Debiensko, Poland Desalination Plant Treats Drainage for Zero Liquid Discharge (ZLD)

Authors: Janusz Sikora, Debiensko Coal Mine
Krzysztof Szyndler, Energotechnika Ltd.

Introduction

Massive amounts of water are discharged from Polish mines each day: an estimated 650,000 gallons per minute (gpm) (2500 m^3/minute), or 940 million gallons per day (mpd) (3.5 million m^3/day). The total dissolved solids in these waters range from 600 mg/l to 120,000 mg/l. About 60% of this drainage can be used for drinking, agriculture or industry. The rest, 375 mpd (1.4 million m^3/day), are saline waters that drain directly to rivers and cause substantial damage to Polish water resources.

The largest amount of salty drainage is pumped from 18 mines located in southwestern Poland, in the upper courses of Poland's two main rivers, the Vistula and Odra. More than four million tons of salt was released to the Vistula in 1992. Mine drainage to these rivers is harmful to plant and animal life, causes corrosion and eliminates economical use of the rivers along their entire 250-mile (402 km) stretch through Poland. The drainage problem also intensifies the severe lack of drinking water.

To combat this problem, a large environmental project has begun operation nearKatowice, which eliminates highly brackishwastewater discharge from two coal mines: Debiensko and Budryk.

Starting in the fall of 1993, all drainage from the two mines is desalinated by two evaporators and a salt crystallizer, eliminating 310 tons (356 metric tons) per day of salt discharge. Additional desalination plants are planned at other mines along the Vistula and Odra.

Approximately 3.8 mpd (14,000 m^3/day) of mine drainage is treated in the desalination plant at Debiensko. Wastewater chemistry ranges from 8,000 to 115,000 mg/l total dissolved solids. The plant recovers about 2.6 mpd (10,000 m^3/day) of drinking water and process water, 1.2 mpd (4,500 m^3/day) of distilled water, 276 tons (280 metric tons) per day of pure sodium chloride for sale to the chemical industry and as a table salt and 28 tons (28 metric tons) per day of calcium sulfate.

A smaller desalination plant has been operating at the Debiensko coal mine since 1975, recovering 120 tons (122 metric tons) of salt per day. It continues to operate along with the new system. The new plant was designed by Polish engineers and scientists using water treatment technology from the U.S. and Sweden. This plant began construction in 1989 while Poland was still under the Communist regime. The project was slowed by the economic crisis following the change in government, but has persevered through many financial difficulties.

TP1039EN 0601

Process Description

The desalination process is conducted in five stages::

Pretreatment

The pretreatment section prevents fouling in the RO membranes. This section of the plant is not yet completed. It will consist of:

- storage of feed in retention tanks for algicide dosing
- sedimentation with polymer dosing
- disinfection, chlorination and intermittent shock treatment with sodium bisulfite
- flocculation, performed in four tanks in series with alum and sulfuric acid dosing for pH correction
- filtration in dual media sand-anthracite and granular activated carbon open gravity type filters
- thickening of sludges settled after flocculation and disposal of settlings

Reverse Osmosis

Construction of the reverse osmosis plant is not yet completed. Plans call for the pretreated water to enter a two-stage microfilter section: 50 micron cleanable steel baskets and 5 micron disposable cartridge filters. After microfiltration the saline water will be concentrated up to 80,000-90,000 mg/l TDS in the RO system. The RO system will be pressurized up to 870-1000 psi. Spiral wound RO membranes are contained in more than 500 pressure vessels. After decarbonation, chlorination and lime treatment, permeate will be used as drinking water. RO membranes will be cleaned periodically with a prepared solution and neutralized after washing.

Brine Concentration

Until the pretreatment and RO section is complete, mine drainage will be sent directly to the two Brine Concentrators (BCs) which operate in parallel. The chemistry of the feed from the mines is shown in Table 1.

Table 1: Feed to Brine Concentrators

Feed to Brine Concentrators (mg/l)	
Ca	1,063
Mg	981
Na	26,451
K	382
Sr	36
Fe	0.5
Silica	3
Cl	42,698
NH_4	16
HCO_3	1,145
NO_3	58
SO_4	3,420
F	5
TDS	76,400
pH	7.3

(When the reverse osmosis plant is complete, the TDS is expected to range from 90,000 to 100,000 TDS.) The Brine Concentrators, supplied by Resources Conservation Company, are vertical-tube, falling film evaporators driven by a vapor compressor. The falling film design gives a high heat transfer coefficient. The BCs are designed to significantly reduce the volume of the feed without scaling the heat transfer surface. The feed is concentrated to near the point where NaCl would precipitate. Calcium sulfate "seeds" are added to the feed at startup, which gives the precipitating salts a place to attach themselves and stay in suspension. The "seeds" are continuously recycled in a series of hydrocyclones.

Wastewater is treated in the BCs as follows: sulfuric acid is added to the RO reject in the BC feed tank. The feed then passes through a plate heat exchanger, which raises the temperature to near boiling. It then passes through a deaerator, where carbon dioxide and oxygen are removed by steam stripping. The hot deaerated brine then goes to the BC sump, where caustic soda and antifoam are added. The brine is pumped to the top of a bundle of 2-inch (5-cm) heat transfer tubes, where it falls in a thin film down the inside of the tubes. A portion evaporates; the rest falls back into the sump for recirculation. The vapor from the inside of the tubes passes through mist eliminators and then into a vapor compressor. Compressed vapor is sent to the outside of the heat transfer tubes, simultaneously heating the brine falling inside and condensing as distilled water on the outside of the tubes. Distillate is fed back through the heat exchanger and then sent to the nearby power and heat generating plant where it is used for boiler feed, cooling tower makeup and other industrial use at the coal mine.

Crystallizer

Saturated brine from the BCs, now concentrated to about 258,000 ppm TDS and 3,000 ppm TSS, is pumped through a lamella clarifier which separates suspended calcium sulfate. Caustic is automatically added to keep the pH near neutral. About 60% of the prepared brine is then sent to the preheater of a forced-circulation, submerged-tube crystallizer driven by a vapor compressor. The remaining 40% of the feed is sent to the elutriation leg of the crystallizer, which will be discussed later.

In the crystallizer, also supplied by Resources Conservation Company, 60% of the brine is pumped through two submerged-tube heat exchangers. Because the tubes are flooded, the brine is under pressure and will not boil. This prevents scaling in the tubes. The recirculating brine enters the crystallizer vapor body at an angle, where it swirls in a vortex. As the water vapor is drawn out, precipitating crystals of sodium chloride and calcium sulfate appear in the brine slurry. The larger sodium chloride crystals sink to the bottom of the elutriation leg where they are blown down from the crystallizer, sent to two pusher centrifuges and then to a fluidized bed dryer-cooler. These salts are of uniform quality and purity (99.5%) and will be sold as table salt and to the chemical processing market.

Forty percent of the crystallizer feed stream is sent to the bottom of the elutriation leg to flush the small sodium chloride and calcium sulfate crystals back up into the crystallizer sump. The smaller crystals are then trapped and released with the crystallizer purge.

Vapor from the evaporating brine is sent through a series of mist eliminators to remove entrained solids on its way to the vapor compressor. As in the Brine Concentrators, the crystallizer vapor compressor raises the vapor saturation temperature above the boiling point of the recirculating brine. The compressed steam is then introduced to the shell side of both heaters. Here it gives up its heat of vaporization (to heat the brine slurry inside the tubes) and condenses on the outside of the tube wall. The condensate is pumped back through the Brine Concentrator heat exchangers, to be used in the nearby power and heat generating plant.

Purge Treatment

At this time, crystallizer purge is stored in a reservoir for future chemical and thermal treatment which will recover distillate and other valuable chemical products. Polish scientists and engineers from the Central Mining Institute of Katowice have invented technologies to recover these chemicals; a purge treatment pilot plant has been operating at the Debiensko mine since 1987. Plans call for enlargement of the pilot plant within the next two years to accommodate purge from the new desalination plant. Other options for purge disposal, such as deep well injection, are also being investigated.

The pilot plant uses the following technologies to recover chemicals from crystallizer purge:

- Calcium sulfate precipitation
- Thermal preconcentration and additional sodium chloride crystallization, iodine and bromine desorption and absorption
- Final stage thermal concentration and sodium chloride crystallization
- Carnallite crystallization
- Magnesium chloride crystallization

Using these methods, the following products will be recovered:

- Distillate: 16,500 gpd (62 m^3/day)
- Sodium chloride: 30 tons (30 metric tons) per day
- Carnallite: 4,638 tons (4712 metric tons) per year
- Magnesium chloride: 4,840 tons (4917 metric tons) per year
- Iodine and bromine: 122 tons (124 metric tons) per year

Cleaning and Materials

The crystallizer is washed weekly with an automatic boilout cycle designed into the system. Brine Concentrators will be mechanic-ally and chemically cleaned once a year. Treatment of hot brine creates a large potential corrosion and erosion hazard. To avoid failures, only high grade construction materials have been used: titanium grade 12 and 2 alloys for heat exchanger tubes and plates; high molybdenum stainless steel (254 SMO and AL6XN) 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 reject and reinforced epoxy painted concrete for pretreatment filters and tanks.

Energy Consumption

Energy consumption in the RO section, mostly for the high pressure pumps, is expected to average between 4 to 5 kWh/m^3 raw feed. Approximate energy consumption for the pretreatment section is not significant—0.4 kWh/m^3 feed. Total energy consumption for the thermal plant, including BCs, crystallizer and purge treatment section is 44 kWh/m^3 feed. Most of the energy is consumed by the vapor compressors.

Economics

The cost for the entire desalination plant is about US$60 million. The pretreatment system accounts for about 40% of the cost. Because the plant produces valuable products such as drinking water, distillate, salts and other chemicals, the payback is quite good for an environmental project—about 10 years. About 80% of the maintenance and operation costs of the existing desalination plant are recovered by selling the salt. The mines will also avoid paying about $3 million USD per year in fines for salt dumping into the river, a factor also taken into consideration when calculating payback.

Economics has been the major limiting factor in construction of the desalination plant. Plans for the plant were being drawn up as early as 1983 and equipment purchase began in 1989. The project persevered through the fall of the Communist government and the economic crisis that followed. Personnel involved in the project also changed due to the political restructuring of Poland.

The project has been halted countless times due to lack of funds. In recent years, money has come from the Polish environmental fund, which is made up of fines imposed upon polluting industry, including the coal mines. Essentially, the money paid out in fines by the coal mines has been returned to finance the cleanup. Normal procurement and construction time for a project of this size would have been 24 months; instead it has taken four years to startup and there is still much work to be done on the pretreatment and purge treatment sections.

Table 2 shows a calculation of the economic benefits of the desalination plant.

Table 2: Products produced from mine drainage

Product	Quantity per day	Price
Distilled water	1.2 M gallons	$3,000 / M gallons
Drinking Water	2.6 M gallons	$40/metric ton
Salt tablets for water softening	150 metric tons	$40/metric ton
Bag and bulk salt	250 metric tons	$40/metric ton
Products from crytallizer purge:		
Lower quality salt (animal feed)	30 metric tons	$15/metric ton
Iodine to chemical industry	54kg	$4/kg
Bromine to chemical industry	280 kg	$0.3/kg
Carnallite for fertilizer	12.5 metric tons	$90/metric ton
Magnesium chloride for bricks	13 metric tons	$60/metric ton
Total income:		**$7.7 million/year**

Construction

The Brine Concentrator and crystallizer vessels were fabricated in Sweden and shipped to Poland via barge up the Odra River. The bridges along the Odra are so low and the crystallizer vessel is so large it was intercepted at Katowice and traveled the last 30 miles (48 km) by road despite the difficulties imposed by power and phone lines, narrow bridges and overhanging trees. The Brine Concentratorvessels did make it under the Odra's low bridges after the barges were sunk and hauled along the bottom of the river. Erection of the vessels and peripheral equipment and completion of the building has taken three years due to erratic funding. Construction was also hampered by the problem of building large concrete tanks on ground severely damaged by mining activity several hundred meters underground. Problems were overcome by special construction calculations, materials and technology, all of which added time and cost to the project.

Thermal Plant Startup

Equipment checkout began in May 1993 and the Brine Concentrators were running on cold water by June.

Full startup was delayed for about one month because of a problem with the crystallizer recirculation pumps. Because the pretreatment section is still not completed, the Brine Concentrator/crystallizer system began producing distilled water and sodium chloride from feed directly from the coal mines rather than feed preconcentrated by RO. The first Brine Concentrator was successfully started up August 16, 1993 and the crystallizer followed a week later.

Conclusion

Years of planning and hard work have finally resulted in the goal of zero liquid discharge to the Odra River at the Debiensko and Budryk Coal Mines. It may take several more years before the project is completely finished, but in the meantime it serves as a model for future desalination plants at other mines along the rivers of Poland.