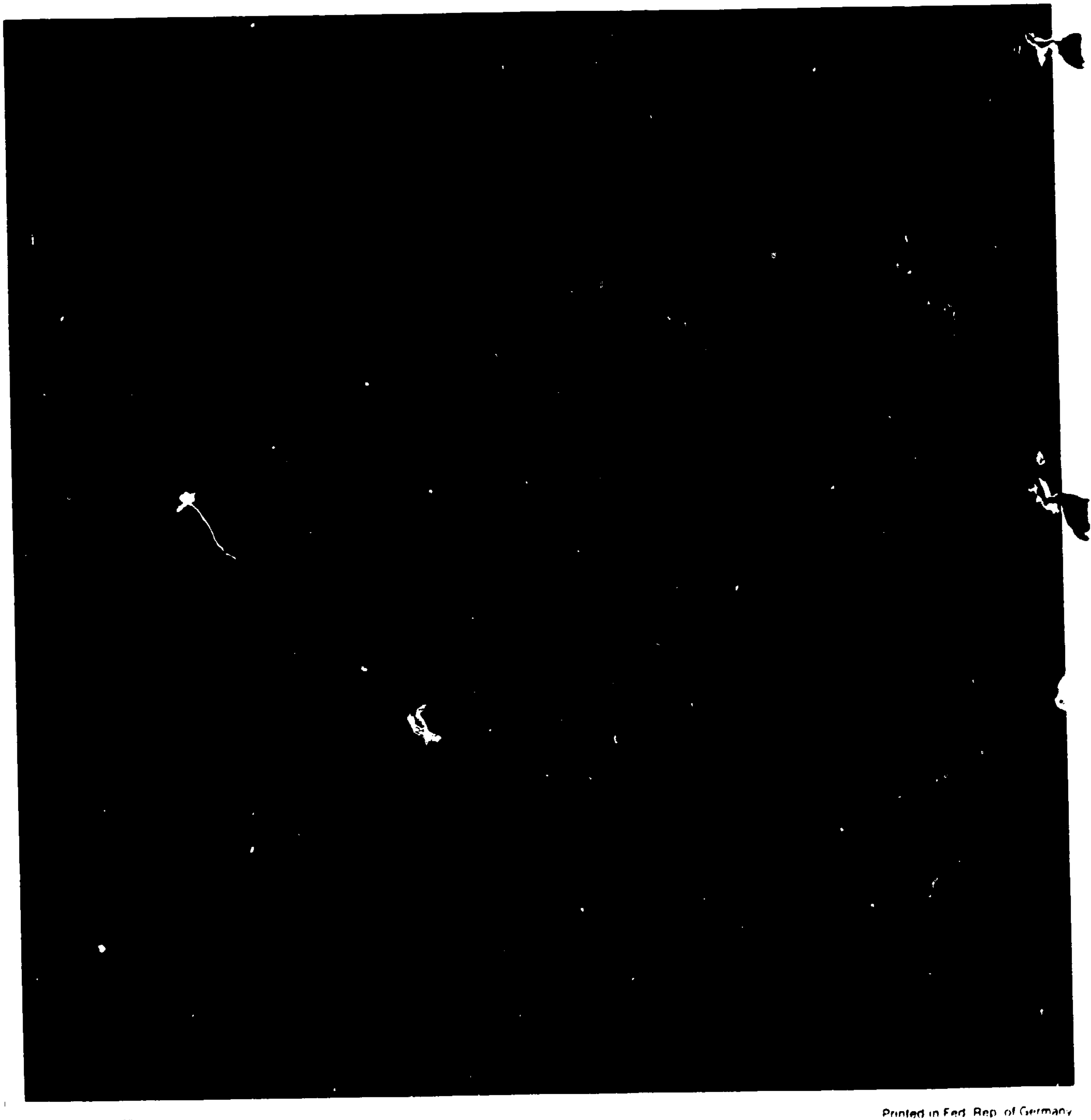

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