Yuhuan Power Plant Seawater Desalination System: Integrated Membrane System Introduction and Operation Performance Analysis

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Abstract
Huaneng Yuhuan Power Plant is the largest sea water desalination system built in China so far, using the IMS (Integrated Membrane System) with capacity of 1440 m\textsuperscript{3}/h. IMS comprises the ECC (Enhanced Coagulation Clarifier), S-UF (Submerged Ultrafiltration) and RO (Reverse osmosis). The operation performance of the system for more than 2 years demonstrates the technical feasibility of the enhanced coagulation and submerged ultrafiltration as RO pretreatment to cope with sea water of high turbidity (100-250 NTU). The SWRO system performance shows that the rejection rate of RO is larger than 99.5\%, which demonstrates the stable performance of SW30HRLE-400.

Key words: Integrated Membrane System, IMS, Seawater Reverse Osmosis, SWRO, SW30HRLE-400, Ultrafiltration, UF, ZeeWeed 1000

1. BACKGROUND
Huaneng Yuhuan Power Plant is located at Xiaqingtang, Damaiyu Development Zone of Yuhuan County, Taizhou, Zhejiang. The plant site is surrounded by mountains at three sides with the remaining side facing the sea. The planned capacity of the power plant is 6x1000MW units. The demand of freshwater of Huaneng Yuhuan Power Plant is about 8 million ton per year. However, the total volume of seven reservoirs in Yuhuang county is less than 20 million ton. In order to solve the problem of freshwater shortage, Huaneng Yuhuan Power Plant has applied the IMS (Integrate Membrane System) for desalination, which is composed of SUF (submerged Ultrafiltration) and RO (Reverse Osmosis). In the SUF system, the submerged hollow fiber UF modules, ZeeWeed 1000 are used. In the RO system, FILMTEC SW30HRLE-400 is used as the first pass SWRO (Seawater Reverse Osmosis), and TORAY TM720-430 is used as the second pass BWRO (Brackish Water Reverse Osmosis). It is the first case of applying IMS for power plant seawater desalination system in China. With the investment of 200 million RMB, the desalination system can produce 1440 ton freshwater per hour. It fully meets the requirement from the plant operation.

2. DESALINATION PROCESS DESIGN
The desalination process in Yuhuan Power Plant is presented in Fig.1. According to this figure, after adding NaClO and FeCl\textsubscript{3}, raw water is sent to ECC (Enhanced Coagulation Clarifier). Then the clarified water goes via S-UF and CF (Cartridge Filter) to the first pass SWRO. During this phase, antiscalant and reducing agent (NaHSO\textsubscript{3}) are added. PX (Pressure Exchanger) has been used for the first pass SWRO for energy recovery. Then, the second pass BWRO is applied to produce the permeate water. During this process, the UF backwash water is drained to the coagulation, flocculation and sedimentation pool and the 2nd pass BWRO concentration is recycled to the UF tank.
The following part will introduce the raw water analysis, raw water intake system, ECC (Enhanced Coagulation Clarifier), CF, PX, SUF and RO in details.

2.1 Raw water analysis

The raw water of Yuhuan Power Plant is taken from the Yueqing Bay in East Sea of China. As shown in Fig.2, there are some rivers from the inland adjacent with Yueqing Bay, bringing much suspended mud and sands into it. Due to the special geographical condition of Yueqing Bay, the turbidity of the sea water from it varies frequently and largely, which is demonstrated in the Fig.3.
Generally, the turbidity of Yueqing Bay is around 100–250 NTU and sometimes increases to as high as 2500 NTU. The turbidity of the feeding water is not quite stable. The raw water analysis is presented in Table 1 as follows.

<table>
<thead>
<tr>
<th>No.</th>
<th>Items</th>
<th>Unit</th>
<th>Analysis date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pH</td>
<td></td>
<td>8.03</td>
</tr>
<tr>
<td>2</td>
<td>SS</td>
<td>mg/l</td>
<td>165</td>
</tr>
<tr>
<td>3</td>
<td>TDS</td>
<td>g/l</td>
<td>42.29</td>
</tr>
</tbody>
</table>
According to the water analysis in Table 1, the SS (Suspend Solid) of the sea water is relatively high and fluctuates, in accord with the turbidity. The TDS (Total Dissolved Solid) of sea water varies, from the minimum 26.69 mg/L to the maximum 46.6 mg/L. Ions, like Na\(^+\), SO\(_4\)\(^{2-}\) varies a lot and the content of oil fluctuates as well. The conductivity of sea water detected varies between 33600 and 50700 uS/cm and the average one is around 47000 uS/cm. The water quality variation is probably due to the influence of river water injection near Yueqing Bay.

### 2.2 Raw water intake system

The RO feed water temperature basically needs to maintain in the range of 20~30\(^\circ\)C. Therefore, there are two ways to intake the raw sea water to maintain the feed water temperature:
- Open intake (unheated raw sea water before flowing into the once-through condenser)
- Beach well (heated effluent sea water from once-through condenser)

The sea water desalination system fully utilizes the cooling water system to reduce cost. Meanwhile, the raw sea water temperature can be increased around 9 \(^\circ\)C in summer and around 16 \(^\circ\)C in winter by taking advantage of the residual heat from the condenser.

The principle of choosing water intake is:
- if the raw sea water temperature is larger than 15 \(^\circ\)C, using open intake solely
- if the raw sea water temperature is smaller than 15\(^\circ\)C, using open intake and beach well together or using beach well along to maintain the temperature

### 2.3 Enhanced coagulation clarifier

In order to remove the suspended solid, organic matter and colloids in the seawater, the coagulation, flocculation and sedimentation process is necessary. The coagulant is FeCl\(_3\) with dosage of 10ppm. There are 4 units of ECC construction in the process with the capacity of 1000m\(^3\)/h for each. The pool is built with concrete without rotation components, which reduce the anti-corrosion cost.

The turbidity of the raw sea water typically maintains around 100-250 NTU. After the coagulation and sedimentation, the turbidity can be reduced to lower than 20NTU. To prevent the residual micro-organism growth in the piping or devices in the desalination system, the sterilizing chemical sodium hypochlorite (NaClO) is injected in the downstream tank after coagulation and sedimentation process. The effluent free chlorine concentration is around 1~1.5ppm. After ECC treatment, the analysis of clarified water is presented in Table 2.

<table>
<thead>
<tr>
<th>Effluent water turbidity</th>
<th>Max</th>
<th>Min</th>
<th>Typical value (80% of the time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity (NTU)</td>
<td>50</td>
<td>5</td>
<td>&lt;20</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>20</td>
<td>5</td>
<td>&lt;10</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>10</td>
<td>3</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Alkalinity (mg/L)</td>
<td>168</td>
<td>125</td>
<td>150</td>
</tr>
<tr>
<td>pH</td>
<td>8.5</td>
<td>7.5</td>
<td>8</td>
</tr>
<tr>
<td>Temperature ((^\circ)C)</td>
<td>32</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>
Table 2 Enhanced Coagulation Clarifier Operation Performance

2.4 Submerged UF

According to the water analysis of Yuhuan Power plant, the submerged UF system is superior as the pretreatment for RO due to its high tolerance of feed water turbidity, no requirement of 100 μm automatic rinsing disk filter and stable permeate water quality. ZENON ZeedWeed 1000 hollow fiber membranes are used here for the pretreatment of RO. A low-pressure vacuum applied to the membranes draws filtrate through the UF membrane. Particles, colloidal materials and microbes are rejected. The residual particles remain in the process tank are periodically removed by backwashing. Turbidity meters continuously monitor the quality of the Zeeweed permeate to ensure the operation performance is within the design parameters. The UF permeate quality is high, with SDI less than 2.5, turbidity less than 0.1 NTU, and TSS (Total Suspend Solid) less than 0.5 mg/L during 90% of the time. The UF membrane system provides 76800m³/d of treated water with a recovery rate of 95%.

2.5 Cartridge filter

To protect RO membrane from unexpected mechanical damage from residual particles, the cartridge filter is usually the final guard in the desalination system. Ultipleat® High Flow Series Filter Cartridges from Pall Corporation is used. It is a large-diameter, coreless, single open-ended, pleated cartridge with an inside-to outside flow pattern.

2.6 Energy recovery device

In the first pass SWRO, energy consumption shares a great part of total operation cost. The emergency of energy recovery device and its application in SWRO make the application of RO membrane in sea water desalination more economical. The energy recovery device manufactured by ERI (Energy Recovery, Inc.)^5, which composite of pressure exchanger (PX) has been applied here.

![Figure 4 Operation Performance of ERI PX-220](image)

The Energy transfer efficiency expressed as the ratio of the sum of the energy leaving the PX® unit or array divided by the sum of the energy entering, as calculated with the following equation:
Efficiency = \frac{\sum (\text{Pressure} \times \text{Flow})_{\text{OUT}}}{\sum (\text{Pressure} \times \text{Flow})_{\text{IN}}} \times 100\%

By introducing the operation data in Figure 4 into the above equation, it yields

Efficiency = \frac{4.5 \times 280 + 0.16 \times 288}{0.23 \times 280 + 4.56 \times 288} \times 100\% = 94.2\%

which shows the high energy transfer efficiency.

2.7 Reverse osmosis system: SWRO system and BWRO system

Dow FILMTEC SW30HRLE-400 is used for the first pass SWRO and Toray TM820E-400 is used for the second pass BWRO. The first pass SWRO plays a key role in the desalination process. Therefore, the operation data for SWRO, including the flux, pressure drop, permeate conductivity and rejection rate are shown as follows.
In Figure 5, it can be seen that the flux of the SWRO maintains in the range of 10-16 LMH; the pressure drop during the whole period is kept at around 0.1-0.25 MPa. And the permeate conductivity and rejection rate variations with date are presented as well. After more than 2 years of operation, the average rejection rate is still larger than 99.5%.

3. SUMMARY AND CONCLUSION

Although, the turbidity of raw water in Yuhuan Power Plant is as high as 100~250 NTU and the average conductivity around 47700 uS/cm due to its territory condition, the turbidity, TSS and SDI of permeate water can be reduced to less than 0.1 NTU, 0.5 mg/L and 2.5 after the enhanced coagulation clarifier, SUF, SWRO and BWRO treatment. Especially, SWRO system (SW30HRLE-400) performance shows that the rejection rate of RO is larger than 99.5% after more than 2 years operation.

REFERENCE

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5 http://www.energyrecovery.com/