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Technical Progress of Salt Production in Japan

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INTRODUCTION

Japan possesses no salt resources such as rock salt or saline lakes or springs. Therefore, since prehistoric times salt has been obtained from seawater. In Japanese salt is called 'Shio', and the tidal ebb and flow of the sea is also called 'Shio' or 'Ushio'. This reflects the basic idea held by the Japanese that salt and the sea are intimately related to each other.

Since ancient times, the Japanese have been deeply involved with the sea and are, indeed, blessed with the sea. For example, fish and shellfish are essential to the Japanese diet. In addition, the sea plays an important role as a means of transporting goods. Even more important, the sea brought people and their advanced cultures from the Asian Continent to Japan. These influences blended into Japanese life and stimulated our culture to develop further. Therefore, as seen in such Japanese words as 'Umi', the sea, and 'Umu', to give birth, the Japanese have always paid great respect to the sea as the 'mother of life', and this since time immemorial when people had no scientific knowledge. Thus, salt has always been seen as the sea's gift to our ancestors.

TRANSITION OF SALT-PRODUCING TECHNOLOGY IN JAPAN

Sea salt in Japan

Seawater contains about 3% weight of salt, so in order to extract salt from seawater the 97% of water must be removed. In many countries, salt has long been produced by solar evaporation of seawater in vast saline fields. However, such a practice is not feasible in Japan. This is partly because the nation has limited land resources, especially flat land, and partly because the seasonal wind brings a lot of rainfall in summer when the sun's rays are strongest. Because of these topographic and climatic factors, a two-stage process of making salt has evolved and has remained important in Japan. This two-stage process consist first of a concentration stage, called 'Saikan' in Japanese, in which seawater is concentrated into brine. The second stage is one of crystallization, called 'Sengo'.

Salt and culture

Salt is vital to our life; since they first appeared on earth, people must therefore have obtained salt somehow. Historically, the development of Japanese salt technology started with the method of 'Moshio Yaki' in the 6th century. In this method, seaweed containing seawater was first exposed to sunshine. After thus concentrating the seawater into salt, on the surface of the seaweed, the salt was extracted in seawater to form a brine concentrate. Lastly, the brine was heated up in a clay pot and crystallized. This method can still be observed at the 'Shio-gama Jinja', or Salt Pot Shrine, in Miyagi or other Prefectures. The priests of the 'Shio-gama' shrine demonstrate this method as one of the rituals of Shintoism every July. In addition, the shrine is dedicated to a god, or 'Kami', called 'Shio-Tsuchi-Oji', who is said, in legendary folklore, to have introduced to the Japanese the technique of how to make salt from seawater.

Interestingly, to the Japanese, a god or 'Kami' is neither the 'Creator' nor the 'Absolute'. Rather, the Japanese gods symbolize the elements of nature, namely the sea, mountains, grass, trees, and so on, which people saw as a blessing of abundant gifts which enabled them to live. So, within Shinto, people worship the gods in order to express their appreciation of nature. Accordingly, Shintoism is free of ideological dogma, and within it people can find no reason for conflict with those who believe in a differ-

ent religion. It is this open and flexible cultural attitude which has enabled the Japanese to accept the peoples and cultures of the Asian Continent so easily over the centuries.

Returning now to the cultural background of salt, there is no real evidence that salt was ever worshipped as a Kami, despite the fact that millions of different Kami have been worshipped in Japan. However, salt is a traditional offering to the Kami, as is rice wine, Sake. Salt has been also used for centuries to clean-away and purify things viewed as dirty or malevolent; throughout history it was considered a medicine and commonly used as a folk remedy. Furthermore, salt, together with rice was offered as a tax, or was paid to workers as salary. Such customs and habits relating to salt are well known in certain foreign countries, and many were introduced to Japan from the Asian Continent.

Agehama-type salt field

In the 8th century, people began to concentrate seawater by using sand instead of seaweed. In the earliest application of this process, seawater was collected on a natural beach at ebb tide so, to concentrate the seawater, people had to switch fields from one beach to another. Later, a fixed beach site was employed to concentrate seawater and the used sand was recycled. In fact, this represents the beginning of the salt field method in Japan. In individual salt-producing areas, the way in which seawater was transported from the sea into the salt field was determined by the local topography and tidal range. On the Pacific and Japan Sea Coasts, where the tidal range is rather small, seawater was manually drawn from the sea by a wooden bucket, and sprayed over a salt field. The salt-encrusted sand was then collected, and fed into a wooden extractor, or 'Nui'. Finally, additional seawater was poured over the sand to dissolve out the salt to form a brine. The corresponding salt field is called the Agehama-type salt field, and this method is still practised in the Noto Peninsula as a tourist attraction.

Irihama-type salt field

In contrast, around the coasts of the Seto Inland Sea and of Northern Kyushu, where the tidal range is large, seawater was always transported into the salt field by taking advantage of the tidal range. Among salt fields making use of this method, the Irihama-type salt field developed into the most advanced and efficient salt field on the coast of the Seto Inland Sea in the middle of the 17th century. The Irihama-type salt field was made by reclaiming tidal land, building the foundation of the salt field in the middle lying areas located between the high tide and ebb tide levels. The foundations were composed of about four layers consisting of coarse sand, laid down at the bottom, covered by progressively finer sands, used in the upper parts. In addition, the salt field was cut into rectangular plots by a network of channels designed to conduct seawater into the salt field. In technical terms, seawater penetrated into the field through the channels, and was carried to the surface by means of capillary action. The seawater then became concentrated by solar evaporation, forming a crust of salt attached to the sand in the surface layer of the salt field. Fortunately, the coastline of the Seto Inland Sea is favourably situated with regard to its climate and topography, as well as its proximity to large markets. Climatically, the region receives little rainfall because it is sandwiched between the Chugoku and Shikoku mountains. Topographically, it possesses the advantage that there are many relatively gently-sloping sandy beaches. Finally, market-wise, the Seto coastline is located near the huge consumer cities of Osaka and Kyoto. As a result, the region developed into the leading salt manufacturing area in Japan and, by the beginning of the 18th century, the area of salt fields along the Seto coastline totalled about 16 km^2, producing some 200,000 metric tons of salt per year, 50% of the national production. In the middle of the 19th century, the Irihama-type salt fields of the Seto Inland region further expanded to cover an area of about 40 km^2, delivering 80–90% of the total salt production in Japan.

Working in the Irihama-type salt fields was heavy and painful labour in which huge amounts of sand had to be moved. The efficiency of recovering the salt deposited within the surface sand was around 7%, so, in order to produce one ton of salt, about 14 tons of salt-encrusted sand was needed. As in earlier times, the salt was extracted by dissolution in a wooden vessel or Nui. After extraction, the sand had to be returned to the salt field. Adding up all the operations, about 28 tons of sand had to be moved to make one ton of salt. Carrying seawater and brine by wooden buckets was also hard work. Such hard work made the labourers working in the salt fields very fit, and it was said that some of them became excellent marathon runners.

Finally, it is noteworthy that the Irihama-type salt field method was quite unique compared with other salt field methods employed around the world. Furthermore, for 300 years until the middle of the 1950s, the basic method, though improved many times, remained unchanged. Thus, the Irihama-type salt field has played a leading role as a concentrating process in Japan.

Crystallization

Regarding the crystallization process, Sengo, technical developments were initiated by the introduction of salt making pottery. In even earlier times, vessels such as vertically halved bamboo containers or stones carved into a dish shape also seem to have been used. Around the time when the salt field method first emerged, an open pan made from a mortar of seashells and wood ash mixed with clay and seawater, began to appear. Similar open pans have also been found in China and Korea. Accordingly, this technique is understood to have been brought into Japan from the Asian Continent. In some parts of Japan, an open iron pan or a pan made of a bamboo core and mortar mantle were used instead.

Around the coast of the Seto Inland Sea, where the Irihama-type salt fields prospered, an open pan made of local granite prevailed. This type of pan was embedded firmly within a mortar rim on top of a furnace. At the bottom of the pan, slabs of granite were cemented together with mortar made from the ashes of burnt seashells, clay, rice husks and bittern. For support, iron hooks were fastened into the granite slabs in the bottom of the pan, and these were roped to an overhead beam. This type of pan was typically 2.2 m wide, 1.8 m long and 12 cm deep, and had a capacity to thermoevaporate the brine produced from an area of 7000–8000 m^2 of salt field. Some even bigger pans could process the brine made from salt fields with a total area of 1.5–2 ha. Unfortunately, however, the average life of a pan was only twenty to thirty days.

Fuel

As a fuel for the various open pan crystallization processes, the leaves or branches of pine and other trees were used. However, log wood was not suitable, because its strong caloric power resulted in the production of rather coarse salt. It is said that the quantity of fuel used for a single open granite pan corresponds to about 77 ha of woodland.

Entering the 18th century, fuel for salt crystallization became scarcer. During the 17th and 18th centuries, Japan's climate passed through a semiglacial period, and the temperature was lower by about 2°C than at present. This meteorological condition encouraged people to burn the trunks and roots of pine trees, which have high caloric power for domestic heating. In addition, burning the oil extracted from pine roots was commonly practised by the grass-roots population as a source of lighting. The more suitable rapeseed oil was far too expensive for them. Thus, the pine trees which had previously been an important fuel resource for salt production were sweepingly uprooted, and the mountains soon became bare. As a result, a serious shortage of fuel developed and a sharp price rise occurred. In the middle of the 18th century, 50% of the total cost of salt making was taken up in fuel costs.

In the late 17th century, coal had already made its first appearance as a fuel resource for salt production in the northern part of Kyushu. In the late 18th century, coal may also have been used for salt production along the coast of the Seto Inland Sea. At that time, the price of coal was only 40–50% of that of wood. Despite this, however, the introduction of coal as a fuel met strong opposition from wood suppliers and farmers, since it seriously threatened their livelihoods. Eventually, a compromise to using both coal and wood was reached in many regions. Such measures were presumably taken by the feudal lords, who owned the woodlands. They imposed a tax on the trees collected, thus stabilizing their incomes. The measures were also intended to avoid drastic socio-economic changes which the feudal lords feared might trigger unrest and the collapse of their rule and administration. The above illustrates just how large and important the salt industry was in the 18th–19th centuries in Japan.

AFTER THE MEIJI RESTORATION IN 1868

Monopolization of the salt industry

After the Meiji Restoration in 1868, the Japanese Government implemented drastic programmes of political, economic and social reform as well as measures to promote commerce and industry, aiming at the construction of a nation led by a centralized government as in the United States or in European countries. As for the salt industry, in 1882 the Agriculture and Commerce Ministry conducted a study of the state of the salt industry in Japan. For conducting this study, a German scientist, Dr. Oskar Korschelt was appointed, to take full responsibility. Subsequently, he drew up and submitted a report entitled "Thoughts on Sea-Salt Manufacturing in Japan". In this report, Korschelt reported observations on facilities, salt-making technology and business management in the salt industry and, furthermore, made several suggestions for improving the existing salt manufacturing system in Japan. His suggestions contributed substantially to the subsequent development of the Japanese salt industry.

Following the Meiji Restoration, salt prices in Japan began to go up from around 1880. In 1895, when the Sino–Japanese War was over, the salt price sky-rocketed alongside surges in both coal prices and wages. In the same year, a mission was despatched to China with the aim of studying the

Chinese salt industry and assessing the potential for exporting salt from Japan to China. However, the study in China revealed that standards in the Japanese salt industry lagged far behind the rest of the world. Furthermore, in 1896, imports of salt from Taiwan awakened concerns about the salt industry in Japan, and created the feeling that something should be done to stimulate improvement. Against such a background, when the Russio–Japanese War broke out in 1905, the government decided to monopolize the salt industry in order to secure national revenue as well as protecting and fostering the salt industry.

Due to this monopolization of salt, a new system of production, transaction and distribution was established. Under the new system, the following regulations applied: (a) only authorized manufacturers were allowed to produce salt; (b) the government purchased all salt produced; (c) only appointed distributers were allowed to supply salt to retailers. Furthermore, salt grades were established according to its purity, and these formed the basis on which the price paid by the government was fixed. In addition, the basis of measurement for salt transactions was changed from by volume to by weight.

Technology of crystallization

(1) Kanawha-type evaporator

The quality of salt is determined by whether or not the technique used for the crystallization process, Sengo, is effective. Quality considerations thus stimulated efforts to improve the apparatus and technology used for the crystallization process. In 1909, the Monopolies Bureau of the Ministry of Finance set up the Mitajiri Experimental Station in present-day Hofu, Yamaguchi Prefecture, to begin research and development projects in the area of crystallization process technology. Amongst its projects, the station began further development of the Kanawha-type salt-making vessel. This vessel was originally used at the salt manufacturing plant on the Kanawha River, a feeder of the Ohio River in the United States. Researchers at the Mitajiri station paid careful attention to the vessel and tried to improve it, with the aim of making it feasible for brine obtained from salt fields. In this system, the brine concentration vessel was heated directly by burning fuel and the vapour generated was used to heat the crystallization vessel. Generally, the most serious problem encountered in applying the crystallization process to salt-field brine was one of how to prevent scales of gypsum growing on the inside of the vessel. So, in the improved Kanawha-type vessel, a revolutionary scraper was fixed in the brine concentration pan, so that the scales were removed mechanically. In 1913, the experimental station completed the project. Because of this development, the quantity of fuel consumed was cut drastically. In addition, the quality of the salt which could be obtained was upgraded, compared with that made using traditional stone or iron crystallization pans. However, the capacity of the improved Kanawha vessel was so large in comparison with individual salt fields providing brine at that time, that it took several decades to be adopted in practice.

(2) ST-type evaporator

In the meantime, a smaller scale crystallization vessel, the ST-type open pan, was invented. Here, ST stands for the initials of the inventor, Shingo Tanaka. In his design, he attached a small vessel to the edge of an open pan from which precipitating salt and fine particle of gypsum were manually transferred to the smaller vessel, from time to time. His device thus prevented gypsum scales from growing on the open pan, and this resulted in improved thermal efficiency. The ST-type possessed the advantage that its capacity was commensurate with the size of the salt fields. Therefore, the ST-system was widely introduced in Japan from around the 1930s.

(3) Vapour Re-use method

In 1925, the Vapour Re-use apparatus for the crystallization process was developed. In this method, brine was preheated using vapour generated from a tightly shut crystallization vessel, which was directly heated, the vapour being passed through a heat exchange pipe in the brine. Because of its simple structure and flexibility of capacity, compared with systems of the improved Kanawha-type, the vapour re-use method became the dominant process for a while.

(4) Vacuum evaporator

In 1913, the development of the Vacuum-Evaporation Method was initiated, and in 1927, the Monopolies Bureau started direct operation of a crystallization process plant equipped with a triple-effect vacuum evaporator. Actually, the plant was designed to refine imported solar salt. At around the same time, however, a manufacturer in the private sector brought into operation a crystallization plant for salt field brine. This plant utilized the same triple-effect vacuum evaporator, and enabled 15,000 metric tons of salt to be produced per year. Above the evaporator, the factory featured 15 concentrator units filled with the revolutionary gypsum scrapers invented for the improved Kanawha vessel.

(5) Bittern feeding method

In 1937, another method designed to remove gypsum scale was invented. This was the bittern feeding method, in which bittern fed into an evaporator led to an increased concentration of the mother liquor and a decrease in the solubility of gypsum. Thus the gypsum could precipitate out of the mother liquor, so that the growth of gypsum scales on the inside of the vessel was prevented. After the appearance of this method in the salt manufacturing industry, the previous scraper method became obsolete.

(6) Vapour compression evaporator

From the 1920s, people began the study of technologies for making salt directly from seawater using the vapour compression method. After the Second World War, great expectations regarding the development of such technology were raised against a background in which there was an urgent need to increase salt output, due to its shortage after the Second World War. Furthermore, the salt fields had become eroded away and labour was in short supply. Accordingly, the Odawara Salt Experiment Station, the forerunner of the Seawater Research Institute of Japan Tobacco Inc,. was established. It focused on studying the development and design of a salt manufacturing plant introducing the vapour compression method. In 1952, a pilot plant, with an output of 100,000 metric tons per year, was finally brought into operation in Onahama, Fukushima Prefecture. In 1955, as a counter measure against vessel scaling, a new method was developed in which gypsum seeds were added to the vessel. Applying this, together with the technology of removing dissolved carbon dioxide gas from seawater, subsequently enabled the stable operation of the vapour compression method. The method was then widely introduced into the salt manufacturing industry. In 1959, 200,000 metric tons of salt were produced using the method.

Technology of concentration

(1) Sloping salt field

Let us now look back to the development of the brine-making process, Saikan. From the 17th century, the Irihama-type salt fields continued to be used until 1955. However, the long-running salt industry underwent substantial reorganization in 1911/1912 and 1929/1930 respectively. As a result, the less competitive and relatively small salt fields were abandoned, and through technological improvements, productivity rose to 130 metric tons per hectare per year in 1935, against 60 metric tons in 1906. However, by the 1950s the time had finally come when the Irihama-type salt field, which had dominated the industry in Japan for 300 years, was replaced by the more productive 'sloping salt field'. This consisted of a sloping soil bed, forming a salt field plus a concentration facility built of branches of bamboo. In this system, seawater was first passed over the sloping soil bed and evaporated under the action of solar energy. The brine produced was then passed through the bamboo concentrator thus flowing down the bamboo branches and coating them with a film of running seawater. During this process, the liquid evaporated further, partly as a result of wind action and partly due to the under-saturation of the air with moisture. With this bamboo-branch facility, the concentration process could even be operated in winter. In addition, the productivity per unit area of salt field increased by 2.5 to 3 times that of the Irihama type. Consequently, it became clear that salt would be overproduced by the shift to sloping-bed salt fields. Then in 1959/1960, the third reorganization of the salt industry was carried out. This resulted in a total operating area of 2,700 hectares of sloping-bed-type salt fields, six major manufacturers operating the vapour compression method, and 22 crystallization process factories using the vacuum evaporation method. This led to a total capacity in Japan of 900,000 metric tons per annum.

(2) Ion-exchange membrane electrodialysis method

Later, because of the emergence of the ion-exchange membrane method, Japanese salt-making technology underwent another drastic change. Thus in 1971, the salt industry was reorganized for the fourth time. Under this reorganization, salt production became restricted to seven manufacturers, applying the following methods for the two main processes in manufacturing salt, namely (1) the ion-exchange membrane electrodialysis method of concentration and (2) the multiple-effect vacuum evaporation method of crystallization.

With regard to the ion-exchange membrane method, research has been conducted in Japan since the beginning of the 1950s by the Tokuyama Soda Co., Ltd., the Asahi Chemical Industry Co., Ltd. and the Asahi Glass Co., Ltd., as well as by the Japan Monopoly Corporation. Initial U.S. research into the method was aimed at introducing it as a desalination process. However, in Japan, studies were targeted at the ion-exchange membrane process as a means of concentrating seawater. The essential principle of the method is that seawater is concentrated by electrolytically forcing the anions and cations to penetrate corresponding anion exchange and cation exchange membranes. Later, both ion types are combined together in a concentrated solution. In 1960, two new factories brought the method into

operation. Further, by 1969, 208,000 metric tons of salt per annum, i.e. 23% of total salt production in Japan, was produced using this concentration method. Since the ion-exchange membrane method enables reduction of fuel cost plus stable production, independently of the weather conditions which always ruled salt-field production, it sweepingly replaced the pre-existing technologies. Even after this period of introduction, the ion-exchange membrane method has been continuously improved. At present, performance has reached level of 193 KwH of electricity for the production of one metric ton of salt and brine concentrations of 180 g/l. In addition, a membrane life of about 10 years has now been achieved.

Turning now to the way in which an entire present-day manufacturing plant operates, electricity is first generated in-house to operate the ion-exchange electrodialysis apparatus. Next, steam emitted from the turbines of the generating system is used to drive the vacuum evaporation crystallization apparatus, as well as for other energy needs. The question of how to utilize energy efficiently has been thoroughly studied. At present, the total energy required for the production of one metric ton of salt is about 1,500,000 Kcal.

Advantages of ion-exchange method

Nowadays, the annual demand for salt in Japan amounts to about 9.4 million metric tons, of which 85% is imported solar salt supplied mostly to the chloralkali industry. Domestic salt totals about 1.4 million metric tons, accounting for 15% of total demand. Every single particle of this domestic salt is made by the ion-exchange membrane concentration method, along with the multiple-effect vacuum evaporation method of crystallization. In fact, the ion-exchange membrane method has several further advantages. Firstly, it ensures the quality of salt as a healthy food. Although industry is prone to contaminating coastal waters, the ion-exchange method removes hazardous heavy metals, organic substances and micro-organisms from seawater, thus guaranteeing safe salt. Secondly, it achieves high productivity per unit area of land used. Comparing this measure of salt productivity for the Irihama-type salt field, the sloping salt field and the ion-exchange membrane method, yield ratios of 1:2.5–3.0:300 respectively. The thus-liberated salt fields have been progressively converted to factory sites or sites for other purposes, one after another. This in turn has helped to drive our nation's industrialization. Lastly, thanks to the introduction of the present technology, productivity has become surprisingly efficient with respect to the labour force needed. Comparing productivity per labourer for the Irihama-type salt field, the sloping type, and the present ion-exchange method yields ratios of 1:10:80, with the ion-exchange membrane method possibly doing even a little better than the figure of 80. Furthermore, the quality of working life in the salt industry has improved, and this is also worth taking into account. In the same way as in farming, working the salt fields was labour intensive. In contrast, labour in industrialized salt making has become more intelligence intensive, with workers having responsibility for monitoring and analyzing information on the progress of production, for research and development, and for the development of new salt commodities.

CONCLUSIONS

In this paper, I have given an overview of the historical development of salt manufacturing technology in Japan. These developments have been driven by a great deal of cooperation from a wide range of industries, academic institutions and governmental organizations, along with the salt industry itself, of course. In this way, the technology has finally reached its present level. Amongst the various organizations which have contributed, the Japan Society of Seawater Science — the only association in the world responsible for seawater — has been playing a key role in studying certain areas of seawater science. It has also made a great contribution to the development of seawater desalination technology, such as the reverse osmosis method or flash evaporation method. Furthermore, besides being the centre of research on recovering uranium from seawater, it has also studied the separation and use of bittern, a by-product of the salt-making process, and the results have been put to practical use by salt manufacturers and other industries. At present, the association is committed to interdisciplinary studies in four main areas of salt-making technology, as well as to the study of seawater resources, the relationship between seawater and environment, and oceanic life. Its members include experts from the ranks of industry as well as academic and governmental organizations.

A second major body is the Salt Science Research Foundation, the sponsor for this Salt Symposium. This was founded by Japan Tobacco Inc., the salt industry, and other industries. It provides financial support for basic research in the areas of salt production, use of seawater resources, the physiological influence of salt, and the role and use of salt in foodstuffs as well as for food processing.

In addition to the above, a third organization, the Seawater Research Institute of Japan Tobacco Inc.,

has formed the principal centre conducting research into salt manufacturing technology in Japan. Fourthly, as the makers of ion-exchange membranes, the Asahi Chemical Industry Co., Ltd., Asahi Glass Co., Ltd., and Tokuyama Soda Co., Ltd. have carried out ongoing R & D programmes to improve further the performance of ion-exchange membranes and to expand their potential use. Last but not least, the Japan Salt Industry Study Group is responsible for salt-related research activities in the social sciences. Expert members of this group specializing in such disciplines as history, economics, law and anthropology, have conducted research into the history of salt-making in Japan, Japanese salt economics and governmental policies on the salt industry. The group has already published twenty annual volumes under the title "A Study of the Salt Industry in Japan" as well as "An Historical Outline of the Salt Industry in Japan" in seventeen volumes.

Thus, the Japanese salt industry has been supported by many people. This really demonstrates that the Japanese truly appreciate salt and its importance. The main reason for this is that Japan is in fact an entirely unsuitable environment for producing salt, so that the Japanese have had to commit themselves to salt-making with their full ingenuity and passion. In the long history of salt production in Japan, there have been many unfortunate conflicts of interests. However, in many cases, such conflicts were settled by people with a missionary vision to produce and provide this essential substance for human life — salt! Geographically, Japan is an archipelago, made up of more than 6,000 islands. Furthermore, about 10% of the world's mountains exceed a height of 3,000 m in Japan. Therefore, many parts of Japan consist of mountainous areas, with people living right up to the footlands, due to the scarcity of flat land. People living in such remote, mountainous regions and on isolated islands naturally need a continuous supply of salt, without missing it for even a single day. Thanks to the history summarized here, salt can now be obtained everywhere in Japan, for the same price nationwide.