The Materials and Performance of the Latest Quadruple Effect Evaporator System

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Naikai has been producing salt from sea water since 1829. In 1993, the former 21-year-old triple-effect vacuum evaporator was replaced by the new system with the annual capacity of 0.22 mill. tons. In 1998, by installing another evaporator on schedule, the plant construction was completed as initially planned and the Japanese latest quadruple-effect vacuum evaporator is now running smoothly .

1. Introduction

Since Japan is not bestowed with rock salt resources, virtually all of the domestic salt comes from the sea water surrounding the islands. Although it becomes quite hot in summer, the humid and rainy climate does not allow purely solar salt. In order to economize fuel , two-staged production methods have developed ; the first stage is to concentrate the sea water, and the second stage is to boil it to obtain the salt crystals. Several types of salt ponds have been historically used in the first stage for hundreds of years. In the early 70's an electrodialytic process using ion-exchange membranes totally replaced the salt ponds. It is combined with a multi-effect vacuum evaporator. An in-house power plant supplies both electricity and steam used in the whole process. Performance of the ion-exchange membranes has improved, which leads to higher current efficiency. So, to make the best use of fuel coal , converting the plant to a quadruple-effect evaporation system has been carried out stepwise since 1993 till 1998. Corrosion resistant metals have been adopted in the key parts of the process to ensure the long service life of this new plant. Preventive countermeasures against the scaling and salting-up have been employed in order to raise the operation efficiency and availability. Furthermore, by making use of in-line sensors , the plant is equipped with a fully automatic control system.

2. Outline of the System

Dimensions of the quadruple-effect evaporator are shown in Table 1. Figure 1 is the flow chart. No.4 evaporator is a falling-film type, that is used as the concentrator of the brine from the membrane system. No.1, 2 and 3 evaporators are the forced-circulation type which are used as crystallizers. No.0 evaporator is the forced-circulation type, that is used as the concentrator of the mother liquor.

Typical operating conditions are shown in Figure 2.

3. Materials used in the Equipment

Typical liquor compositions are given in Table 2. Materials applied in this systems are listed in Table 3. They are carefully selected to endure the severe conditions.

Only titanium and titanium alloy are used for the heat exchanger tubes, which are chosen for their high resistance against corrosion and erosion.

Monel metal cladded steel is applied in the evaporator vessels.

In order to prevent the galvanic-cell corrosion, insulation between the neighboring different metals is carefully maintained.

Table 1
Some Key Figures of the Quadruple-Effect Evaporator System

	Units	NaCl in Brine (g/kg)	Vapor (t/h)	Salt Yield (t/h)
Total Evaporator Process	5	180.4	141	27.3

		No.0 (Mother Liquor Concentrator)	No.1 (Crystallizer)	No.2 (Crystallizer)	No.3 (Crystallizer)	No.4 (Brine Concentrator)
Type of the Evaporator		Forced-Circulation	Forced-Circulation	Forced-Circulation	Forced-Circulation	Falling-Film
Heat Transfer Area (m^2)		400	1000	1000	1000	1285
Heat Transfer Tube	Diameter(mm)	42.7	42.7	42.7	42.7	42.7
	Thickness(mm)	0.75	0.75	0.75	0.75	0.75
	Length(mm)	7600	7600	7600	7600	8000
Evaporator	Diameter(mm)	3000	5000	5800	6500	5000

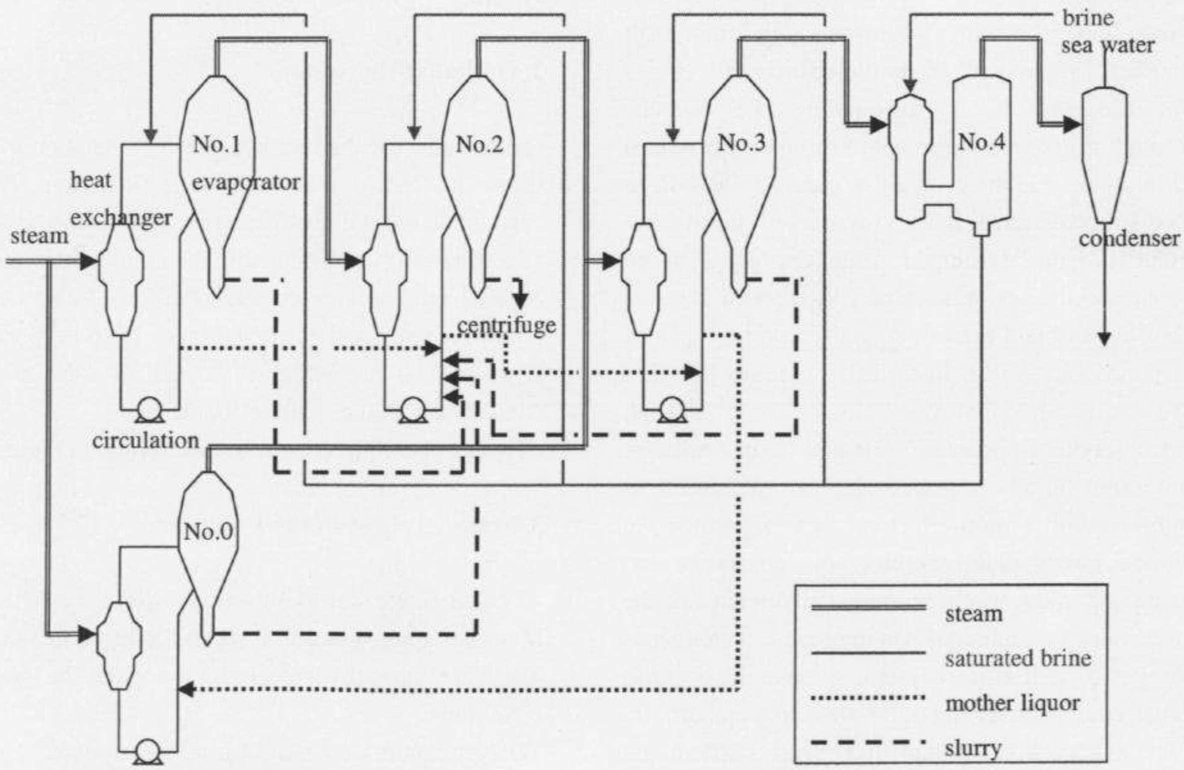

Figure 1 System Flow Chart

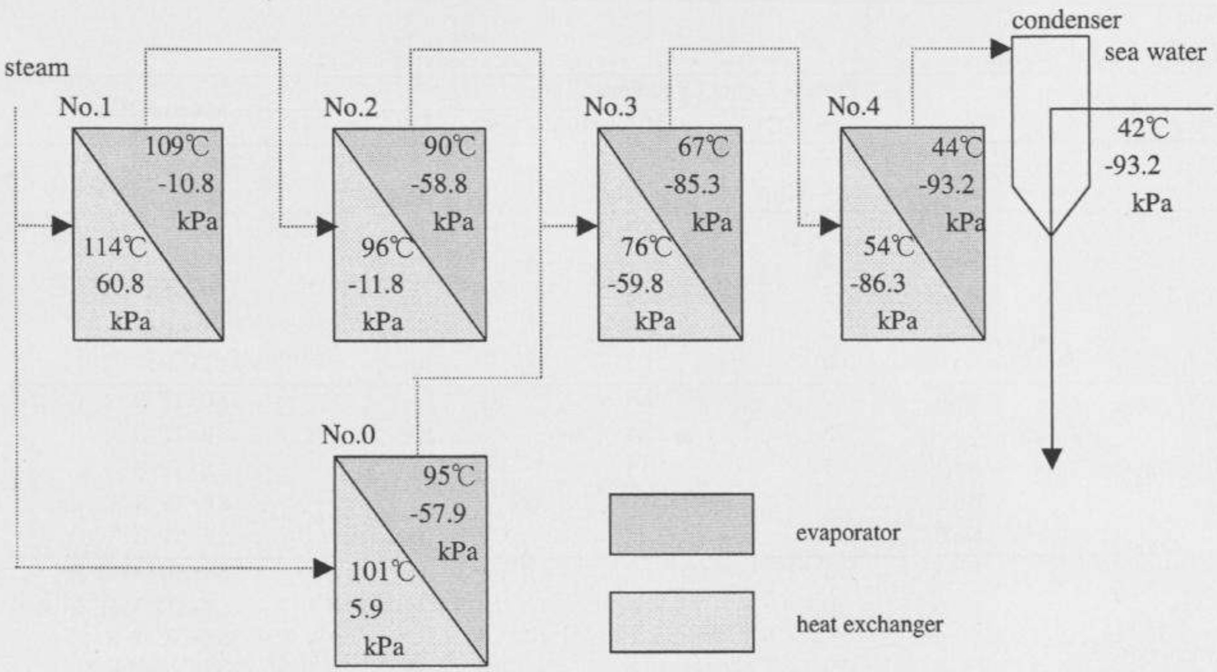

Figure 2 Typical Operating Conditions of the Quadruple-Effect Evaporator System

Table 2
Analyses of the Liquors. (wt.%)

	NaCl	$CaCl_2$	$MgCl_2$	KCl	T-Cl
Sea Water	2.50	0.19	0.32	0.07	1.78
Brine	15.51	0.37	1.07	0.60	10.60
No.4 Saturated Brine	19.10	0.50	1.12	0.90	21.62
No.3 Mother liquor	5.86	3.28	8.43	6.73	24.30
No.2 Mother liquor	7.25	2.98	7.37	5.85	23.45
No.1 Mother liquor	9.76	1.81	4.60	3.81	19.98
No.0 Mother liquor	7.25	5.69	15.03	10.63	22.80

data:1998 Sept.-Dec.

4. Corrosion and Erosion Resistance

4.1. Heat Transfer Tubes

Surface conditions of some heat transfer tubes from each evaporator were examined and their thickness was periodically measured in order to grasp the magnitude of damages caused by erosion and corrosion. No change of color and lustre of the tubes has been observed up to now. The measurements of the inner diameter with the use of micrometer do not show any change either. So, it may well be said that the heat transfer tubes made of titanium and titanium alloy are living up to the expectations to be extremely corrosion and abrasion resistant even in these difficult environments.

Titanium and titanium alloy have smaller heat transfer coefficients than copper alloys, so the thickness of the tubes has been set as thin as possible, and the flow velocity in the tubes is kept somewhat higher than that in the previous system. The results of the calculations of the overall heat transfer coefficients reveal better heat-transfer performance than what was initially estimated. Although it had been apprehended that the tubes might be too thin to resist the abrasion caused by the circulating hot

Table 3
Materials Used (JIS)

Equipment		Process Liquor Conditions			Material(JIS)
		Temp.(℃)	$MgCl_2+CaCl_2$(%)	Salt Slurry(%)	
Pipe		20～100		–	FRP & PP
		80～110		20～50	SUS329J2L & TTP
Heat Transfer Tube	No.4	50	1.9	–	TTH
	No.3	75	12.4	10～20	TTH
	No.2	95	10.8	10～20	TTH-Pd
	No.1	115	6.6	10～20	TTH-Pd
	No.0	100	21.7	10～20	TTH-Pd
Heat Transfer Sheet	No.4	50	1.9	–	SB+TP-B
	No.3	75	12.4	10～20	SB+TP-B
	No.2	95	10.8	10～20	SB+TP-B
	No.1	115	6.6	10～20	SB+TP-B
	No.0	100	21.7	10～20	SB+TP-B
Evaporator	No.4	45	1.9	–	SS+SUS316L-R
	No.3	70	12.4	0～20	SS+SUS316L-R & SS+NCuP-R
	No.2	90	10.8	0～20	SS+NCuP-R
	No.1	110	6.6	0～20	SS+NCuP-R
	No.0	95	21.7	0～20	SS+NCuP-R
Circulation Pump	No.3	70	12.4	0～20	SCS16
	No.2	90	10.8	0～20	SCS16 & NCuC
	No.1	110	6.6	0～20	SCS16 & NCuC
	No.0	95	21.7	0～20	SCS16 & NCuC

slurry, no sign of erosion has been observed so far. Besides, higher flow velocity in the heat transfer tubes seem to have contributed to the prevention of scaling. Therefore, the usage of the thin 0.75mm titanium and titanium alloy tubes is believed to be a success.

4.2. Evaporator

All of the evaporator vessels except the low-temperature evaporator are made of monel clad steel. In the circulation lines, monel metal is used in pumping impellers and shaft sleeves too. Because the heat exchangers have been made of titanium and steel, as shown in Table 3, and the valves of stainless steel, sufficient insulation is pursued to prevent the galvanic cell corrosion to occur between the different kinds of metals. Based on the observation of the monel metal surface, corrosion has been

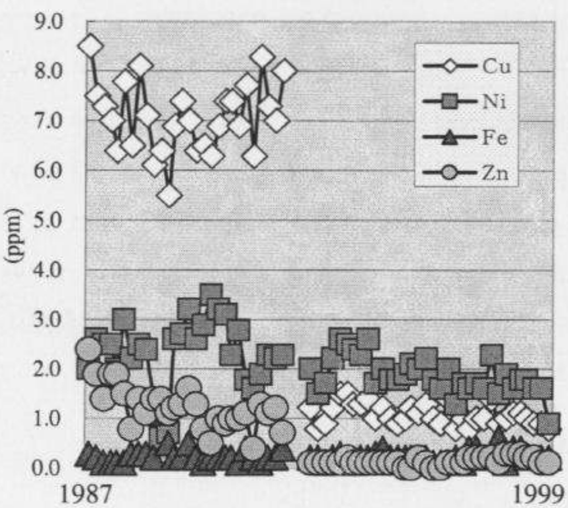

Figure 3 Heavy Metal Contents in Mother Liquor of No.0 Evaporator

slightly recognized. Maintaining the monel metal surface to be flat and smooth , contributes also to the prevention of salting up.

Copper and nickel contents in the mother liquor and salt slurry have been periodically measured in order to gather information about the long time effect of corrosion. Figure 3 is an example; it clearly shows that the copper content has decreased drastically since 1993. Nickel and zinc have decreased as well. These facts reveals that the previous heat exchanger tubes made of copper alloy used to be worn off gradually, while no serious corrosive elusion is currently occurring.

4.3. Piping

For the transfer piping of salt slurry, mother liquor and such as under the severe conditions, tubes made of titanium and duplex phase stainless steel have been employed. As for the piping made of titanium, not a single liquor leakage caused by to corrosion has been recorded ever since the installation, and for the piping made of duplex phase stainless steel, leakage has been found only once quite recently. Based on the data accumulated in these six years of operation, it may well be said that the employment of these rather expensive materials for the piping has been rewarding.

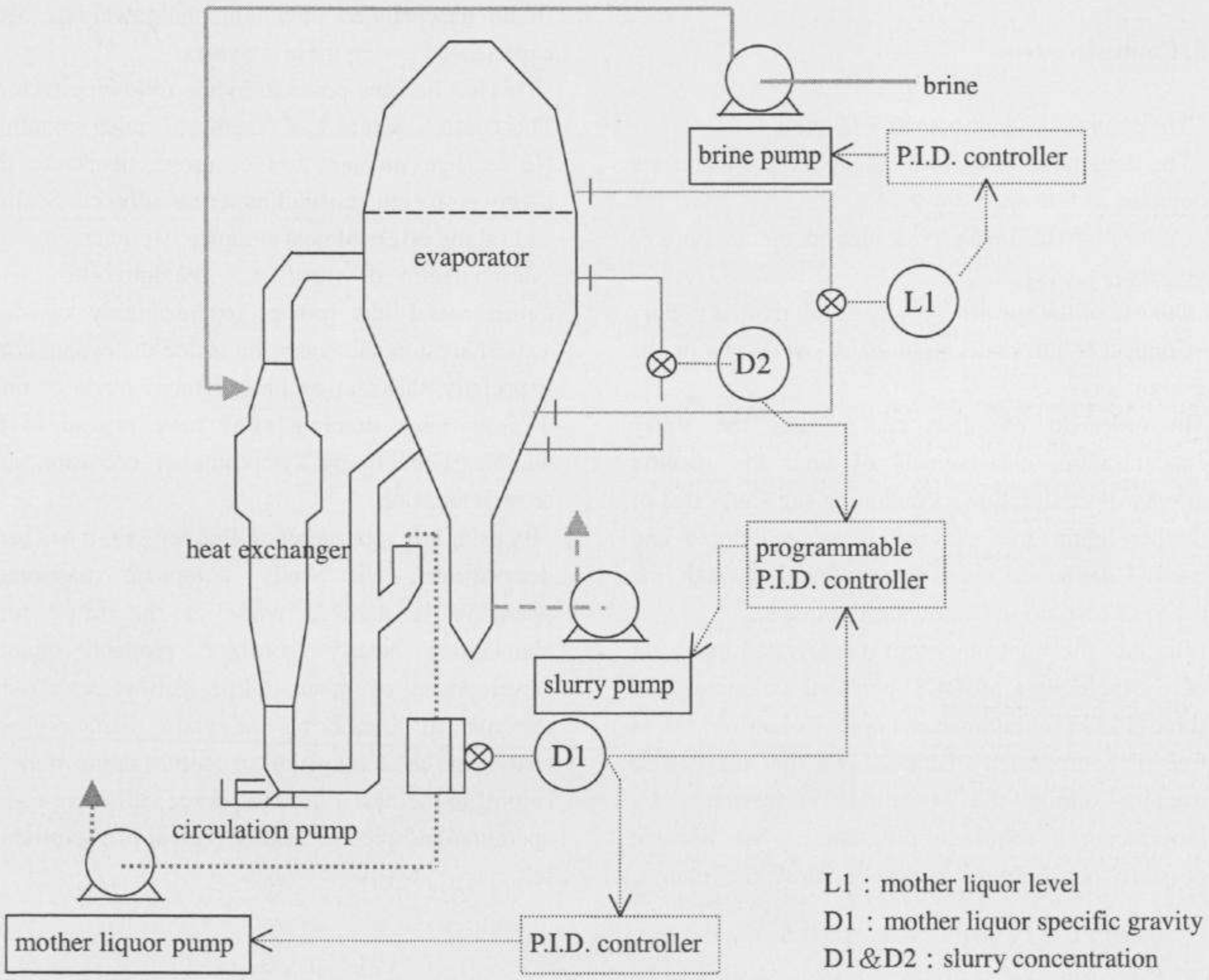

Figure 4 Control System

4.4. Outer Structures

Since this out-door plant is located just beside the sea, it is exposed to wind and rain containing salt, and so both the steel frameworks and the metal covers of the thermal insulation of the vessels are subjected to corrosion accelerating environments. Such a corrosion not only degrades the external appearance and increases the cost for maintenance, but may also shorten the life time of the plant. Although the initial cost becomes higher, corrosion prevention has been carried out by adopting stainless steel for the covers coated with recently developed fluororesin coating. Fluororesin coating is also used on the frameworks.

5. Control System

The control system is shown in Figure 4.

The distinctive features of this control system are depicted as follows.

Control of the levels of liquor in the evaporator vessels.

Control of the specific gravity of the mother liquor.

Control of the concentration of salt slurry in the evaporators.

In order to calculate and control the slurry concentration, data signals of both the specific gravity of mother liquor containing salt slurry and of mother liquor free of crystals are monitored and used. Continuous control is realized through the usage of revolution control slurry pumps.

Because this control system is integrated into a set of a single unit of DCS personal computer and some PLC(Programmable Logic Contorller), it is free of complicated manipulations that may cause troubles during the operation. Furthermore, by introducing a sequence program, it has become possible not only to remote control the pumps, valves and others, but also to operate the whole process automatically. So, to operate the crystallization process, one needs only to type in the set SV values and to click the buttons on the display panel of a PC . Moreover, the adoption of the DCS personal computer made it easy to adjust the control system in-house to the alternation of piping lines that occurs from time to time.

6. Conclusions

The targets that were set prior to the construction of this quadruple-effect evaporator system have been reached. It is worth which just to mention that not a single unscheduled operation shutdown has been experienced during these six years.

This has become possible by the following factors. The control system has functioned quite smoothly. No leakage accident has occurred, thanks to the highly corrosion resistant materials adopted. Scaling and salting up are almost completely prevented.

Combination of titanium / titanium alloy with monel metal has proven to be highly resistant against erosion and corrosion inside the evaporators. Especially, the heat exchanger tubes made of only 0.75mm thick titanium alloy have proved to be durable without any symptoms of corrosion and erosion abrasion.

By using the appropriate in-line sensors, it has been demonstrated that fully automatic unmanned operation is feasible while at the same time maintaining nearly constant product quality. Development of other in-line sensors which are effective for measuring the grain diameters and analyzing the composition of mother liquor may be helpful in the near future to pursue still more stable operation and precise quality control of the product salt .