

# Thermal and membrane systems for combined desalination plants

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## Abstract

Desalted water is the source for thermal and nuclear power stations. Sea water is desalted in many cases if power stations are located on the sea shores. The operating types of reverse osmosis systems and thermal desalting installations don't meet the requirements for the water quality for power stations. Additional water desalting is required. The possibility of combined desalting installations application is considered in this paper. These installations include membrane systems at the first stage and thermal systems for water desalting at the second stage. Different schemes of combined desalting installations have been considered. The methods of optimized calculations of such systems have been presented. The parameters of desalting processes which provide the required quality of desalted water have been determined. The paper includes some recommendations for combined desalting installations application for thermal and nuclear power stations.

*Keywords:* Thermal desalting installation; Reverse osmosis and electro dialysis system; Desalination

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Structure analysis of the operating desalination plants at thermal power stations shows that those systems process water with great content of salt, organic and mechanical admixture. It hampers the receiving of high quality distillate. At the same time demands of water quality after processing are becoming higher. The cost of water production

using reagents and additional ion-exchange filters for water cleaning is increasing.

To overcome economic and technological problems in water production systems at thermal power stations the apparatus which operate on the principle of membrane technologies of water desalting should be used more purposefully [1,2].

Traditional schemes with evaporators and filters are used to examine the combined water

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production systems. Membrane desalination plant is suggested to be included into the structure of water production in those schemes. It allows to decrease the salt content in sea water by 70–80% even at the first stage of desalination before evaporators and ion-exchange filters.

Fig. 1 demonstrates the scheme of water production for power stations with membrane technology and desalinating thermal methods (MED—Multiple Effect Distillation, MSF—Multiple Stage Flash or BE—Boiling Evaporator) combination. Additional equipment for partial sea water desalting (or softening) is used in the scheme mentioned, electrodialysis (ED) and reverse osmosis (RO) modules being applied.

Brine from the third stage evaporator is used as the desalted water in the scheme mentioned. Sea or feed water is added to the brine. The mixture with high content of salt passes through RO modules and is partially desalted. Then this water may be used for evaporating system feeding after heating and removing dissolved gases. The steam from turbine is the source of thermal energy for evaporators.

The level of sea water salt content decrease in RO modules under multi stage processing

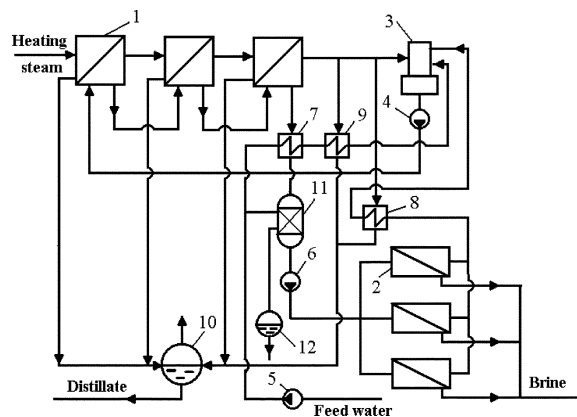


Fig. 1. Water production scheme for power stations with boiling evaporators (BE) and RO modules: 1 – BE; 2 – RO modules; 3 – deaerator; 4, 5 – pumps; 6 – high pressure pump; 7 – brine cooler; 8, 9 – water heaters; 10 – distillate tank; 11 – cartridge filter; 12 – brine tank.

reaches 90–95%. However it's insufficient for obtaining the required quality of feeding water for power stations with steam boilers of high pressure or for nuclear power stations. That is why evaporating plants are suggested to be used as the second stage of processing. As the water obtained behind the membrane modules in the combined schemes of water production has practically no hard salts it may be put into different types of evaporators and it may also be used as feed water for systems of heat supply. It allows lowering the cost of thermal desalinating plants by simplifying their construction raising specific thermodynamic indices and productivity [3].

Evaporators for sea water desalination are expensive. Their use at power stations is not always economical. The distillate cost at thermal desalination guarantees water preparing profitability only at the large industrial desalinating systems producing more than 1000 m<sup>3</sup>/h of desalted water [4].

The investigation showed that high quality water expenditure for steam boiler and thermal net feeding at the power stations does not exceed 200 m<sup>3</sup>/h. For this reason thermal desalination plants are replaced by membrane desalinating systems (ED apparatus of the required productivity for example) for water production.

The scheme with boiling evaporators and RO modules is recommended for the systems of water production at the large power station if salt concentration in feed water at the second stage of desalting process is not more than 150 mg/L.

Combined scheme of water production is demonstrated in Fig. 2. Here sea water is cleaned with the help of sand filters. Then it is passed to the cartridge filters and to the sterilizer and then to ED modules for desalting. To make deep desalting, ion-exchanging filters are applied in two stages by the following scheme: cation-exchanging filters—decarbonization—anion-exchanging filters.

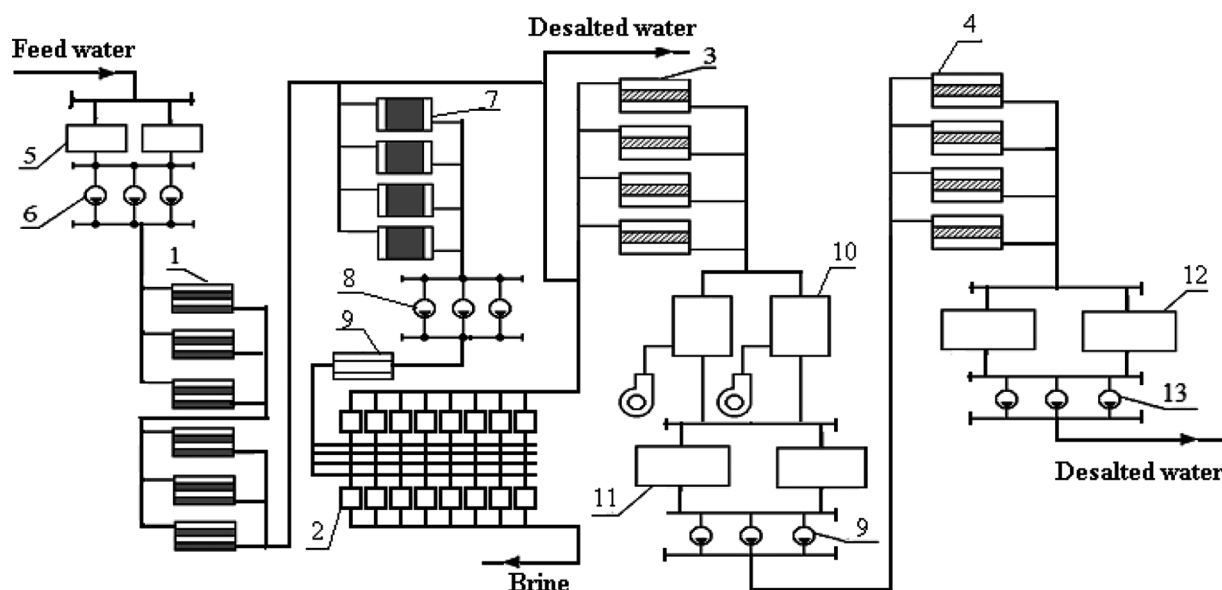


Fig. 2. Water production scheme with ED modules: 1 – sand filters; 2 – ED modules («AQVAMIN» system [7]); 3 – cation-exchanging filters; 4 – anion-exchanging filters; 5, 11, 12 – tanks; 6, 8, 9, 13 – pumps; 7 – cartridge filters; 9 – sterilizer; 10 – decarbonizers.

Such simplified scheme of water desalting can be used when the requirements for the heater quality are not so high. The advantages of this scheme are low energy expenditures for desalting, minimum quantity of ion exchanging filters while the productivity is high and reagent expenditure for water processing is low [6].

If the heater must be of high quality (for nuclear power stations for instance) the scheme for water production becomes multi-staged (Fig. 3). The productivity of complex combined water production systems usually does not exceed 50–100 m<sup>3</sup>/h of distillate. RO modules where the desalting depth may exceed 90% are recommended for use at the first stage of water production.

The scheme (Fig. 3) ensures that the water production system operates without decreasing the power station equipment and with its complete reservation.

The disadvantage of this scheme is that a large number of ED or RO modules are

required. Higher quality of desalted water is achieved by the desalted water processing in the ion exchanging filters by the following scheme: twice cation-exchanging filters—decarbonization—twice anion-exchanging filters.

Of the schemes considered (Figs 2 and 3) the first one is more ecologically advanced. The quantity of harmful wastes is decreased as much as almost twice and water expenditure is decreased by 60–70% in this scheme.

The equations allowing to define the number of ED and RO stages of desalting system using membrane apparatus and energy expenditures for the desalting process are presented in the paper.

The number of processing stages ( $n$ ) for ED systems under the given technological parameters of the process is influenced by the desalting depth ( $C = C_r - C_d$ )

$$n = \frac{26,8 \cdot \Delta C G_d}{\eta_e F_M i_{op}} \quad (1)$$

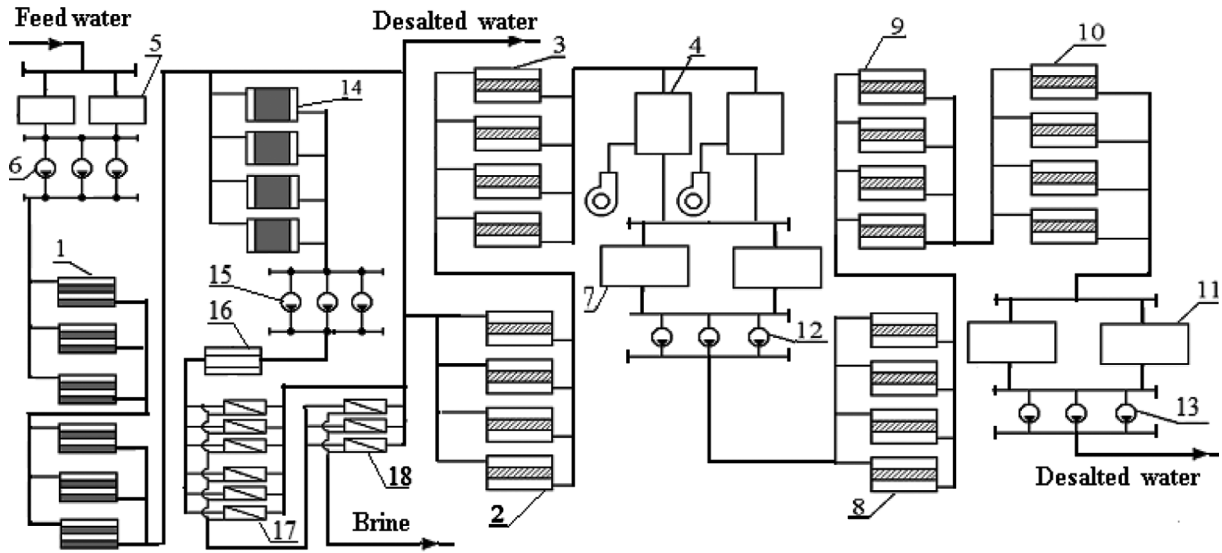


Fig. 3. Scheme water production with RO modules: 1 – sand filters; 3, 8 – cation-exchanging filters; 2, 9 – anion-exchanging filters; 4 – decarbonizers; 5, 7, 11 – tanks; 6, 12, 13 – pumps; 10 – mixed ion-exchanging filters; 14 – cartridge filters; 15 – high pressure pumps; 16 – sterilizer; 17, 18 – RO modules.

where  $F_M$  is the membrane area in the module,  $i_{op}$  is the optimum value of the current density passing through the plant having the productivity at  $G_d$  distillate.

Theoretical water expenditure for the desalting process is defined by taking into consideration the initial  $C_f$  and the final  $C_d$  and  $C_b$  of electro dialysis product concentration (diluate and brine):

$$W_{min} = 2RT(C_f - C_d) \left[ \frac{\ln\left(\frac{C_f}{C_d}\right)}{1 - \ln\left(\frac{C_f}{C_d}\right)} - \frac{\ln\left(\frac{C_f}{C_b}\right)}{1 - \ln\left(\frac{C_f}{C_b}\right)} \right] \quad (2)$$

In operation this quantity depends upon electro dialysis module electric parameters

$$W = \frac{26,8(C_f - C_d)\Delta U}{\eta_e} \quad (3)$$

When the salt content of water and distillate is known, electro dialysis system operation can be optimized by lowering the tension losses  $\Delta U$  in the electrolyte, membranes, on the anodes and cathodes. Raising the coefficient  $\eta_e$ , which will estimate the ED module technological efficiency is an important task.

Minimum energy of the division process in RO modules

$$W_{min} = RT \int_{C_d}^{C_f} \ln S^* dC = RT \int_{C_d}^{C_f} \ln \left( \frac{j_M \Delta P_M}{j_\pi \Delta \pi} \right) dC \quad (4)$$

where  $S^*$  is the potential of the forces providing the salt and water mass carrying through the membranes. In the equation (4)  $j_\pi$  and  $j_M$  are osmosis and actual coefficient of the module membrane permeability,  $\Delta P_M$  is pressure

overfall on the membranes,  $\Delta\pi$  is osmosis pressure.

Actual energy expenditure for feed water pumping through RO module is calculated according to

$$W = \frac{G_f \Delta P_M}{(1 - \theta)\eta_p} \quad (5)$$

where  $\theta = G_b/G_f$  is concentration coefficient,  $\eta_p$  is the pumping plant efficiency.

The number of water desalination stages in RO system depends on the selectivity coefficient  $\varphi = 1 - C_d/C_f$  of module and concentration coefficient  $\theta$ :

$$n = 1 + \ln\{(1 - \theta^{1-\varphi})/[(1 - \varphi)(1 - \theta)]\}/|\varphi \ln \theta|.$$

Maximum value of the selectivity coefficient  $\varphi$  while the energetic function analysis [5], connecting the distillate and feed water concentrations with the probability of finding salt ions in the solutions at the given energetic level  $\frac{C_d}{C_f} = \exp\left(\frac{-\Delta W}{K_b T}\right)$  will be presented in

$$\varphi = 1 - \exp\left(\frac{-\Delta W}{K_b T}\right)^{-1} \quad (6)$$

where  $\Delta W$  is the desalinating process energy spent for water or ions transferring through the membrane,  $K_b$  is Boltzman constant,  $\Delta W = W_{\min}$  may be accepted at the initial approach. It results from formula (6) that membrane selectivity in the desalinating plants is directly connected with the energy level, spent for the desalination process and increases if the temperature raises due to the activity of salt ions in the solution.

Economic estimation of desalination processes using the combined systems of water preparing has been made on the basis of the equations mentioned (Fig. 4). The

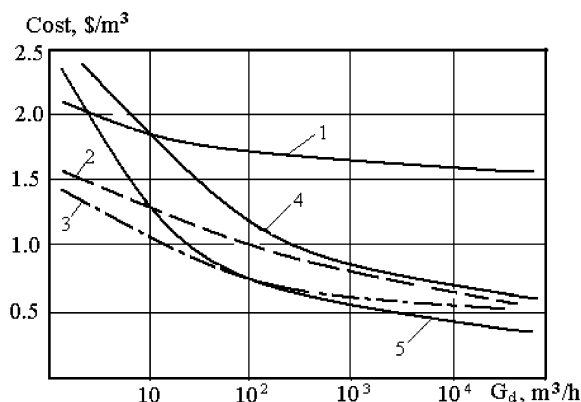


Fig. 4. Dependence of desalted water cost upon the productivity system of water production at the power stations: 1 – for ion-exchanging filters; 2 – for RO modules and ion-exchanging filters; 3 – for ED modules and ion-exchanging filters; 4 – for boiling evaporators; 5 – for RO modules and boiling evaporators.

graphs show that if the productivity of the desalinating net is less than 100 m<sup>3</sup>/h the combined schemes with RO or ED apparatus and ion-exchange filters are profitable if the distillate expenditure at the power station is more than 100 m<sup>3</sup>/h application of RO and ED nets with evaporators is more profitable.

### 1. Conclusions

According to the analysis it is recommended for desalination and water production processes at the power stations:

- to use RO and ED as the first stage of water desalination to decrease the salt load on the ion-exchange filters;
- to apply RO and ED modules to decrease the water salt content and feed water carbonate hardness before the evaporators and to decrease the expenditures for sea water desalination including the application of more simple and not expensive types of evaporators;
- to estimate the desalination process effectiveness according to the total amount of

the energy expenditures at all stages of water production;

- to use the scheme presented in this paper to choose the optimum structure of water production at the power stations.

### References

- [1] H. Strathmann, Reverse osmosis and electro dialysis in water desalination. Proc. of the IDA World Congress on Desalination, Abu-Dhabi, UAE, 1 (1995) 61–90.
- [2] L. Melnic, O. Vysotskaya and B. Kornilovich, Boron behavior during desalination of sea and underground water by electro dialysis, *Desalination* 126 (1999) 97–106.
- [3] V.N. Slesarenko and V.V. Slesarenko, Desalting plants in sea ships, Vladivostok, Publishers FETU (2001) 448.
- [4] V.N. Slesarenko and V.V. Slesarenko, Peculiarities of boiling seawater in distillation plants, *Desalination* 108 (1996) 109.
- [5] E. Gluekauf, A new approach to ion exchange polymers, Proc. Royal Soc., 1962;268A (1334):350.
- [6] V.V. Slesarenko, Electro dialysis and reverse osmosis membrane plants, power stations, *Desalination* 158 (2003) 303–311.
- [7] UK Patent GB No2265633A, 1993.