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Treatment of saline wastewater for zero discharge at the Debiensko coal mines in Poland

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Abstract

The drainage water from mines in Poland has a daily contribution of, in the order of magnitude, 6,500 tons of chlorides and 0.5 ton of sulphates to the rivers Vistula (Wisla) and Oder (Odra). The largest amounts of these salts, about 78%, derive from 18 mines located mainly in the Katowice mine district. The high salt content in the water from the Vistula prevents at present its use in agriculture and causes tremendous economic losses due to corrosion attacks on pipes, machines, etc., within the industry. At present only about 4% of the river water can be classified as drinking water. To combat this problem a desalination project in Katowice has now almost been completed, including advanced treatment of wastewater for zero discharge from the two adjacent coal mines, Debiensko and Budryk. It implies elimination of 310 tons/d of salt discharge to the Odra River. The complete treatment processes are divided into three main sections: (1) pretreatment before reverse osmosis (RO) of about 12,400 m^3/d drainage water from the two mines with a salinity of around 16,000 mg/l TDS on the average; (2) RO plant including post-treatment of the RO permeate; (3) a thermal plant for concentration of brine (about 4,600 m^3/d) and separation of sodium chloride (NaCl) by crystallization, centrifuging and drying. The RO pretreatment includes algicide dosing in a storage tank, disinfection, flocculation/sedimentation and dual media filtration as well as granular activated carbon filtration. After a two-stage microfilter system (50 μ and 5 μ, respectively), the pretreated water is desalinated at 6–7 MPa in a RO system with spiral wound RO membranes. The RO permeate is decarbonated in a part-flow followed by addition of chemicals for disinfection and increase of the temporary hardness before distribution in the drinking water net. The flow into the thermal plant consists of the RO reject (about 2,700 m^3/d) with a salinity of around 80 g/l TDS and the brine flow (about 1,870 m^3/d) from the Budryk mine with about the same salinity. The first section of the thermal plant is composed of two brine concentrators, designed by Resources Conservation Company (RCC), USA. By using the seed crystal recycling technique it is possible to concentrate the feed to near the precipitation point for NaCl. The second section of the thermal plant includes one crystallizer for production of NaCl, two pusher centrifuges for salt removal from supersaturated brine and one fluidized bed dryer. The crystallizer is a forced circulation submerged-tube evaporator equipped with a mechanical vapor compressor. An additional section is also planned to be constructed for treatment of the purge from the crystallizer in order to recover other valuable chemical products and distillate. The process is fully automatic and controlled by programmable logic controllers. The plant has finally been designed by Energotechnika, Poland, after preparation of technical and economical planning of the project in coordination with Nordcap Ltd., RCC and VBB Viak-SWECO, Stockholm. In the summer 1994 the thermal plant was started up, and the RO plant is expected to be in operation during the spring 1995. The paper covers the project design with illustrations of the main parts of the plant and summarizes the results of the initial operation.

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1. Introduction

A very ambitious environmental protection plan until the year 2010 has been presented by the Polish Government. At present only around 4% of the river water can be classified as drinking water, and a large part cannot be used for agriculture and industry. The discharge of phosphorus and nitrogen from the Vistula River to the Baltic Sea is very large and affects therefore all countries around the Baltic Sea. A special problem is the high salt content in the Vistula and Odra Rivers depending on the discharge of mine drainage water from the coal mines. Desalination plants will therefore be constructed according to the environmental protection plan. Such a desalination project has now been realized for treatment of drainage water from the coal mines at Debiensko and Budryk in the vicinity of Katowice.

The drainage water from mines has a daily contribution of, in the order of magnitude, 6,500 tons chlorides (Cl^-) and 0.5 ton sulphates (SO_4^{2-}) to the rivers Vistula and Odra. The largest amounts of these salts, about 78%, derive from 18 mines located mainly in the Katowice mine district. It has been estimated that the river Vistula contributes to about 55% of the water resources in Poland. About 35% of the water demand is withdrawn from the river Vistula itself. The high salt content in the water from the Vistula prevents at present its use in agriculture and causes tremendous economic losses due to corrosion attacks on pipes as well as machines and other equipment within the industry. The drainage problem has also intensified the severe lack of drinking water. During recent years the authorities in Poland have greatly increased the environment payment and penalty fees to mines draining their saline water to the rivers. The desalination project at Debiensko coal mines is regarded as a model for treatment of saline drainage at many other mines in Poland and throughout Eastern Europe.

The contractor of the new plant is a joint venture between the Swedish firms Axel Johnson International Ltd. and Nordcap International Ltd. Resources Conservation Co. (RCC), USA, is responsible for the thermal plant and VBB Viak-SWECO, Sweden, for the design of the RO plant including the pretreatment plant. Also Polish engineers from Energotechnika have been involved in the design of the new plant. During the construction, the technical staff from another Polish firm, Energomontaz, has planned organization of the erection work, designed assembling of the main equipment and pipelines and prepared numerous studies regarding welding high-alloy austenitic steels and connecting fiberglass reinforced epoxy pipes. The Swedish Technical Office, Katowice, has been a great help in solving many problems.

2. Project description

The desalination project in Katowice includes advanced treatment of wastewater for zero discharge from two adjacent coal mines, Debiensko and Budryk. The wastewater flow and salinity are about 8000 m^3/d and 9,900 mg/l, respectively, for Debiensko. The corresponding values for Budryk are about 4,440 m^3/d and 26,900 mg/l TDS. The complete treatment processes are divided into three main sections (Fig. 1):

- Pre-treatment before reverse osmosis (RO)
- RO-plant including post-treatment of the RO permeate
- Thermal plant for brine concentration and separation of NaCl by crystallization.

As valuable main products drinking water, distillate and sodium chloride for household and industrial use are obtained. Thickened pre-treatment sludge and separated calcium sulphate in the thermal plant are disposed of. No wastewater will accordingly be discharged from this plant.

3. Process description

3.1. Pretreatment section

The aim of the pre-treatment section is to ensure proper operation of the RO section. The

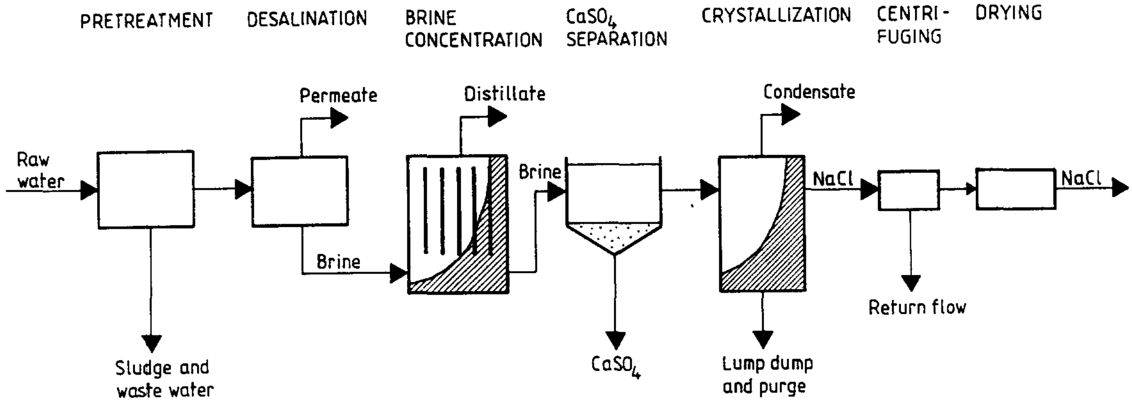

Fig. 1. Simplified process flow scheme.

water flow from each mine is treated separately according to the original design. Now it is possible to mix the water flows before RO to a desirable degree for optimization due to the changed raw wastewater composition.

The raw wastewaters from Debiensko and Budryk are pumped from two existing detention ponds equipped with algicide dosage, to the following pre-treatment stages before RO:

- pH adjustment with sulphuric acid, alum flocculation with a polymer as flocculation aid and sedimentation
- dual media filtration (sand+anthracite) with or without dosage of a polymer
- granular activated carbon filtration for removal of hydrocarbons due to occasional oil spills
- in-line dosage of sodium hexametaphosphate (SHMP) to prevent scaling on the membranes
- continous or intermittent dosage of disinfection chemicals such as sodium hypochlorite and sodium bisulphite (the latter also for dechlorination). During the summer period it may be necessary to dose an algicide in the detention ponds.

The sludge from the settling tanks and the clarified backwash sludge from the filters are thickened before disposal in sludge lagoons. The pretreatment has been tested both on laboratory and pilot plant scale.

3.2. Reverse osmosis section

3.2.1. RO desalination (Fig. 2)

The pretreated water from Debiensko and Budryk is desalinated in the RO plant. There are four RO lines in operation for Debiensko and three RO lines for Budryk. The number of stages in series is two and three, respectively.

After microfiltration in two filter stages in series (50 μ cleanable baskets and 5 μ cartridge filters), the pretreated water is pumped by high pressure pumps of the multi-stage centrifugal type to feed the separate RO lines. Each RO unit can be operated independently, which has advantages from the point of view of membrane cleaning and fluctuating feed flow.

The sulphuric acid injected in the pretreatment section of each plant is controlled by a pH analyzer after the microfilters. Each RO line has full instrumentation to ensure proper operation. Recorders are installed to determine the operational parameters.

The operating pressure is controlled by a regulating valve mounted at each pump discharge pipe. The reject flow can either be controlled by a "normal" reject flow controller or by the product flow meter to ensure maximum recovery at constant water conversion rate. Flow regulators as well as pressure regulators are controlled from the control room.

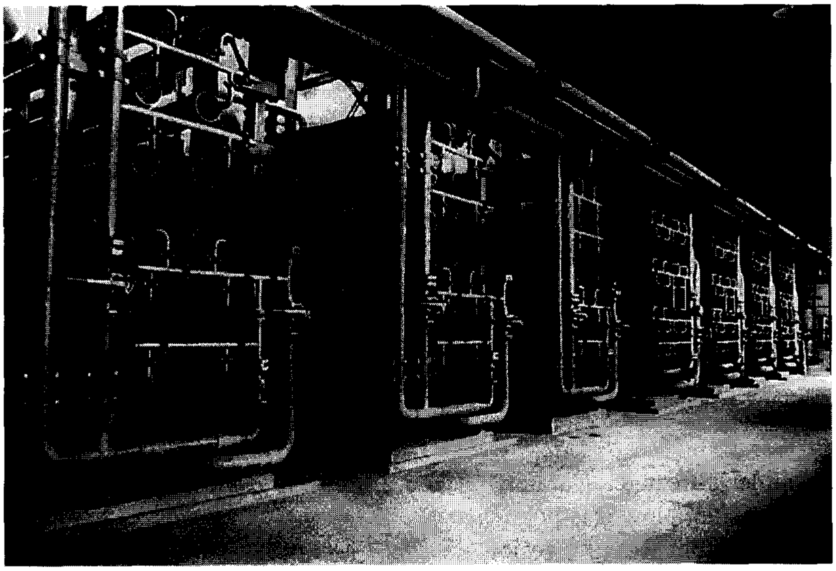

Fig. 2. RO stacks.

A conductivity meter measures the quality of the permeate. If the quality is not within specifications, a three-way valve will dump the permeate to waste.

3.2.2. Posttreatment of RO permeate

The permeate from Budryk will be mixed with the permeate from Debiensko and then be passed through two decarbonators in parallel (one shut-down if not required) for the removal of excess carbon dioxide which has been regenerated by the acid dosage in the pretreatment process. A small by-pass flow (about 30–35 m^3/h) will be admixed after the decarbonators in order to adjust the CO_2 concentration at about 44 mg/l.

Before the permeate can be used as potable water, post-treatment with chlorine and calcium hydroxide is required. The chlorine dosage will prevent bacteriological growth in the storage tank and pipes. The calcium hydroxide (lime water) will increase the pH value as well as the temporary hardness of the water in order to decrease the corrosion risk. The turbulent admixture of the chemicals is obtained in the installed in-line mixer.

Instruments for measurement of the pH-value and residual chlorine will control the dosing pumps for each chemical. The post-treated drinking water is pumped to the storage tank for distribution.

3.3. Thermal plant including NaCl separation (Figs. 3 and 4)

3.3.1. Brine concentration (Fig. 5)

The RO reject and the high saline wastewater from Budryk are pretreated for pH adjustment with acid and for scale inhibition. The flow is then divided into two parallel trains of brine concentrators. Oxygen and carbon dioxide are removed by deaeration to prevent corrosion and scaling downstream.

The evaporator is a seeded, falling film evaporator with vapor recompression. The falling film design gives the highest heat transfer coefficient of all arrangements. Brine concentrators are designed to significantly reduce the volume of the feed without scaling of the heat transfer surface. The feed is concentrated to near the point at which NaCl would precipitate. Calcium sulphate coming out of solution will preferentially deposit

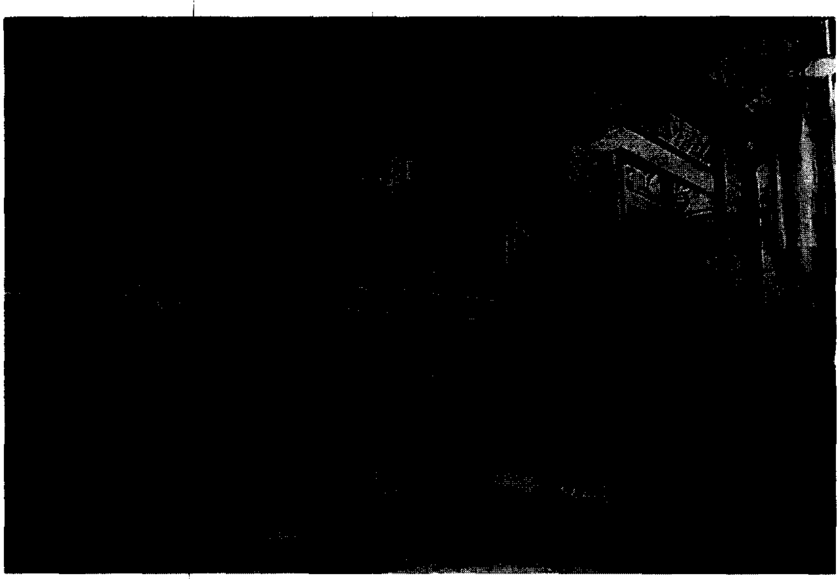

Fig. 3. Interval view of the thermal plant with the brine concentration heat exchanger and compressor in front.

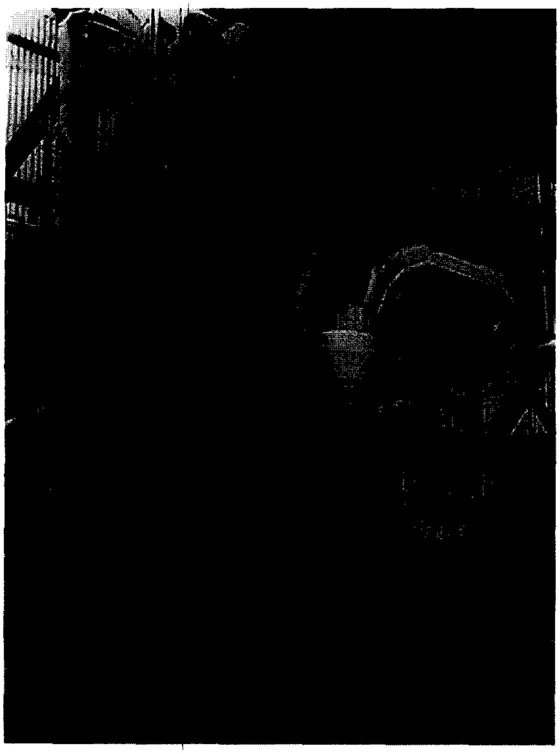

Fig. 4. Interval view of the thermal plant with the brine recirculation pump in front.

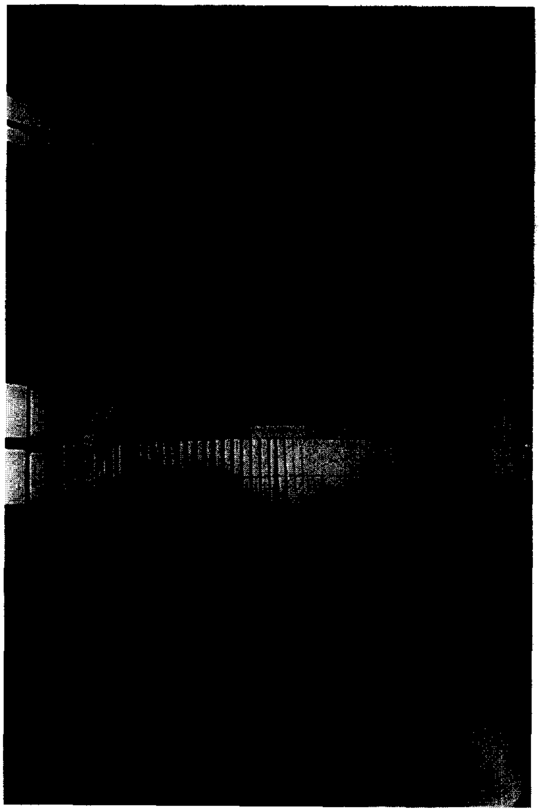

Fig. 5. Brine concentrator.

on the nucleation sites provided by recycled seed crystals instead of on the heating surface.

The brine product from the evaporators is collected in the waste/seed tank and transferred to the clarifier for separation of calcium sulphate. The overflow from the clarifier is transferred to another tank for pH adjustment with caustic soda and then fed to the crystallizer.

3.3.2. Crystallization of sodium chloride (NaCl) (Fig. 6)

The crystallizer set is basically a single train of equipment which produces a crystalline sodium chloride product of uniform quality, a distillate stream and a purge stream containing mainly non-sodium chloride impurities entering with the feed. The crystallizer is a forced circulation submerged tube evaporator equipped with a mechanical vapor recompressor. A washing or boil-out cycle is designed into the system. The volume of the body is determined by the residence time required to produce NaCl crystals of an acceptable size.

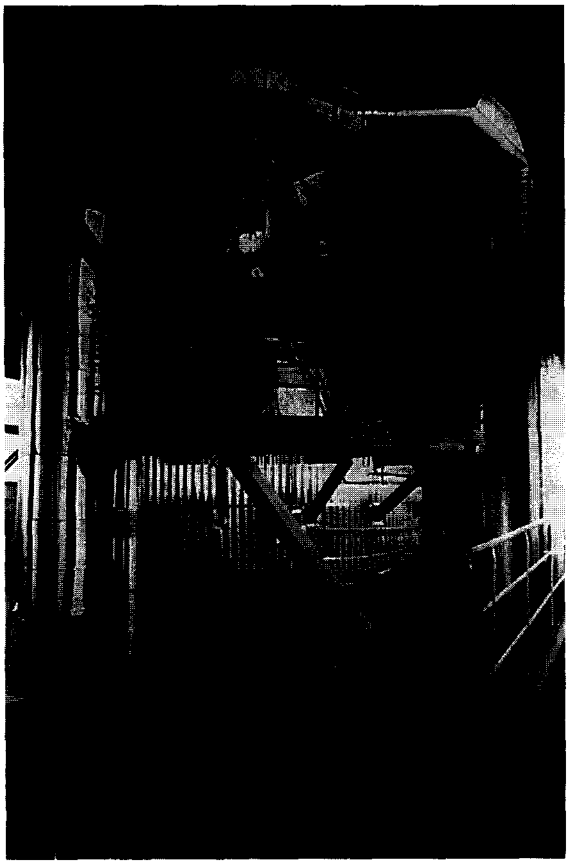

Fig. 6. Crystallizer.

Large amounts of water must be boiled away to make salt. The resulting steam is mechanically compressed and condenses in the twin crystallizer heaters, supplying all the heat normally required. The salt slurry is drained in the centrifuge thickener vessel and then dewatered in two pusher-type centrifuges operating in parallel.

3.4. Salt production and purge treatment

The salt is removed from supersaturated brine in two pusher centrifuges prior to the drying operation. The dryer is a fluidized bed dryer-cooler equipped with an air heater fed with saturated steam.

The salt has the following guaranteed quality:

NaCl	—	99.5% min
Ca	—	0.06% max
Mg	—	0.03% max
SO_4	—	0.15% max
Fe	—	0.001% max
H_2O	—	0.01% max
Insolubles	—	0.01% max

This quality is secured by the following arrangements:

- The use of an elutriation leg where the countercurrent flow of cooler crystallizer feed redissolves smaller crystals
- Screens, returning oversized salt lumps to the cycle
- Appropriate purge and providing a purge separator, to limit the level of dissolved impurities
- Salt cake washing in the centrifuges to improve purity

The purge from the crystallizer, which is transported via purge separator, is treated by chemical and thermal means to obtain distillate and recover valuable chemical products according to the following steps:

- Calcium sulfate precipitation
- Thermal preconcentration and additional sodium chloride crystallization
- Iodine and bromine desorption and adsorption
- Final stage thermal concentration and sodium chloride crystallization
- Carnallite crystallization
- Magnesium chloride crystallization

3.5. Process control

The computer process control system, selected by RCC, is the American system of Allen-Bradley. This system includes the programs Advisor, Grafix and PLC and is used by RCC as tools for preparation of user programs to control and monitor the desalination plant according to the following:

- fully automatic control of the process regarding optimization requirements and including emergency protection, interlocks and alarms
- operators service, including: monitoring of process parameters, alarming in all states treated as emergency, possibility of manual control, change of controllers settings and response to typical failures
- Archivization: listing of all alarms, trips, operators, actions and transients of selected parameters

3.6. Materials

Great potential corrosion and erosion problems are created by the treatment of the hot brine. Therefore only high-grade construction materials have been used in order to avoid failures, e.g: titanium grade 2 and 12 alloy for heat exchanger tubes and plates; high molybdenum (254 SMO and AL6XN) stainless steel for the evaporators and crystallizer vapor body; fiberglass reinforced epoxy (GRE) or polyester (GRP) for low temperature piping, polyethylene or PVC for RO permeate and water; and epoxy painted reinforced concrete for pretreatment filters and tanks.

3.7. Economy

In the RO section the energy consumption is calculated to be 4.0–5.0 kWh/m^3 raw feed, mainly for the high pressure pumps. The energy consumption in the pretreatment section is relatively small, 0.4 kWh/m^3 feed.

In the thermal plant the total energy consumption, including brine concentration, crystallization and purge treatment, is calculated to be 44 kWh/m^3 feed. The biggest energy consumer is the vapor compressors.

The total investment cost for the entire plant is about US $60 million. The economy of the plant is related to the sale of such valuable market products as salt, drinking water, distillate and other recovered chemicals. The income of these products, without any environmental fees and penalty fines for discharge of saline wastewater, implies that the estimated investment cost recovery time would be less than 10 years.

4. Plant construction and start-up

The milestones of the project have been summarized below:

- October 1988: contract signed
- February 1989: ground works started in RO/thermal plant area
- May 1989: technical documentation transferred to the buyer
- July 1989: concrete works for RO/thermal plant begun
- November 1989: ground works started in pretreatment plant
- April 1990: concrete works for pretreatment plant begun
- May 1990: building steel stucture erection in RO/thermal plant begun
- April–November 1990: main process equipment delivered to site

- August 1990: beginning of equipment erection
- October 1991: building for RO/thermal plant ready
- 1992: equipment erection in RO/thermal plant in progress; concrete works in pretreatment in progress; beginning of equipment erection in pretreatment plant
- April 1993: thermal plant ready
- May 1993: beginning of start-up procedure for thermal plant
- August 1993: first salt produced
- September 1993–May 1995: periodical operation of thermal plant (equipment modifications and process stabilization)
- 1993–1994, beginning 1995: equipment erection in pretreatment and RO plant
- May/July 1995: start-up of pretreatment and RO plant (planned)

5. Operation data

As shown above, the thermal plant has been in periodical operation since September 1993. A great number of problems causing interruptions has been identified and solved. The longest plant stop occurred in March 1994 due to a broken impeller in the crystallizer compressor. The time required for impeller replacement was 3.5 months. The difficulties encountered from the point of view of both process and equipment seem to be overcome now. The final acceptance test for the thermal plant was scheduled to be performed at the end of May, 1995.

The operation results from different treatment stages are in accordance with the design data. The composition and the salinity of the mine drainage wastewater from Debiensko and Budryk has been changed considerably since the original planning and design. This primarily has an influence on the operation of the RO section, but it is now possible to mix the two wastewaters to a desired degree in order to optimize the operation of the RO section and to increase the operation flexibility.

The mass balance of the plant with respect to flows and salt contents is shown in a simplified flow diagram (Fig. 7).

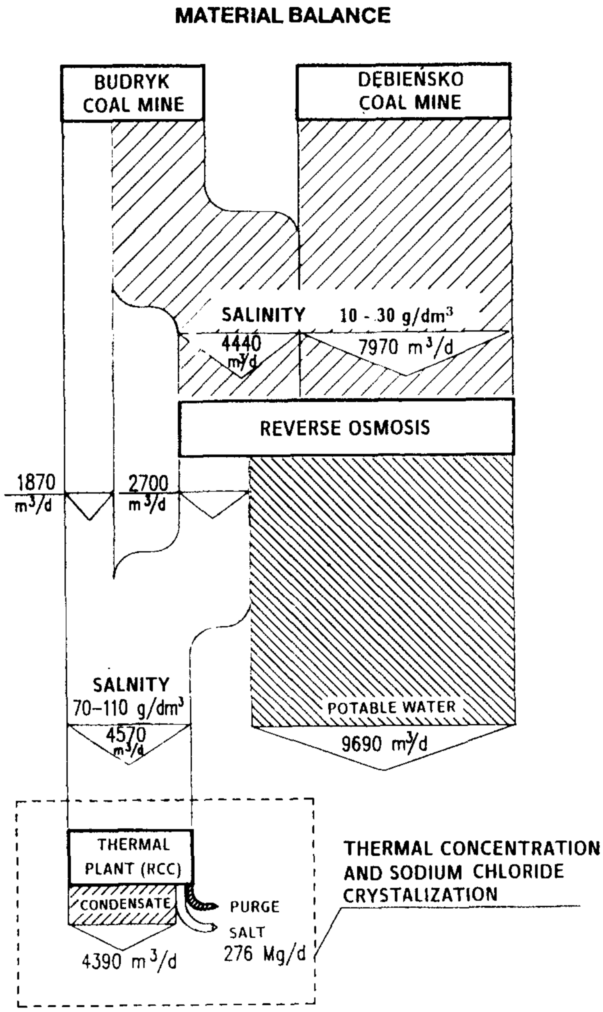

Fig. 7. Mass balance of the plant.

Operation data related to the brine concentrator and crystallizer are shown below.

A. Brine concentrator:

Feed flow rate: 92 m^3/h
Feed TDS: 100 g/l
Distillate production: 56 m^3/h
Waste flow rate: 32 m^3/h
Waste brine TDS: 300 g/l
Sump temperature: 106°C
Condenser pressure: 40 kPa
Energy consumption: 1700 kWh=18.5 kWh/m^3 feed

B. Crystallizer:
- Feed flow rate: 67 m^3/h
- Elutration: 31 m^3/h
- Combination tank: 36 m^3/h
- Distillate production: 50 m^3/h
- Purge flow: 10 m^3/h
- NaCl production: 12.5 t/h
- Salt purity: >99.6%
- Crystallizer vapor body temp.: 111°C
- Heaters outlet temp.: 114.5°C
- Compressor discharge pressure: 85 kPa
- Energy consumption: 2270 kWh/h = 33.9 kWh/m^3 feed

According to recent information, the start-up of the pretreatment and RO plant was scheduled to be at the end of May with performance tests in July, 1995 (cf. above).