

# **An Effective Way for Sustainable Water Resource in China- Seawater Desalination**

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**ABSTRACT:** With the fast development of the economy and population, fresh water shortages have become very serious in China. Especially in northern coastal cities where China's population and economy are concentrated, the poor water condition has become a critical constraint factor for socio-economic development in the long run. For northern coastal zones, as there is 18,000 km of coastline, which contain abundant seawater, seawater desalination is an effective way for sustainable water resource. Diverse of current applications for seawater desalination in China are concentrated on, which include MSF (Multi-stage Flash), RO (Reverse Osmosis) and MED (Multi-effect Distillation). A feasible evaluation of applied desalination technologies is specified. The future prospect of seawater desalination in China is analyzed based on the comparison among different desalination technologies.

**Keywords:** Seawater desalination; Sustainable water resource; prospect

## **1. INTRODUCTION**

China has a total amount of  $280 \times 10^9$  m<sup>3</sup>/year of fresh water resource. The average water resource per capita is only 2171 m<sup>3</sup>/year, which is less than a quarter of the average of the world. According to the index, the national rank among all the other nations in the world is 121st<sup>[1]</sup>. It is estimated that the capita volume will go down to about 1700 m<sup>3</sup>/year, which reaches a critical value<sup>[1]</sup>. The absolute amount can not show the real situation of water resource as China is with great variations in both the spatial and temporal distribution of water resource. There is sufficient water in the south, but there is a water deficiency in the north. The total amount of the Yellow River, the Huaihe River and Haihe River etc. are only one eighth of the southern rivers, Yangtse River, Zhujiang River etc. According to the statistics, more or less 80%

of the total water resource is distributed in the southern China<sup>[1]</sup>. As to the temporal term, 70% of the total precipitation is concentrated during 4 months annually<sup>[2]</sup>.

The water shortage is particularly serious in the northern coastal, where the population accounts for 40% of the total, but the area is only 13% of the country. In northern littoral cities such as Dalian, Tianjin, Qingdao etc., the average volume of water resource per capita is one fourth of the national average one. Poor water conditions have been a factor restricting socio-economic development. For example, in the summer of 2000, with consecutive years of drought in the northern coastal, the emergency measures have been taken by the authorities to counter serious water shortage occurred. The quota policy was adopted in the year with freshwater per capita per month lowered from 2 m<sup>3</sup> down to 1 m<sup>3</sup>. The fine for the water overuse was raised from □10/

$\text{m}^3$  to  $\square 40/\text{m}^3$ . This seriously affected the living standard of more than 3 million people in 22 cities. The water shortage also seriously affected the normal industry production. About 80% of industrial factories were shut down at that time. While the overuse of underground water causes serious seawater invasion to the areas round about  $1000 \text{ km}^3$ , which in turn deteriorated the environment

It is of equal significance to foresee the future potential of water resource. A report from the Chinese Academy of Engineering has recently been released, which forecasts water resources and water demands for the next 50 years<sup>[1]</sup>. The report consists of industrial, domestic and agricultural demand, which takes into consideration population growth, urbanization, industrialization, etc. Three assumptions were applied in this report, namely high economic growth, moderate economic growth and low economic growth. It is estimated that the population in China will grow to 1.6 billion, and GDP will reach \$12 trillion under moderate economic growth in 2050. The water demands in 2050 will reach  $800 \text{ km}^3$  and about  $700 \text{ km}^3$  with high and low economic growth respectively. Compared with 1997, the increase in water demands varies between 23% and 41% for different economic growth. As Chinese government has already built many dams, reservoirs and other infrastructure to meet water demand in the past, it is difficult to expand the storage capacity. The water demand and supply conditions in northern three main river basins will be very serious, which are Yellow River, Huaihe River and Haihe River. The water shortage will be  $46 \text{ km}^3$  with high economic growth,  $31 \text{ km}^3$  for moderate one and  $25 \text{ km}^3$  for low one. If the amount of population is higher than expected, the severe situation will be even worse. From above sensitive analysis about future water demands in China, apparently water resources cannot grow symmetrically with increasing demands for water

consumption. Hence, water shortages will become strikingly severe.

In order to mitigate the water shortage problem in China, many methods has been carried out. Firstly, laws and regulations are enacted by different levels of governments to encourage people to save water, which plays positive effect on resolving the water shortage. But the problem cannot be effectively resolved, as the total amount of water resource remains constant. Secondly, the groundwater is widely exploited in China, especially in the northern. The overdraft has resulted in a discontinuous flow, declined groundwater table, and degradation of the ecological system. Growing demands and requirements will further deteriorate the side-effect. Thirdly, inter-basin water transfers on a large scale have been considered and approved. As the water supply under the current scheme can not be able to meet future demands, a huge national project known as the scheme of transferring water from the south to the north is implemented. The project will deliver water from the upper, middle and lower reaches of Yangtze River respectively to meet the water demand of northern China, which can transfer a stable water source about  $44.8 \text{ km}^3/\text{y}$  by 2050. One the one hand the project will be an important and basic facility for mitigating the existing crisis of water resources in North China, on the other hand, it has a negative environmental impact, which may counteract its benefits. By the above analysis the applied methods may not completely solve the problem of water scarcity, still leaving a water shortage in Northern China. It is of necessity to find new alternative water source to effectively resolve the problem.

Desalination may pave the way to more accessible water. China has plenty of seawater resource. There is about 18,000 km of coastline in northern coastal zones that face severe water scarcity. And desalination has many advantages such as little negative effect on environment, hardly depending on

climate and season, and stably producing freshwater. So the desalination is a

prospective and reliable technology for China to increase water resource.

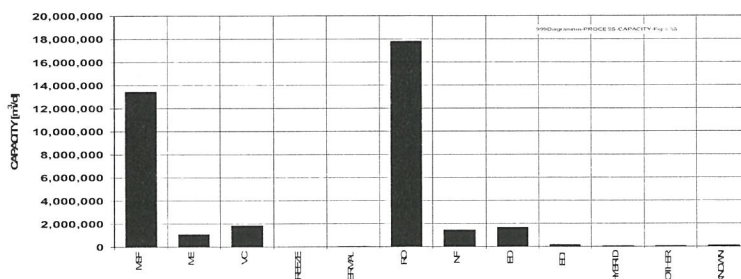


Fig. 1 Capacity of all land based desalination units by technology

## 2. DEVELOPMENT OF DESALINATION PROCESSES

Desalination is an energy intensive process which extracts freshwater from seawater. Decades of distillation and membrane technologies are available, including multiple-effect distillation (MED), multistage flash distillation (MSF), reverse osmosis (RO) and electrodialysis (ED). The former two are thermal distillation processes and the latter two are membrane technologies. Fig.1 shows that MED, MSF and RO are used for large-scale desalination plants<sup>[3]</sup>. How to select desalination technology essentially depends on the capacity, the quality of produced water, raw seawater, local know-how, etc.

### 2.1 MSF Process

The MSF process is the second largest installed, most widely used and most developed desalination technology<sup>[4]</sup>. The major users of MSF are distributed in the gulf area. As the process of heating and evaporating are separated, the scaling problem can be effectively reduced. So it developed rapidly and accounted for the biggest installed desalting capacity in the world. Its development tends to be big scale units. The capacity of MSF in dual-purpose power plant in AlJubail reaches between 45,400 and 57,700m<sup>3</sup>/d<sup>[5]</sup>.

Fig.2 shows the most commonly adopted configuration for large plants today. The

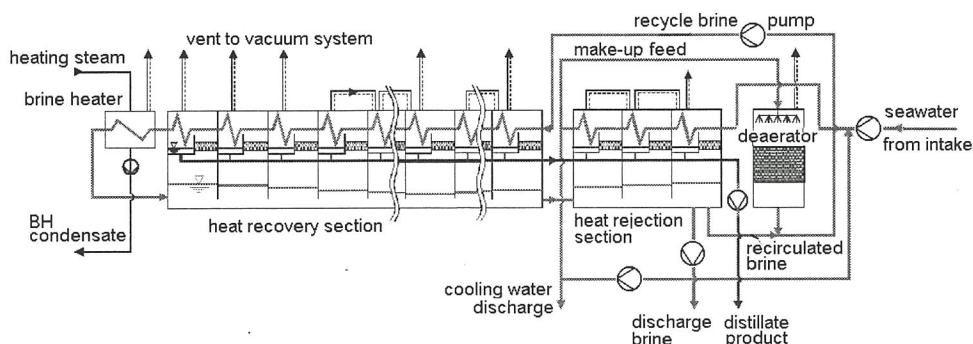


Fig.2 Configuration of MSF

heating resource of flashing comes from the sensible heat of seawater whose temperature decreases in each flashing stage. For the ratio of sensible heat to latent heat is 2/1000, the methods of thermodynamic improvement in MSF are enlarging flashing temperature difference, the number of flashing stage, and specific heat area of distillation. In order to control the scaling and corrosion of seawater, the top brine temperature is below 120°C. It is beneficial to increase the gained output ratio (GOR), the thermodynamic index of desalination, that the number of stage is increased and the temperature difference of each stage is decreased, but the heat transfer area increases dramatically, which leading to the augment in production cost. Thus GOR is no more than 13-14 by the limitation on the number of flashing stage.

## 2.2 RO Process

The RO process shares the largest installed capacity of desalination units. With the significant achievements in improving technology, the RO process has developed rapidly during the past decades. Fig.3 indicates the process of RO. The innovation in technology causes the water cost greatly

reduced due to lower cost and higher performance membrane, improvement in pressure recovery device and new technology adopted in seawater pretreatment. The membrane can work at lower pressure and higher salt-rejecting, the pressure recovery device can greatly reduce energy cost by transferring pressure energy of the rejected brine to fresh seawater, and the new way of pretreatment, such as microfiltration, ultrafiltration, nanofiltration, prolongs the service life of membrane. For the above new technologies, RO has come to be utilized to desalting seawater while it was mainly for brackish. The key defect of RO technology lies in the reduction in membrane's salt-rejecting ratio that may reach 99% for the initial 6 months, which reducing to 90% later<sup>[6]</sup>. In general, most of the RO plants have a smaller capacity than MSF plants.

## 2.3 MED Process

The process of MED desalination experiences several stages, which is submerging evaporation, vertical falling film evaporation and horizontal falling film evaporation. Due to serious scaling problem,

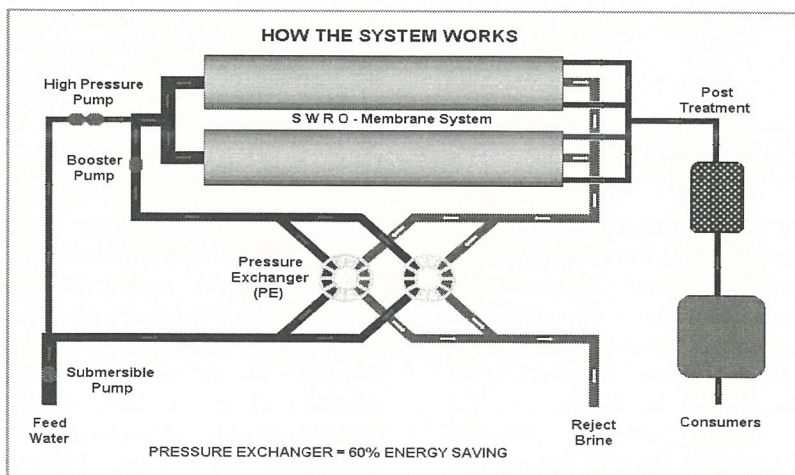


**Fig.3 Configuration of RO**

big temperature difference, low heat transfer coefficient, etc, the submerging evaporation is hardly used for desalination. For the vertical falling film evaporation, there is a brine pump between successive evaporators, which results in complex control system,

augment in water cost and difficult maintaining and operating. In order to reduce serious scaling problems, research on low-temperature multi-effect distillation (LT-MED) has drawn more attention. Fig.4 shows how the process of LT-MED works.

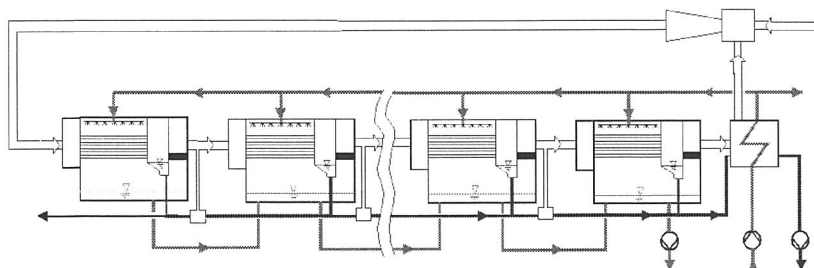


**Fig.4 Configuration of LT-MED**

As the top brine temperature is controlled below  $70^{\circ}\text{C}$ , the scaling and corrosion has been effectively reduced. As a result, relatively cheap aluminium alloy can replace expensive copper or titanium, thus the production cost can be greatly cut down. Another advantage of LT-MED is the possibility of utilizing low temperature waste heat source, which causes the reduction in energy cost of LT-MED. The research on LT-MED focuses on increasing heat transfer coefficient, optimal design of structure, etc.

### 3. CURRENT STATE OF DESALINATION IN CHINA

China is at the beginning of desalination, but will undergo a rapid development in the future decades. Several demonstration seawater desalination plants have built up. The RO desalination plants are small scale, serving for power stations' own uses or for drinking water source in islands. The RO desalination plants include  $1,000\text{m}^3/\text{d}$  Changdao Island and  $500\text{m}^3/\text{d}$  Zhangzidao Island in Dalian,  $1,000\text{m}^3/\text{d}$  Dalian Huaneng Power Plant,  $1,000\text{m}^3/\text{d}$  Weihai power plant, etc. The first industrial MSF

desalination plant was Tianjin Dagang power plant in 1997 whose capacity was  $3000\text{m}^3/\text{d}$ . The largest capacity LT-MED desalination plant is Guohua power station in Hebei Province, which produces  $10,000\text{m}^3/\text{d}$  fresh water. Several big-scale LT-MED desalination plants are being built in Tianjin and Hebei, whose capacity is more than  $10,000\text{m}^3/\text{d}$  respectively.

Seawater desalination has been studied in many institutes and universities in China since the 1960s, particularly membrane science and technology. The major institutes are Institute of Seawater Desalination and Multipurpose Utilization in Tianjin and Development Center of Water Treatment Technology in Hangzhou, the former concentrating on thermal and membrane desalination and the latter focusing on research of membrane process. With their technical support, several RO and MED demonstration desalination plants mentioned above were built up. Universities did research on thermal desalination since seventies of last century, which include Dalian University of Technology<sup>[7]</sup>, Tianjin University, North China Electric Power University, etc. Dalian University of Technology has done elementary research work on LT-MED and thermal vapour

compressor. One of the typical work is the conceptual design of a 12,000 t/d LT-MED desalination plant. Tsinghua University has recently developed atomic reactors to

provide heating to desalinate seawater by burning used fuel from nuclear power stations under normal pressure<sup>[8]</sup>.

**Table I:** Comparison of MSF, MED and RO processes.

|                             | MSF                | LT-MED                | RO          |
|-----------------------------|--------------------|-----------------------|-------------|
| Top brine temperature       | 110□               | 65□                   | 20-40□      |
| Energy quality              | High quality steam | Waste or exhaust heat | Electricity |
| Heat transfer coefficient   | Low                | High                  | None        |
| Concentration ratio         | 1.5                | 2.0                   | 1.5         |
| Requirement of pretreatment | Moderate           | Low                   | High        |
| Water quality               | 5 ppm              | 5 ppm                 | 200-500 ppm |

#### 4. COMPARISON OF DIFFERENT DESALINATION PROCESS

Germany scholar Rautenbach drew the conclusion that the prospective development is decided by the process of MSF, RO and LT-MED<sup>[9]</sup>. LT-MED will be the dominant technology in dual-purpose power plants<sup>[10]</sup>. By Table I, the comparison among them is as follows. To begin with, compared with top brine temperature 110 □ in MSF, the operation temperature is below 70 □, even below 65 □, which results in scaling and corrosion problem being effectively controlled. Next, the heat source of LT-MED comes from waste heat or exhaust heat due to its low operation temperature while that of RO and MSF are high-quality electricity and steam respectively. Thus LT-MED is the optimal process in dual purpose power plant. In addition, as there is phase change on both side the heating tube, steam condensing inside and seawater evaporating outside, the heat transfer coefficient of horizontal falling film evaporation is relatively high, which is adopted in the evaporator of LT-MED. Besides, the concentration ratio of brine of LT-MED is higher than that of MSF, correspondingly LT-MED consumes less pump power. Then, the seawater pretreatment of LT-MED is simpler than that of the other two processes.

For LT-MED seawater only needs to be filtered and added anti-scaling additive, while the seawater for RO is pretreated very strictly. Finally, the production quality of LT-MED can be directly used as make-up water of boiler, which can reach 5ppm. The salt concentration in the production of two-stage RO process is about 140ppm.

LT-MED in dual-purpose power plants is the suitable desalination configuration in China. While the Chinese economic growth had been keeping continually, steadily and rapidly with an average annual growth rate of about 9.3% in the past two decades, the need of energy has been bigger and bigger rapidly. Seawater desalination consumes a great deal of energy to produce fresh water, so it is of great significance to find a pathway to reduce the energy requirement of water production. In Chinese energy production system, the coal-fired power plant is the dominant contributor to power production. The installed capacity of coal-fired power plants accounted for more or less 74.4% of the total installed capacity, and they produced about 82.2% of the total electric power in 2000<sup>[11]</sup>. Most importantly, the difference of the demand and supply in energy is greater and thereby LT-MED in dual-purpose power plants will play a more important role of Chinese desalination as LT-MED process is adopted in the design

due to its better in utilizing low-grade heat available to minimize energy consumption, less sensitivity to corrosion, scaling and fouling, and its higher operation flexibility in partial load. So the coal-fired power plant integrated with LT-MED is a possible approach to increase thermal efficiency of the dual-purpose power plants, and decrease the water production cost.

## 5. CONCLUSIONS

Based on the discussions above and the consideration on circumstance of its water demand and supply, the following conclusions can be drawn:

1. With the fast development of economy and huge amount of population, fresh water shortages have become very serious in China, especially in northern coastal cities where China's population and economy are concentrated, the severe water crisis will be getting more serious if no strong and effective measures are taken immediately. As desalination can provide a reliable water supply, it will be ultimately economically feasible and effective in China.

2. By comparison of the processes of MSF, RO and LT-MED, LT-MED in dual-purpose power plants is an optimal way to more accessible water due to its possibility of utilizing low temperature waste or exhaust heat, its reduction in scaling and corrosion problem and its efficient heat transfer mechanism.

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