# History of Research and Development for Improving Productivity of Salt under the Salt Monopoly System

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The Salt Monopoly System in Japan was began in 1905 and lasted 92 years. There were five distinct periods of modern Japanese saltmaking during those years, and especially significant research and development occured in the last three distinct periods associated with advancing technology. The organization of research and development under the Salt Monopoly System was the key element in the productivity of Japanese salt production through utilization of new technologies.

## 1. INTRODUCTION

The Salt Monopoly System in Japan was started in 1905 with primary purpose of raising revenues to support the government. In 1919, the objective was changed and the Salt Monopoly directed to advance the public interest in efficient salt production. Specifically, the Salt Monopoly was charged with developing the salt industry, balancing supply and demand and supplying the public with good quality salt at reasonable and stable prices. Until 1948, the Salt Monopoly operated as the Imperial Japanese Salt Monopoly Bureau of the Ministry of Finance. Its name was changed to the Japan Monopoly Corporation in 1949 and the Japan Tobacco and Salt Public Corporation in 1973, and it became the Japan Tobacco Inc. in 1985. Research and development under the Salt Monopoly resulted in significant advances, many of which have been reported by Yamanaka [1] and Ohno [2]. During its 92-year existence, the Salt Monopoly achieved those objectives; it was abolished in 1997, with a five-year transition period. The Salt Industry Center of Japan assumed the operation of the salt business in 1997, but without the administrative authority of the former monopoly. For purposes of this paper, Salt Monopoly will be referred to as Japan Tobacco Inc. (abbreviation: JTI).

## 2. BACKUP SYSTEMS FOR RESEARCH AND DEVELOPMENT

JTI organized research and development into several steps: basic, table and pilot stage, and test plant. The methods and technologies developed were applied in factories operated by Japan's private salt companies in step by step improvements. Fig. 1 shows the academic and technological backup systems used by JTI and others. Facilities were developed and closed as occasion demanded.

Climatic conditions in Japan are unsuitable for making salt from seawater. Japanese technologists developed two processes, i.e. Saikan and Sengou, to overcome the natural inhospitality to saltmaking. The Saikan process makes brine; the Sengou process crystallizes salt in a pan. There were several technological steps in each process and Fig. 1 illustrates the timeline of their development. Section 4 will more fully describe these processes.

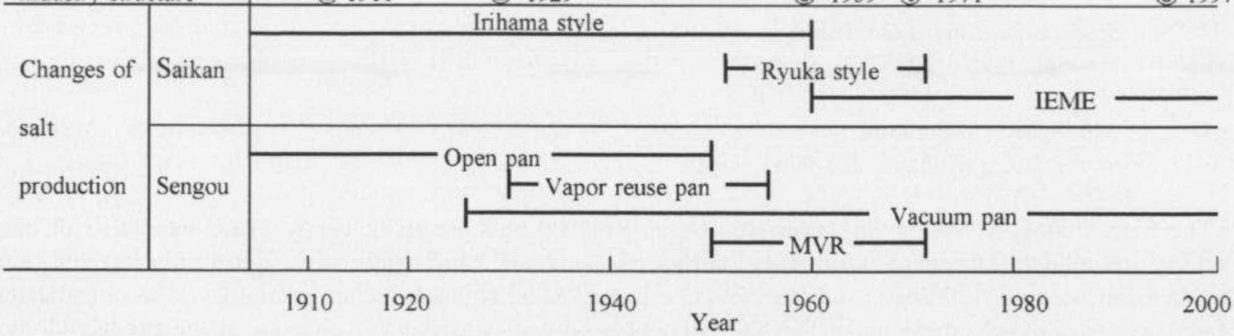
## 3. FIVE EPOCHS OF MODERN JAPANESE SALTMAKING

Five distinct periods occurred during JTI's 92 years as shown in Table 1: 1905-1909, 1910-1928, 1929-1958, 1959-1970 and 1971-1997. Each is characterized by changes in the structure of salt

Table 1
Changes of salt production technology and salt industry structure

| | 1906 | 1912 | 1930 | 1945 | 1955 | 1960 | 1970 | 1975 | 1997 |
|---|---|---|---|---|---|---|---|---|---|
| Area of salt field (ha) | 8,125 | 5,904 | 4,531 | 4,199 | 4,775 | 3,052 | 2,212 | 0 | 0 |
| Number of production site | 15,807 | 6,913 | 3,449 | 1,632 | 599 | 59 | 25 | 7 | 7 |
| A:Production rate ('000 t) | 564 | 620 | 629 | 184 | 595 | 834 | 951 | 1,144 | 1,338 |
| B:Number of worker | 122,312 | 57,551 | 37,783 | 28,777 | 18,741 | 4,768 | 3,977 | 1,329 | 1,067 |
| A/B (t/person) | 4.6 | 10.8 | 16.6 | 6.4 | 31.7 | 175 | 239 | 861 | 1,254 |

Five periods of salt industry structure: First ① 1910 Second ② 1929 Third ③ 1959 Fourth ④ 1971 Fifth ⑤ 1997




Note: IEME; Ion-exchange membrane electrodialysis, MVR; Mechanical vapor recompression

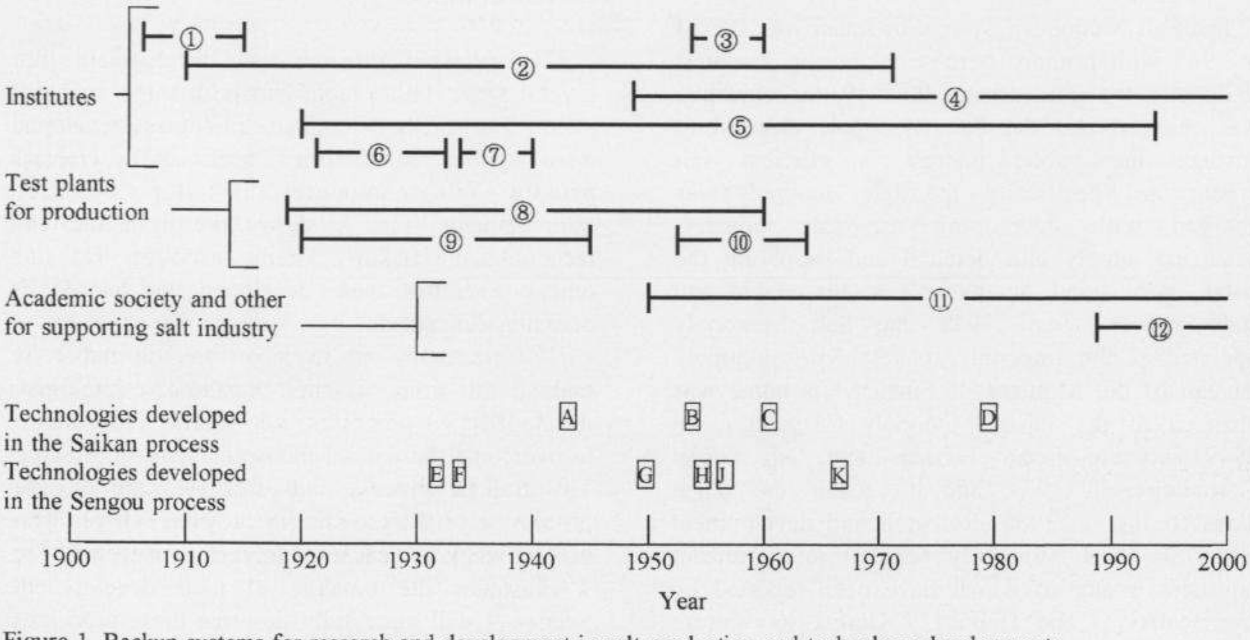



Figure 1. Backup systems for research and development in salt production and technology developments

① Tsudanuma Salt Experiment Station; ② Mitajiri Salt Experiment Station (Hofu Salt Experiment Station from 1938.) ③ Sakaide Experimental Salt Field; ④ Odawara Salt Production Experiment Station (Sea Water Science Research Laboratory from 1988); ⑤ Salt Research Division of Central Research Institute (CRI); ⑥ Isohara Branch of CRI; ⑦ Nagai Branch of CRI; ⑧ Hofu Salt Producing Plant; ⑨ Kudamatsu Salt Plant; ⑩ Onahama Salt Manufacturing Factory; ⑪ Society of Sea Water Science, Japan; ⑫ Salt Science Research Foundation;
[A] Ryuka style salt field (RSSF); [B] RSSF combined with Shijoka (solid evaporator); [C] IEME [D] 50% energy saving electrodialyzer; [E] Vacuum pan; [F] MVR pan; [G] Large scale MVR pan; [H] Anti-scale by seeding gypsum;

industry, the areas used for salt fields, the number of production sites and number of workers at production facilities. Throughout, the area used for salt production, the number of sites and number of workers steadily declined while production rate and per-worker production efficiency increased rapidly.

The periods were divided by closing poor or inefficient salt fields and applying new technologies advanced. The lower part of Table 1 reviews changes in the Saikan and Sengou processes. In the Saikan process, this evolution moved from the Irihama style salt field (ISSF) to the Ryuka style salt field (RSSF) and finally to ion-exchange membrane electrodialysis (IEME). Fig. 2 shows the increasing production rate achieved by this evolution of the Saikan process. Currently, the Saikan process, using IEME, produces about 1.4 million metric tonnes, satisfying Japan's needs for food grade salt. In the Sengou process, evolution proceeded from open pan to vacuum pan with short thermocompression evaporation and mechanical vapor recompression (MVR) evaporation as will be described in Section 4.

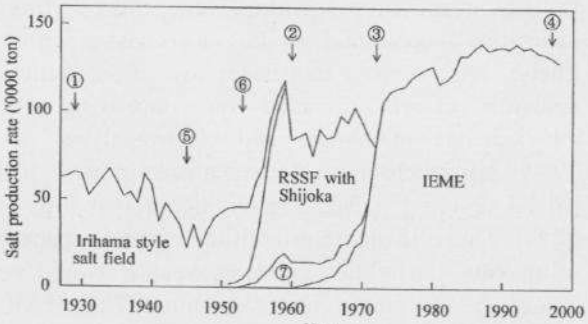



Figure 2. Changes of salt production rate by brine making processes

① Second consolidation; ② Third; ③ Fourth; ④ Abolish of the Salt Monopoly System; ⑤ End of WWII; ⑥ Conversion to RSSF with Shijoka; ⑦ Salt from sea water by MVRE

### 3.1. First period (1905-1909)

There were not any important technical changes in this period. Because it had only five years from the beginning of the Salt Monopoly System enforcement.

### 3.2. Second period (1910-1928)

This period began with the closing of many small and inefficient salt fields in 1910 [3-4]. No new technologies were employed, but because of closing salt fields with poor productivity, improved productivity was more than duobled and the number of production sites was more than halved.

### 3.3. Third period (1929-1958)

The period also began with closure of many inefficient salt fields, again with little technological advance in 1929 [5]. The area of salt field and the numbers of production site and worker decreased considerably. But the production rate was nearly same. So the productivity increased only a little at this point.

Thereafter the Sengou process was improved significantly, in corporating vapor reuse and vacuum evaporators. In 1936, the government launched a major, 8-year program to built salt plants, but the plan was abandoned in the war mobilization. During WWII, the salt industry sustained major damage and production fell by more than three-fourths to only 184,000 tonnes in 1945. The Sengou process was reconstructed and MVR evaporator was also built after the war. And the Saikan process began utilizing the RSSF with a solid evaporator as was used in Europe.

### 3.4. Fourth period (1959-1971)

As the new technology in the Saikan process increased production dramatically, creating conditions of over-capacity, the fourth period began with the closure of about 90% of the existing production facilities in 1959 [6] (see Fig. 2). Because of the high efficiency of the RSSF process, the remaining 10% of the facilities produced nearly 30% more salt than the total output prior to the reorganization. Many salt fields to be close to habitation were closed because of easiness of diversion to other land use.

A new technology of IEME began to be introduced to some salt facilities since 1961. The technology was estimated to be a main technology in salt production in Japan.

### 3.5. Fifth period (1972-1997)

The all-out change from RSSF to IEME facility in 1971 inaugurated the fifth period [7]. A revolutionary change, IEME allowed the existing salt fields to be closed and replaced with only seven salt production facilities. No longer would climate be a limiting factor in Japanese salt production. IEME process depends on the petroleum energy completely. Two times oil crises increased energy cost surprisingly. Development of energy saving electrodializer and change of energy from oil to coal recovered economics of salt production.

## 4. NEW TECHNOLOGIES

Japanese saltmaking consists of two steps: first, making brine concentrating seawater - the Saikan process - and, second, making salt by boiling down the brine - the Sengou process. The Saikan process has evolved from the ISSF of the mid-17[th] century (Edo Period) through the period of RSSF to the current use of IEME.

The Sengou process has evolved from use of open pan evaporation, to use of calandria vacuum pans to the use of outside heater type vacuum pans. Before settling on the current configurations of vacuum evaporators, Japanese saltmakers evaluated, but ultimately abandoned, use of thermocompression evaporators with steam and MVR evaporators. Developments in each technology have increased the productivity of Japanese saltmaking.

### 4.1. Saikan process to concentrate sea water

#### 4.1.1. Ryuka style salt field (RSSF)

After two centuries as Japan's preferred Saikan process, the ISSF gave away after WWII to the RSSF (symbol A showed in Fig. 1). This technology featured gravity-fed concentration ponds and was significantly more labor-efficient. The ISSF used seawater to dissolve salt from sand containing crystallized salt, repeatedly spreading thin layers of salt/sand and generating increasingly-concentrated brine. It required extraordinary amounts of labor every day to spread and rake up the sand and, finally to extract the crystallized salt. By contrast, RSSF utilized an electric-powered mechanical pump to raise seawater and brine to the highest elevation in the salt field and use gravity to aid in the concentration process. This achieved a ten-fold increase in worker productivity.

Moreover, beginning in 1953, RSSF used Shijoka (solid evaporator), a technique utilizing a wooden tower and bamboo branches to achieve another order-of-magnitude efficiency in evaporation (B in Fig. 1). Evaporating ability of Shijoka is about ten times of RSSF. Consequently by means of setting Shijoka with one-tenth area of RSSF, the production per unit of area doubles in total.

#### 4.1.2. Ion-exchange membrane electrodialysis (IEME)

Tokuyama Soda Co., Ltd. constructed IEME test facility (10,000 tonne in capacity) in their factory in 1956. Next Asahi Glass Co., Ltd. operated IEME of 10,000 tonne in capacity in salt production site in 1961 [9] (C in Fig. 1). Kawate told delegates to the Fifth Symposium about development of the IEME facility by Asahi Chemical Industry Co., Ltd. [10]. This technology was developed enthusiastically by competition among three companies. IEME was expected as a revolutionary method to concentrate seawater and it would achieve national self-sufficiency in salt production. So the entire Saikan process had been converted from RSSF to IEME on the base of the conceptional design report by JTI [11] in 1972. The system employed an independent power plant to generate electric power for concurrent operation of both the electrodialysis and evaporation plants and for steam to operate the three- or four-effect vacuum evaporation facilities. Independent power generation was found to be most cost-effective. Energy being a most significant cost of production, research efforts focused on improving the ion-exchange membrane and electrodialyzer. By 1980, efficiencies in electrodialyzer design had halved required power consumption (D in Fig. 1) [9,12]. These advances established current Japanese saltmaking capabilities ensuring weather would no longer be a factor in production. The IEME research and development story was highlighted in a special issue of the *Bulletin of the Society of Sea Water Science, Japan* [13].

### 4.2. Sengou process to crystalize salt in evaporator

#### 4.2.1. Multi-effect vacuum evaporator

The first Japanese multi-effect vacuum evaporator for salt crystallization was constructed and tested at the Mitajiri Salt Experiment Station in 1914. The technology was introduced to a part of the private salt factory around 1931 (E in Fig. 1).

#### 4.2.2. Mechanical vapor recompression (MVR) evaporator

Where available, inexpensive electricity was thought to provide less costly vacuum pan production in preference to using a boiler to heat the pan. In 1934, the Hofu Salt Factory constructed a MVR system using reciprocal compressors to recrystalize imported solar salt (F in Fig. 1). In 1949, turbo-blower compressor was tested in Odawara (G in Fig. 1). And the system was introduced in the Onahama Salt Manufacturing Factory in 1952 and adapted to make salt directly from seawater. Some private companies without salt field adopted the technology as well. This technology was abandoned by appearance of IEME without salt field.

4.2.3. Thermocompression evaporator with steam injector

Further efficiencies in the multi-effect process were achieved by capturing the steam from the first effect and compressing it using a steam injector. This technique was in widespread use by 1957, increasing productivity by 50-60% (J in Fig. 1).

4.2.4. Extending vacuum evaporator operations

Considerable inefficiency accompanies process system shutdown to discharge viscous mother liquor or wash off salt clumps which was required every few days. This was a complicated process and most energy-inefficient. Beginning in 1967, Japanese salt producers began to run their operations for extented periods of time, currently extending for several months, and have recorded improved heat energy efficiencies of 9% and enhanced productivity a further 11% (K in Fig. 1).

4.3. Anti-scaling method

Seawater has calcium and sulfate ions. The Sengou process has a serious problem with scaling of gypsum (calcium sulfate) on the surface of the heat tubes. The scale cannot be removed using acid. To minimize or avoid the problem, Japanese saltmakers learned to add mother liquor (bittern) and, later, the more effective seeding of gypsum to the brine. The calcium sulfate crystals attach to the seed gypsum and can be separated easily. The superior solution, however, awaited the use of the IEME method which resulted in reduced concentration of sulfates and avoided scaling by feeding the brine into the evaporator where the gypsum is not crystallized [8]. In addition, the inside of the evaporator units were simplified and polished to near-mirror smoothness with a buff #300 polisher which prevented scale and salt from adhering to the surface. This increased productivity by more than 30% (H in Fig. 1).

5. DISCUSSION

5.1. Difference of salts deposit sequence during concentration between seawater and ion-exchange brine

In the sequence of salts deposit through concentrating seawater in salt making, calcium carbonate is the only mineral crystallizing as during the first 10% concentration of seawater, about 77% of calcium sulfate having been crystallized by that point. As concentration continues, salt begins to crystallize (along with the remaining calcium sulfate). The concentration process is halted before magnesium sulfate begins to crystallize.

In contrast, in the case of IEME brine, sodium chloride precipitates along with calcium sulfate. Concentration is halted before potassium chloride precipitates. Since the concentration of calcium sulfate is small, the problem of gypsum scaling is less serious than in the solar salt field. Using the selective permeability of ions moving through an ion-exchange membrane, the ratios of calcium sulfate to sodium chloride in the seawater and ion-exchange brine become 0.0511 and 0.0067 respectively. Gypsum scaling controlled in multi-effect evaporating systems by selecting brine or concentrate to feed the evaporators.

5.2. Labor, energy and land for obtaining brine

There was a steady, step-by-step decrease in required labor, energy and land for obtaining brine during the 92 years when JTI managed the Salt Monopoly in Japan. This is particularly so with regard to replacement of the ISSF with more modern technologies. Today, a 200,000 tonne IEME factory employs only about 20 workers; larger plants have not many more. Land requirements are also small: about 50 $m^2$ for each 10,000 tonne in capacity. IEME has also dramatically reduced energy consumption, particularly compared with the MVR system.

5.3. Anti-scale methods for crystallizing salt in evaporators

Preventing gypsum scale is the most serious problem in vaccum salt production from seawater. Since 1916, anti-scale methods have been refined, beginning with the addition of bittern. Calandria evaporators had an agitator at the part of downtake to circulate salt slurry strongly in running in order to scrape scale away from the surface of heat tubes by salt crystals. A significant advance was achieved with seeding the brine with gypsum, nearly solving the problem of scaling in seawater. The best solution, however, has been use of the IEME method which uses the ion-exchange membrane to reduce the concentration of sulfate ions. Refinements in the brine feeding method have further reduced scaling deposits [8].

5.4. Development of evaporator

Research has improved the heat and energy efficiencies of evaporator systems. Japanese saltmakers today all use 3- or 4-effect systems and operate them for several months between maintenance shutdowns.

5.5. Balance of steam and power by independent power plant

JTI members are proud of their development of the IEME process [11] now used in all seven Japanese salt plants. In these plants, cost efficiency is achieved by balancing the steam requirements for the evaporators with the electrical power for electrodialysis. Electricity is expensive. And fossil fuel costs are unstable, witness the oil crises of 1974 and 1976 which resulted in energy cost for Japanese salt production being more than half the total cost of production. Research has developed more energy-efficient electrodialyzers and economical fuels such as coal and pitch. Using these innovations, Japanese saltmakers using 3- or 4-effect systems have reduced energy cost to about 20% of total salt production costs.

## 6. CONCLUSIONS

Using research and development by many institutes of JTI under the Salt Monopoly System, Japanese salt production during the 20$^{th}$ Century has evolved from a primitive agricultural method heavily dependent on weather and requiring vast amounts of land and labor to a modern systematic, industrial method, independent of weather and requiring vastly reduced amounts of land and labor. Using the fruits of this research and development will enable Japanese salt production to remain competitive with imported salt in the post-Salt Monopoly 21$^{th}$ Century.

## REFERENCES


1. H. Yamanaka and M. Murakami, Sixth Symposium on Salt Vol.2 Edited by B.C. Schreiber and H.L. Harner, Salt Institute, (1985) 557-563
2. M. Ohno, Seventh Symposium on Salt Vol. 1 Edited by H. Kakihana, H.R. Hardy, Jr., T. Hoshi and K. Toyokura, Elsevier, (1993) 13-19
3. The Imperial Japanese Monopoly Bureau, A Complete Account of the Monopoly System in Japan, (1912) 42-58
4. The Imperial Japanese Monopoly Bureau, Achievement Report of Salt Field Disuse (in Japanese), (1912)
5. The Imperial Japanese Monopoly Bureau, Outlook Report of Salt Field Disuse (in Japanese), (1931)
6. Salt Department of Japan Tobacco and Salt Public Coporation, Achievement Report of the Salt Industry (in Japanese), (1966)
7. Salt Industry Modenizing Department of Japan Monopoly Corporation, Fourth Achievement Report of the Salt Industry (in Japanese), (1973)
8. S. Sugita, Sixth Symposium on Salt Vol.2 Edited by B.C.Schreiber and H.L. Harner, Salt Institute, (1985) 535-540
9. T. Kawahara, K. Suzuki and K. Asada, Sixth Symposium on Salt Vol.2 Edited by B.C. Schreiber and H.L. Harner, Salt Institute, Inc., (1985) 499-513
10. H. Kawate, T. Seto, R. Komori and Y. Nagasato, Fifth Symposium on Salt Vol.2 Edited by A.H. Coogan and L. Hauber, Northern Ohio Geological Society, Inc., (1980) 317-324
11. Department of the Planning and Development of Japan Monopoly Corporation, Study of the Salt Making by Ion-exchange Membrane Electrodialysis (1971) (in Japanese)
12. H. Kawate, K. Miyaso and M. Takiguchi, Sixth Symposium on Salt Vol.2 Edited by B.C. Schreiber and H.L. Harner, Salt Institute, (1985) 471-479
13. The thirty anniversary memorial special issue of the Society of Sea Water Science, Japan, (1980) 47-143 (in Japanese)