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Production of Acid and Alkali from Brine of Seawater Concentration Plant Using the Ion-Exchange Membrane Process

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ABSTRACT

Application of water-splitting technology was investigated for acid and alkali production from the brine produced in the existing seawater concentration plant. This technology can overcome many of the difficulties inherent in the application of the conventional electrolysis process, when the concentrated brine from seawater is adopted as the raw material of salt. This technology appears to be the shortest method for the industrial use of brine produced in the seawater concentration plant.

INTRODUCTION

Ion-exchange membranes are widely used in the industrial separation and purification of aqueous solutions and production of chlorine and alkali.

In Japan, table salt is produced entirely by the electrodialysis process using ion-exchange membranes and its production cost is largely reduced due to progress of the electrodialysis technology (Kawahara and Suzuki, 1981). However, industrial salt is still imported from overseas countries, because concentrated brine by electrodialysis is not used for the conventional electrolysis process for the following reasons shown in Table 1: imbalance of water due to relatively low concentration; high cost of brine purification. In addition, the electrolysis plant should be located close to the salt manufacturing plant for transport of brine.

Recently, water-splitting technology by bipolar membrane is developed and is being adopted for treatment of waste salts (Uchino, 1990). A combination of the electrodialytic seawater concentration and the water-splitting technology was studied for the production of acid and alkali from brine of seawater concentration plant in order to overcome difficulties in using concentrated brine from seawater.

TABLE 1
Difficulties in brine from seawater

Water imbalance:	Approx. 5 times requirements
Impurities Ca^{2+}:	Approx. 3 times that of imported salt
Mg^{2+}:	Approx. 14 times that of imported salt
Plant location:	Independently constructed

TECHNICAL BACKGROUND

The principle of water-splitting technology is based on work of the bipolar membrane. An expanded view of its construction and operation is shown in Fig. 1. The membrane is a composite and consists of three parts: a cation-exchange region, an anion-exchange region and the interface between the two membranes. When a direct current is passed across the bipolar membrane, electrical conduction is achieved by the transport of H^+ and OH^- ions obtained from the dissociation of water.

A drawing of the generalized three-compartment water splitting cell is shown in Fig. 2. The three compartments — acid, salt and base — are bounded by the bipolar, anion and cation-exchange membranes as shown. The salt, e.g., sodium chloride, is fed to the compartment between the cation and anion-exchange membranes. When an electrical potential is applied across the electrodes, the cations (Na^+) and anions (Cl^-) move across the monopolar membranes and combine with the hydroxide and hydrogen ions generated at the bipolar membrane to form the base and acid. This generation of new pro-

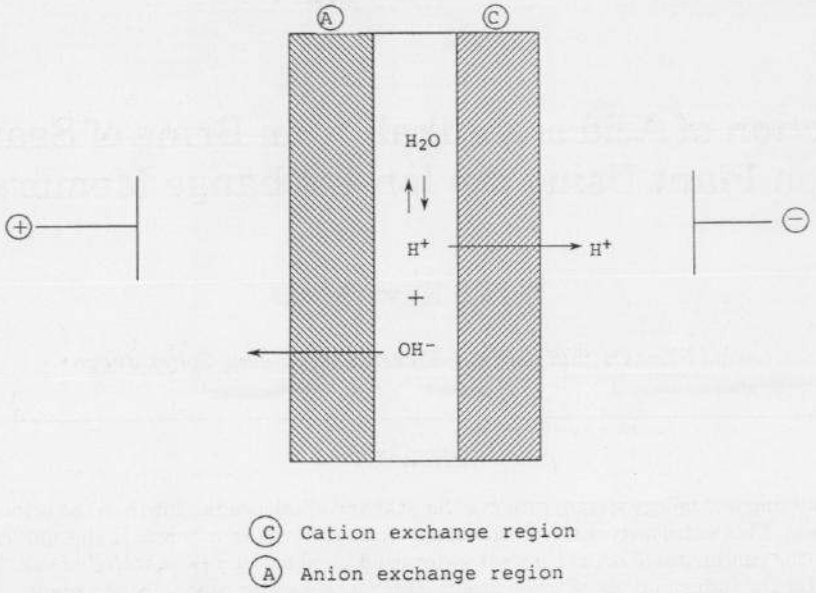

Fig. 1. Bipolar membranes.

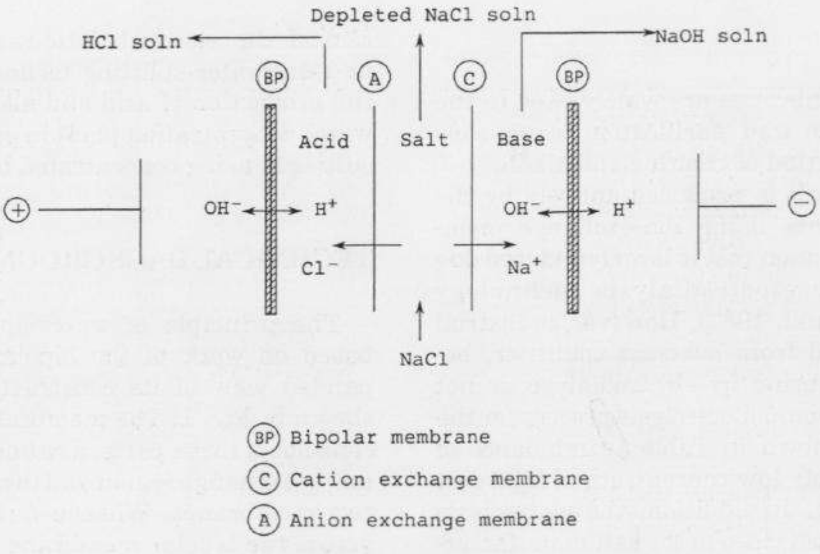

Fig. 2. Three-compartment cell.

ducts distinguishes electrodialytic water splitting from conventional electrodialysis.

The water-splitting process is electrodialytic in nature, because the process merely involves changing the concentration of ions that are already present in solution. Using the data in free energy for dissociation of water, the theoretical potential for generating one normal acid and base for an ideal (i.e. perfectly permselective) bipolar membrane as 0.83 V at 25°C can be calculated. The theoretical energy requirement can be computed to be under 560 kWh/t of NaOH which can be expected to be lower energy consumption compared with the conventional electrolysis process.

Figure 3 shows the water-splitting process combined with the existing salt manufacturing plant. Brine from the electrodialyzer in the existing plant is fed into the water splitter after pretreatment and depleted brine is reconcentrated by the auxiliary electrodialyzer in the pretreatment section. Difficulties of water imbalance and plant location problems can be overcome by combination with the existing salt manufacturing plant; also, the purification cost of brine can be largely reduced by adopting the univalent permselective cation-exchange membrane in the water splitter.

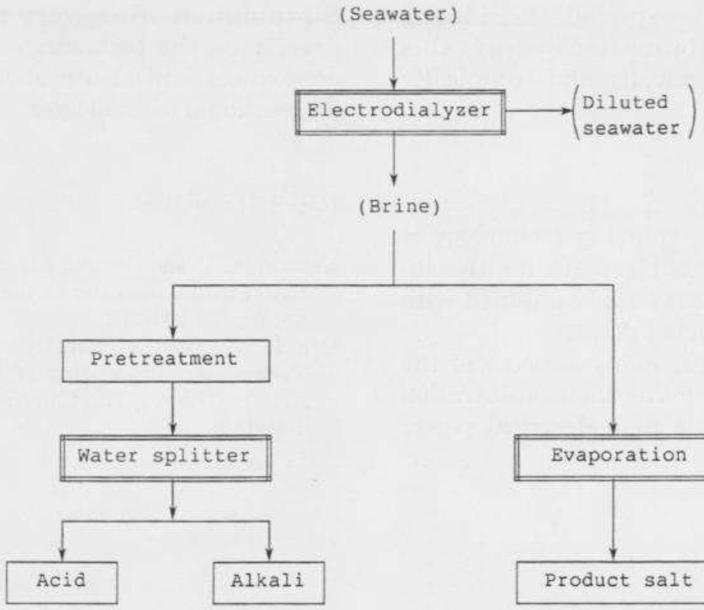

Fig. 3. Water-splitting process combined with salt manufacturing plant.

TABLE 2

Design basis

Production capacity:	NaOH 50,000 t/year (100% base)
	HCl approx. 45,000 t/year (100% base)
Feed salt solution:	Brine from seawater
Product:	15% NaOH
	10% HCl
Plant location:	Within salt manufacturing plant site
Installation cost (all civil works are not included):	Approx. ¥2,345 million
Required membrane area:	4,690 m^2 pair (effective)
Operating conditions:	Current density 1 kA/m^2
	Temperature 25°C
Working days:	330 days/year

TABLE 3

Estimated cost

	Cost (¥/t NaoH)	Remarks
Fixed cost		
Amortization etc.	3,517	Insurance, interest, tax, wear and tear expense
Labor	200	1 person × ¥10 million/person-year
Running cost		
Electric power	10,305	2,061 kWh/t-NaOH × ¥5.00/kWh
NaCl	8,350	1.67 t/t·NaOH × ¥5,000/t
Membrane	12,194	Average life 2.7 years, ¥350,000/m² pair
Others	2,850	Chemicals, steam etc.
Total	37,416	

ECONOMICAL FEASIBILITY

Economical feasibility was studied based on the design basis shown in Table 2. Approximately 45,000 t of hydrochloric acid is produced simultaneously with caustic soda. Concentration of products is adjusted to 15% caustic soda and 10% hydrochloric acid in order to keep high current efficiency. The water splitter is located within the salt manufacturing plant taking into account the piping connection and utilization of the existing plant. The main equipment for installation are water splitter, rectifier, pump and piping, pretreatment equipment and instruments and electrical equipment. The required membrane area of water splitter is 4,690 m^2 pair, i.e., total 14,070 effective area. 1 kA/m^2 of current density is adopted.

Estimated cost of ton/pair caustic soda is shown in Table 3. Unit prices of electric power, steam and sodium chloride in brine are based on the price produced in the existing plant. If 15% caustic soda and 10% hydrochloric acid can be evaluated at the price of ¥50,000/t NaOH (100% base) and ¥10,000/t HCl (100% base) respectively, an approximately ¥1,079 million annual profit can be expected. Considering the development of membrane technology, this process seems to be economically and technically feasible.

CONCLUSIONS

The application of water-splitting technology is nearing a commercially feasible state for the industrial use of brine from seawater combined with the existing salt manufacturing plant.

At present there are still many aspects of the technology to be solved including the concentration and purification of products and electrical power consumption. However, concentrated efforts in developing the technology will make it both more economical and also a shorter method than other conventional technologies.

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