

Salt Industry in Japan

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ABSTRACT

For a long time, in Japan, there have been no available resources to produce salt, such as rock salt or natural brine except seawater. The climate is also unfavourable for solar salt production because of frequent precipitation throughout the year. Thus, the modified solar salt field system "IRIHAMA," which can concentrate seawater by solar energy using sand, was developed in the 17th century.

After the World War II, a new concentrating system which consisted of a sloping down salt field system, "RYUKASHIKI

ENDEN," with a gradient concentrator, "SHIOKA," was developed, and the productivity rose to about 300 tons/ha/year. However, the cost of the salt produced was still very expensive compared to that of imported salt.

In 1971, those salt field systems were switched to the electro-dialysis method by using ion-exchange membrane. Since then, about 1.2 million tons of salt is produced yearly by 7 factories, an amount almost equivalent to the edible salt consumption in Japan.

INTRODUCTION

Annual salt consumption in Japan today amounts to about 7 million tons. About 85% of this amount is imported salt, while only 15% of the amount is domestic.

One of the propositions of the Japanese salt industry in modern times has been the rationalization of domestic salt production and the sufficiency of quality, despite climatic conditions.

This report presents the existing state of the electro-dialysis method in Japan, in relation to the history of the salt production method, and also outlines the present situation of demand and supply of salt.

THE DEVELOPMENT OF THE METHOD OF SALT PRODUCTION IN JAPAN

"IRIHAMA" Salt Field. Because rock salt or brine has never been available in Japan, salt has been obtained only from seawater. In addition, unfavorable climatic conditions for solar salt have forced Japan to utilize two processes. The first process, called the "brine producing process," concentrates seawater to a certain level. The second processes, called the "crystallizing process," evaporates the brine into crystallized salt. Until now, salt producing methods in Japan have consisted of these two processes.

In ancient days, the "MOSHIO YAKI" method, which used seaweed containing seawater, was used to ob-

tain brine. The seaweed was dried by sunshine and the deposited salt was leached out by seawater. Then, the brine obtained by leaching was evaporated in salt pans to produce salt.

In the 6th and 7th centuries, sand was used in place of seaweed. This method was generally called the "SHIOHAMA" salt field.

Later in the middle of the 17th century, the "IRIHAMA" salt field, one of the developed "SHIOHAMA" salt field types, was employed in the Seto-Inland district and had several advantages, such as climatic conditions and proximity to the markets. The salt industry became important in the district.

The principle of this "IRIHAMA" method is as follows: seawater is absorbed in the sand by capillarity and the sand with seawater is exposed to sunshine and wind in the salt field. After the seawater is evaporated to crystallize salt around the particles of the sand, this salty sand is raked by human labor to the leaching well, and then the salty sand is leached by seawater to obtain a concentrated brine.

This method is different from "SHIOHAMA" by the ground level of the salt field, which is situated between the high tide level and low tide level. Because of the position of the salt field, seawater can be introduced into the field without any extra force, merely utilizing the tides. Therefore, the scale of the "IRIHAMA" salt field was larger than that of the "SHIOHAMA" salt field and it

operated more efficiently than the "SHIOHAMA" salt field.

A schematic figure of the "IRIHAMA" salt field is shown in Figure 1. The productivity of this salt field was around 70–130 tons/ha/year. An "IRIHAMA" salt field operated from the 17th century until the middle of the 20th century as a typical salt producing system in Japan.

The Development in "Crystallizing Process." The development of modern salt production technology is focused on the fields of the "crystallizing process" technology. A steam re-use system and vacuum pan evaporating plants which were invented in the early 1900s were introduced to the Japanese salt industry in the 1930s and progressed rapidly in the 1950s.

These developments are indicated by the energy consumption rate in the "crystallizing process," as shown in Figure 2.

Direct Evaporation of Seawater by Auto Vapor Compression System. JTS's (The Japan Tobacco & Salt Public Corporation) factory, which applied this system as a direct seawater evaporating plant, was constructed in 1952 and produced about 10,000 tons of salt annually. In the beginning of the factory's operation, scale problems were very common; however, the method of adding CaSO_4 seeds to the mother liquid was discovered in 1955 so as to solve these troubles, and other salt producing factories using this method were constructed. From 1959 until 1971, consequently, about 200,000 tons of salt was produced by this system. Since 1971, this method has not been applied in Japan because more efficient methods were then employed.

Sloping Down Salt Field System. A schematic figure of the sloping down salt field system is shown in Figure 3. The most important point of the difference between the "IRIHAMA" salt field system and this system is the object of transporting. In the "IRIHAMA" system heavy sand was gathered and scattered again on the salt field by human labor, while in this system seawater itself flowed down if pumped up to the upper level of the salt field.

This salt field is generally constructed by shaping the ground into a gentle slope, on which impermeable mate-

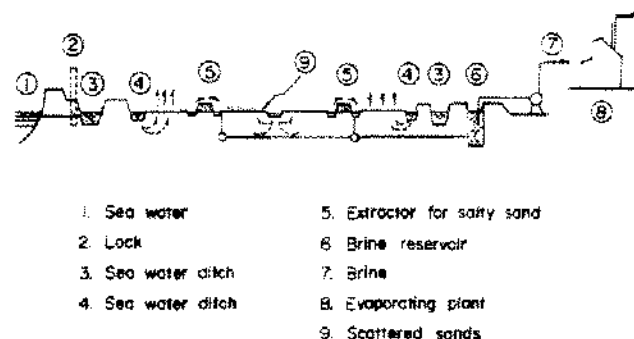


Figure 1. Improved "IRIHAMA" salt field system.

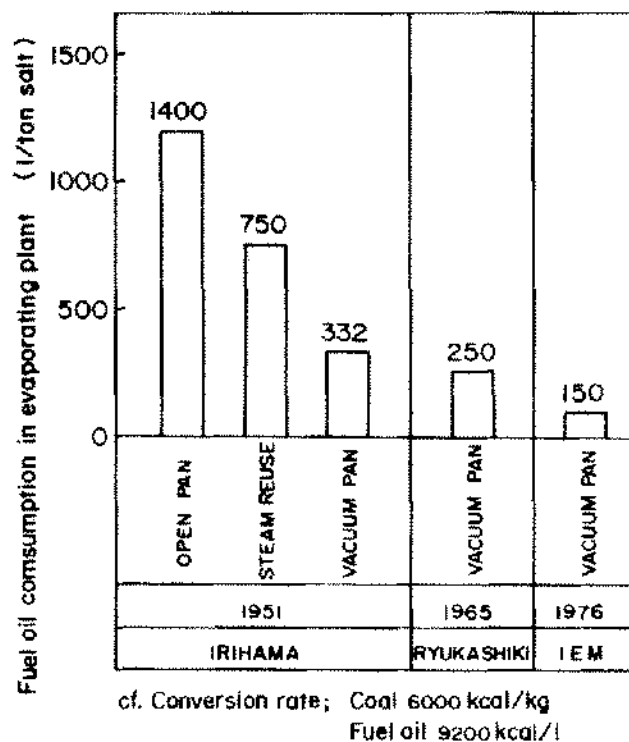


Figure 2. Improvement of fuel oil consumption in evaporating plant.

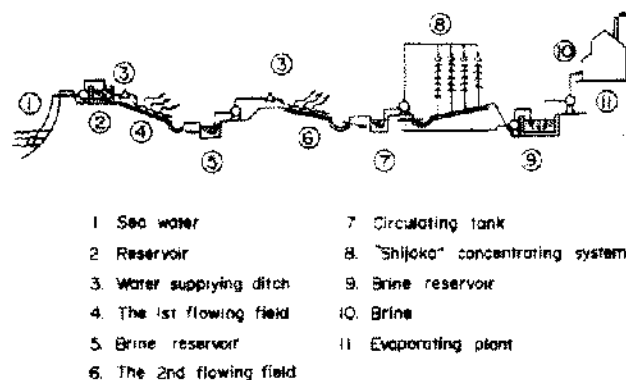


Figure 3. Sloping down salt field system.

rials such as clay are used. Seawater is applied by pump from the upper level so as to form a thin film flow on the surface of the sloping down salt field. Seawater is concentrated as it flows down, by evaporation.

The total evaporation e , in mm/month is calculated by the experimental formula shown below.

$$e = 0.45 L \cdot \sin \theta - 11 \text{ (mm/month)}$$

where

L = sunshine hours in a month (hr/month)

θ = elevation angle of the sun to the south ($^\circ$).

Thus, the evaporation depends on solar radiation.

In the sloping down salt field system, "SHIJOKA" is also constructed. It is made of bamboo bushes, about 6 meters high and looks like a bare cooling tower. While the concentrated seawater flows down from the top of the "SHIJOKA," it is concentrated by the evaporation from the surface of the flow. In this instance, the evaporation surface is spread on the surface of the bamboo bushes and also the surface of splashed water drops.

The experimental formula for the evaporation e (mm/month) is shown as

$$e' = 252 U^{0.6} \cdot \Delta C + 143 \text{ (mm/month)}$$

where

U = average wind velocity in month (m/sec)

ΔC = average air moisture deficit (mmHg).

Thus, the evaporation is influenced by the air moisture deficit and wind velocity. "SHIJOKA" has about 10% of the area of the sloping down salt field. The productivity of the system raised to 250–300 tons/ha/year. Where formerly sand was transferred to obtain brine, in this system water is transported by pump, and accordingly this system saved much labor.

The sloping down salt field appeared in 1952 and all of the "IRIHAMA" salt fields were converted into sloping down salt field systems in 1958.

Application of IEM (Ion Exchange Membrane) Process to Produce Salt. At the time when the "IRIHAMA" salt field systems were converted into sloping down salt field systems, the research of the application of the process in concentration of seawater or salt production was being conducted by the Tokuyama Soda Co. Ltd., Asahi Chem. Industry, Asahi Glass Co. Ltd. and JTS individually. In 1960, the practical test of the IEM process was conducted. Many difficulties in design had to be overcome, but by 1966, the IEM process was successfully applied, and about 210,000 tons of salt was produced by this method in 1969. That is equivalent to 23% of the Japanese total salt production. It was then determined that if the Japanese salt-producing factories could be merged into some large-scale plants, a remarkable cost reduction would be realized. In 1971, all of the salt fields merged into 7 IEM process salt-producing factories.

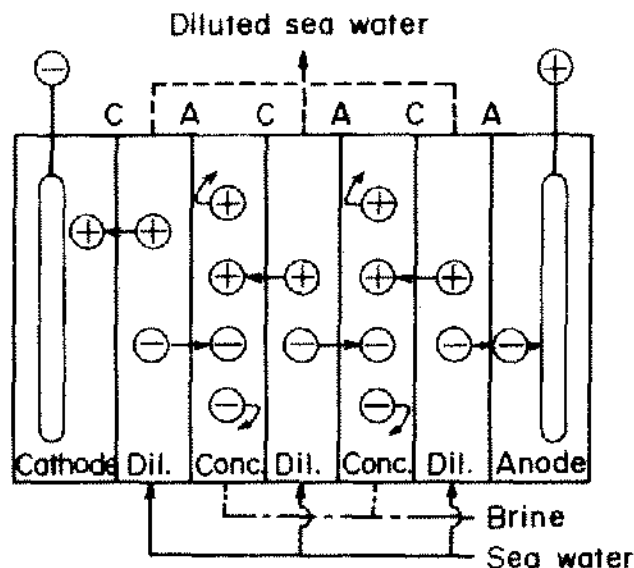
The development of the salt industry in Japan is shown in Table 1.

PRESENT STATE OF IEM PROCESS SALT PRODUCTION IN JAPAN

The Principle and Types of the Apparatus. The electro-dialysis method using IEM is to concentrate seawater applying ion permeability of IEM. The principle of the concentration of seawater is shown in Figure 4. The apparatus consists of a series of alternate concentrating and diluting compartments formed by the alternate cation-

TABLE 1
The Development of the Salt Industry in Japan

Seawater concentration system	Year	Area of salt field	Number of factories	Production amount
IRIHAMA	1935	4,500 ha	3,300	600,000 tons
Sloping down salt field	1960	3,000	29	830,000
IEM	1980	—	7	1,270,000



C : Cation-exchange membrane
A : Anion-exchange membrane

Figure 4. Principle of concentration by electro-dialysis.

and anion-exchange membranes. When seawater is introduced to the diluting compartments, brine is sent to the concentrating compartments, and electric potential is applied between the electrodes, the movement of the cations and anions in the diluting compartments accompanied by hydration water, takes place toward the cathode and anode, respectively. Thus, brine can be produced in alternate concentrating compartments through the permselectivity of the membrane.

There are two types of electro-dialysis apparatus in practical operation: The Unit Cell Type (shown in Figure 5) and the Filter Press Type (shown in Figure 6).

In the unit cell type, a cation membrane and an anion membrane are patched together along their margins to form a bag, as shown in Figure 5. The apparatus consists of about 2,000 of these bags in the bath, and brine is drawn out by tubes attached to the bags.

In the filter press type, alternate cation and anion membranes are inserted between the gaskets made of

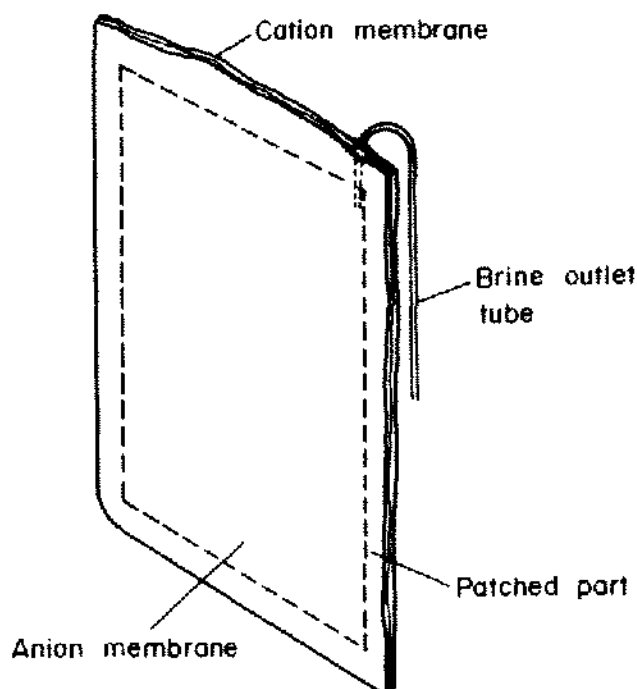


Figure 5. View of unit cell.

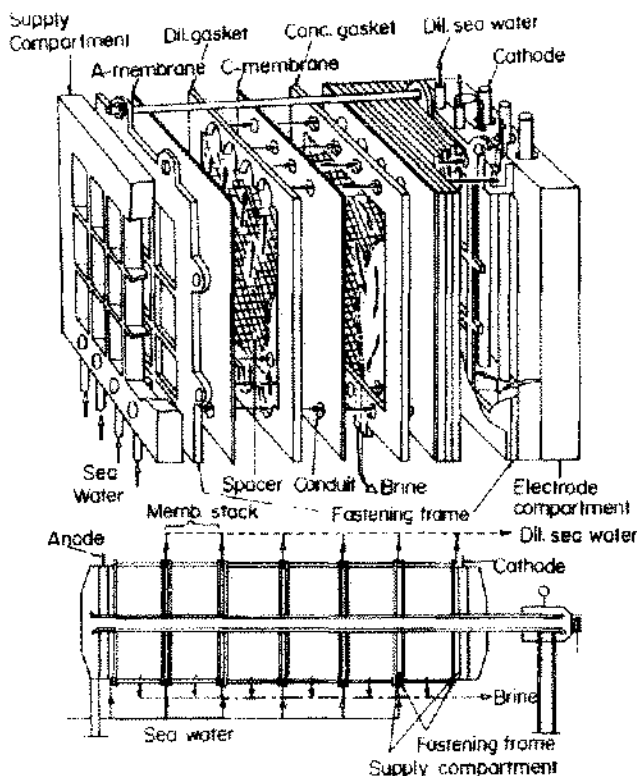


Figure 6. Structure of filter press type apparatus.

non-conducting materials, such as rubber or PVC, as shown in Figure 6, to form alternate compartments.

Hundreds of membranes, intermembrane spacers and gaskets pressed between fastening frames form a membrane stack, and several stacks are assembled like a filter press.

Recent Performance of Salt-Producing Factories

Brine producing process

1. Electric consumption per unit of salt production. The production amount by the IEM method is shown in formula (1)

$$W = 2.18 \times 10^{-6} \cdot I \cdot N \cdot \theta \cdot \eta_{Na} \quad (1)$$

where

W = production amount (ton NaCl in brine)

I = electric current (ampere)

N = number of pairs of the membrane

θ = operation hours (hr)

η_{Na} = current efficiency for Na ion.

Electric consumption is shown in formula (2).

$$w = I^2 \cdot R \cdot \theta \times 10^{-3} \quad (2)$$

where

w = electric consumption (KWH)

R = electric resistance of the apparatus.

The electric consumption per unit of salt production is shown in formula (3).

$$w/W = I \cdot R / 2.18 \times 10^{-3} \cdot N \cdot \eta_{Na} \quad (3)$$

where

w/W = electric consumption per unit salt production (KWH/ton NaCl in brine).

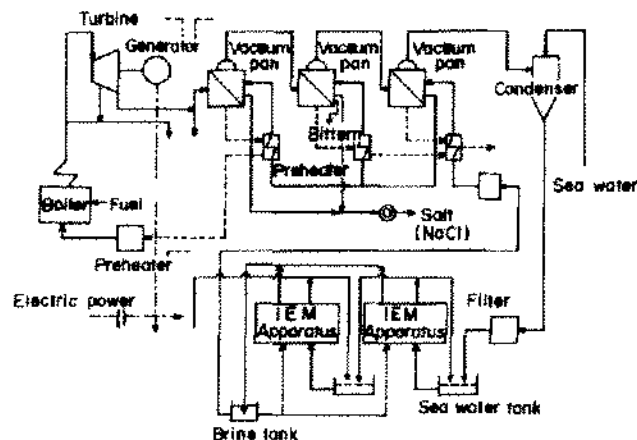


Figure 7. Flow-sheet of IEM salt producing factory.



Figure 8. Location of salt-producing factories.

It is proportional to the electric current and resistance and is inversely proportional to the current efficiency for Na ion, η_{Na} . The practical value in 1980 was about 300 KWH/ton NaCl in brine in A.C.

2. The concentration of the brine. The concentration of the brine needs to be high, because the following evaporating process needs much more energy if the concentration of the brine is low.

Factors influencing the concentration of the brine are the characteristics of the apparatus, current density and the temperature of the seawater. Since the apparatus is fixed to the factory, the controllable factor is the current density. Generally, the concentration of the brine is proportional to $1/3$ the power of the electric current density ($C = KA^{1/3}$). The higher density of the electric current results in the higher concentration of brine.

The average density of the brine in 1980 was about 165 g/l. Thus, usually the performance of the brine-producing process can be estimated on the "equivalent energy cost diagram" shown in Figure 9. In this diagram, the longitudinal axis stands for the electric consumption in the dialysis or "brine producing process" by IEM, while the horizontal axis stands for the fuel consumption in the "crystalizing process." The equivalent energy cost lines are shown in the figure.

3. The influence of seawater temperature. The fluctuation of the temperature of seawater and the density of the brine influence the electrical consumption necessary to produce unit salt. The electric resistance of seawater varies in accordance with its temperature—the higher the temperature, the lower the resistance. On the other hand, the water of hydration accompany ions increases when the temperature is high; consequently, the concentration of the brine decreases.

Thus, the adjustment of IEM operation to the temperature of the seawater is important in accordance with the situations such as energy cost and the amount of production intended.

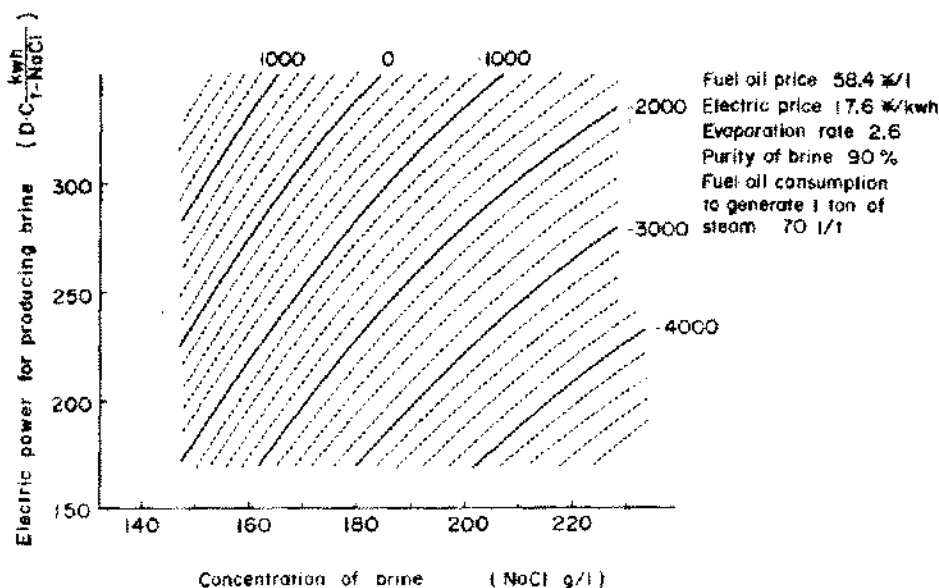


Figure 9. Equivalent energy cost diagram.

TABLE 2

Recent Performance of Brine Production (1980)

Electric power consumption	300 KWH/ton NaCl in brine				
Concentration of brine	165 g. NaCl/l				
η_{Na}	0.70-0.76				
Purity of brine	0.87-0.92				
Composition of brine in N.					
Cl	SO ₄	Ca	Mg	K	Na
3.17	0.01	0.06	0.18	0.08	2.86

The performance of brine production in 1980 is shown in Table 2.

4. Problems in the brine producing process. One of the problems in the brine-producing process by the IEM method is the dissociation of water. This phenomenon is caused by the unusual low ion concentration of seawater in diluting compartments. This phenomenon may be due to the suspended substances in seawater or scale formation on or in the membrane. Those substances form obstacles for both the flow of seawater and electric current, partially. So, it is very important to treat seawater preliminarily by filtration. The turbidity of seawater processed by IEM is usually less than 0.2 ppm.

Evaporating process ("crystallizing process")

As the concentration of brine obtained by the IEM method is about 165 g/l, about 5.5 tons of water must be evaporated to produce 1 ton of salt. In order to produce 180,000 tons of salt annually, 22.5 tons of salt should be produced in an hour (8,000 hours per year). So, the load of evaporation in such factory is calculated as follows:

$$22.5 \text{ (tons salt/hr)} \times 5.5 \text{ (tons water/ton salt)} = 125 \text{ (ton water/hr)}$$

Accordingly, each Japanese salt-producing factory is equipped with a triple or quadruple vacuum pan evaporator system with about 1,000 m² of heating element in each pan.

Recently these multi-effect vacuum evaporating pans in Japan have generally been vertical external heating element types. The recent evaporation ratio in the triple and quadruple effect system in Japan is about 2.6 and 3.4, respectively.

Gross energy consumption rate in factories

As already mentioned above, salt-producing factories using the IEM method need electric power for the IEM electro-dialysis process and also thermal energy for the evaporating plant.

Although the demand for electric power in the factory is not only for the electro-dialysis process but also for the mechanical energy source and amounts to a considerable

quantity, almost all of the electric power is generated in the factory. The remainder is bought from the power supply corporation at a higher price. So, it is desirable that the demand of electric power be balanced to the generated electric power in the factory which is related to the demand of steam consumption.

In Japan, the price of 1 kwh of electric power is nearly equivalent to 0.3 liters of fuel oil. Consequently, the gross energy consumption rate is defined as the sum of fuel oil consumed plus 0.3 times the electric power bought from outside the factory, divided by the amount of produced salt. This rate is related to energy cost. The recent development of the gross energy consumption rate is shown in Figure 10. In this figure, it is notable that in the new type of apparatus recently developed, 200 g/l of brine is produced at the consumption of 230 kwh of electric power. Now, the Japanese salt industry has begun further changes by the application of these newly developed apparatuses.

RECENT SUPPLY AND DEMAND RELATION OF SALT IN JAPAN

The demand and supply relation in 1981 is shown in Figure 11. About 6.4 million tons of salt or 85% of the salt consumed was imported, while 1.2 million tons of salt was produced in Japan. Some 5.8 million tons of imported salt was used in the chlor-alkali industry. The remainder was used for general industry, the food industry and for refining.

The demand for edible salt is about 1,380,000 tons and out of this amount about 460,000 tons is consumed in household use.

In Japan, the monopoly law for salt was established in 1905, and the law provides the government with the nec-

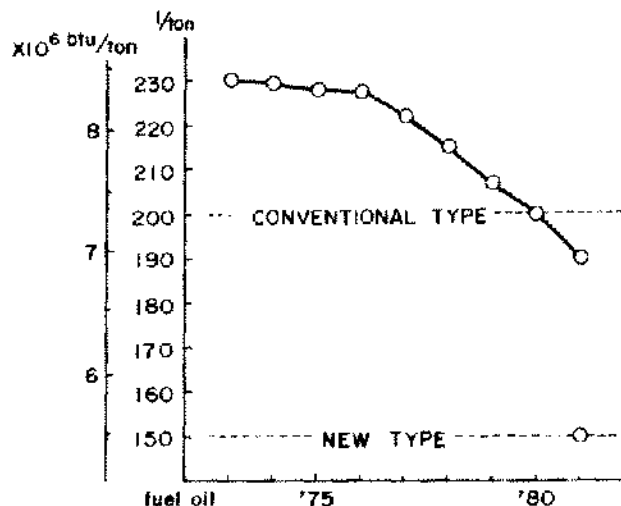


Figure 10. Recent trend of energy consumption to produce salt.

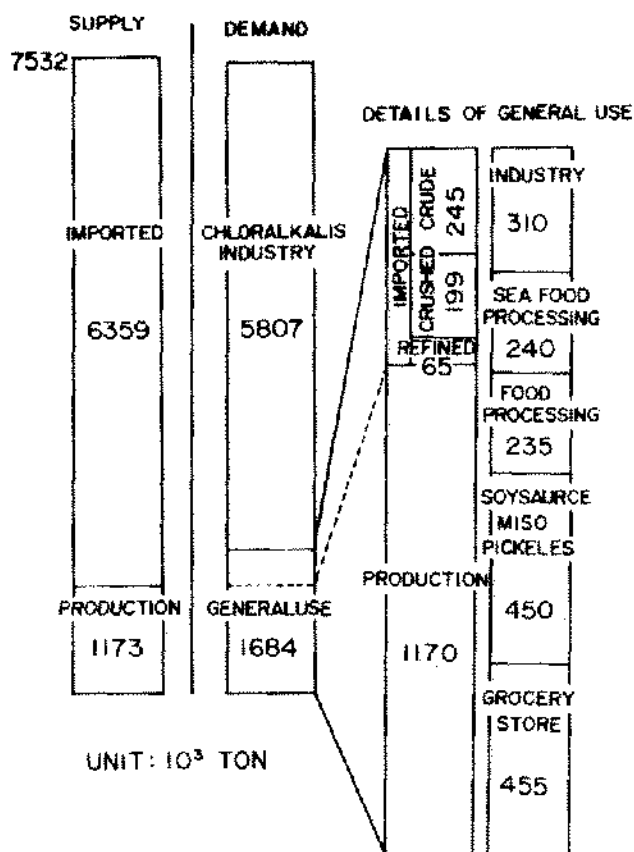


Figure 11. The pattern of supply and demand of salt in Japan.

essary authority to approve all of the manufacturing, purchasing, importing, refining, processing and selling of salt. The Japan Tobacco & Salt Public Corporation (JTS) has been implemented by the government for this purpose since 1949, when JTS was reorganized from the Monopoly Bureau under the Finance Ministry. Therefore, the JTS exerts a great effort to maintain a balance of the supply and demand for salt.

Thus, it was the government or JTS that has been deeply concerned in the rationalization of the Japanese salt industry and also in the development of the salt-producing technology.

Recently, the Japanese salt industry has developed so that domestic salt is able to compete in manufacturing cost with the refined salt from imported crude salt. And now, the Japanese salt industry is making progress in further rationalization, as the domestic salt may compete with crushed imported salt.

REFERENCES

- Kaho, M. and T. Watanabe. 1969. Concentration of sea water by electro dialysis with ion-exchange membrane; 3rd Symposium on Salt 1969.
- Kaho, M. et al. 1980. Salt manufacturing process by electro dialysis with ion-exchange membrane; Bull. Seawater Sci., Japan. Vol. 34, No. 2, p. 47-143.
- Murakami, M. 1982. The history of salt manufacture in Japan. 1. Development of IRIHAMA salt field; Bull. Seawater Sci., Japan. Vol. 36, No. 1, p. 3-13.
- Murakami, M. 1982. The history of salt manufacture in Japan. 2. Progress of salt industry in the 20th century; Bull. Seawater Sci., Japan. Vol. 36, No. 2, p. 67-76.