# OVERVIEW OF HYBRID DESALINATION SYSTEMS - CURRENT STATUS AND FUTURE PROSPECTS[1]

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**ABSRACT**

*Hybrid desalination systems combining both thermal and membrane desalination processes with power generation systems are currently considered a good economic alternative to dual-purpose evaporation plants. Hybrid (membrane/thermal/power) configurations are characterized by flexibility in operation, less specific energy consumption, low construction cost, high plant availability and better power and water matching. In this paper the state-of-the-art of simple and fully integrated hybrid desalination systems is reviewed.*

*In recent years, the concept of simple hybrid multistage flash-reverse osmosis (MSF/RO) configuration has been applied to a number of existing or new commercial desalination plants. The SWCC Jeddah, Al-Jubail and Yanbu existing Power/Water cogeneration plants are expanded for more water production by combining with new SWRO desalination plants. The simple hybrid desalination arrangement enabled the increase of the water to power ratio and utilized effectively the available intake/outfall facilities. A large hybrid 100 MIGD SWRO/MSF desalination plant was recently built in Fujairah, UAE. In this paper, salient features of commercially available hybrid desalination plants will be highlighted.*

*A promising approach for pretreatment of seawater make-up feed to MSF and SWRO desalination processes using nanofiltration (NF) membranes has been introduced by the R&D Center (RDC) of SWCC. NF membranes are capable to reduce significantly scale forming ions from seawater, allow high temperature operation of thermal desalination processes, and subsequently increase water productivity. This paper provides an overview of research endeavors carried out by RDC to develop NF/MSF and NF/SWRO/MSF hybrid desalination systems. The developed fully integrated systems result in high water productivity and enhance thermal performance compared to the currently used simple hybrid desalination arrangements.*

**Key Words:** Desalination, Hybrid systems, MSF, SWRO, NF

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## 1. INTRODUCTION

Hybrid desalination systems integrating thermal and membrane desalination process with power generation in the same site are currently considered a viable alternative to dual evaporation plants. The advantages of triple hybrid Power-MSF-SWRO over the dual power-MSF and single purpose MSF or RO plants were reported [1-6].

Integrating a seawater reverse osmosis (SWRO) unit with a multistage flash distiller provides the opportunity to blend the products of the two processes. Such arrangement allows to operate the RO unit with relatively high TDS and consequently allows to lower the replacement rate of the membranes. If the useful life of the RO membrane can be extended from 3 to 5 years the annual membrane replacement cost can be reduced by nearly 40 percent [4]. Blending the products of the thermal and SWRO allows for the use of a single stage SWRO instead of the two stage SWRO plant normally employed in standalone SWRO plants. Combining thermal and membranes desalination plant in the same site will allow to use common intake and outfall facilities with less capital cost. An integrated pretreatment and post-treatment operation can reduce cost and chemicals.

During cooler seasons, the preheated seawater leaving the heat rejection of the MSF distiller or the last effect of the MED plant can be used as feed water for RO plant. Increase of seawater feed temperature by one degree centigrade will increase the water production of SWRO by 3%. Experiments were carried out in which RO seawater feed was withdrawn from the MSF reject stream [7]. It has been reported that a 42-48% gain in RO product water recovery was obtained for seawater feed temperature of 33$^{o}$C compared to an isolated RO plant using surface seawater temperature at a temperature of 15$^{o}$C.

When the power demand in a dual purpose MSF/Power plant is changing, it is essential to provide an auxiliary boiler to provide supplementary fuel for energy in order to keep water production at a constant level. Figure 1 shows impact of the power load variation on the specific energy consumption of the MSF desalination plant when operating within the context of dual purpose Power/MSF and hybrid MSF/RO desalination power configurations. When the power generation is reduced to zero and the desalination plant is operating as a single purpose desalination plant (point A), the specific energy consumption is 47.5 kWh/m$^3$ which is around 42% higher than when the dual purpose plant is operated with 100 per cent power generation [8]. Point B represents the specific energy of single purpose SWRO desalination which is only 4.5 kWh/m$^3$. The specific energy consumption of the MSF plant when operating within the context of dual purpose plant combining a gas turbine power generation cycle with a MSF desalination plant, is influenced by the variation of the power load. Conversely, the specific energy consumption for water production in a hybrid system integrating combined gas-vapor power generation cycle with MSF and SWRO desalination plants, is not influenced by partial power load operation as shown in Fig.1 and it is around 60% of the specific energy consumption required by the dual purpose plant.

An optimization methodology was proposed for the design of fully integrated trihybrid power-MSF-RO plants [9]. The optimal design is based on exergo-economics and on profit optimization. The optimization parameters are extraction pressure (or temperature) of steam from turbine and the capacity ratio between the MSF and RO sections. The proposed model is flexible and suitable for comparative applications.

A hybrid system integrating MSF and RO desalination processes where MSF is fed by brine reject of the RO is proposed [10]. The MSF represents a second stage in series to increase the amount of water produced. Such configuration provides the opportunity to reduce the size of the pretreatment unit with consequent decrease of cost. It will also make it possible to use less expensive membranes and improve the thermal efficiency of the cogeneration plant. Permeate from RO and distillate from MSF can be mixed which will consequently allow the use of RO membranes with low salt rejection.

It has been reported that the blow down stream leaving the MSF plant which is sterile and deaerated can be used as a feed to the RO plant [1]. It has been argued that although a higher TDS at the inlet of the RO plant decreases the membrane flux, the higher temperature of the blow down increases the flux, thereby compensating the negative effect.

A study was carried out to determine the economic impact on the water production of an RO unit when integrated with an MSF plant [11]. A number of hybrid desalination configuration were analyzed [12]. The study revealed that the simple hybrid MSF/RO desalination plant in which the RO product is blended with MSF product results in significant reduction of RO water production cost and is around 13 per cent lower than the water production cost of non-hybridized RO plant. The cost savings resulted from smaller intake, use of single-stage RO process and longer membrane life. When a fully integrated MSF/RO desalination plant is used, selection of RO membranes of high flux and low salt rejection coupled with the blending of the products of MSF and RO plants have a relatively higher impact on the reduction of water production cost of the non-hybrid RO plant.

An optimization study for the prediction of the minimum water cost of seven different designs of RO/MSF hybrid desalination plants was reported [12,13]. The MSF plants are either of brine recycle or once-through flow configurations and are coupled to single stage SWRO with energy recovery system. For comparison the water cost of a stand- alone two-stage SWRO unit and a stand-alone brine recycle MSF plant, was also determined. The study revealed that the two-stage RO plant yields the lowest water production cost. Hybridization of the RO and MSF processes would result in better economics and operation characteristics than those corresponding to the stand alone MSF process.

## 2. COMMERCIALLY -AVAILABLE HYBRID DESALINATION PLANTS

A number of desalination plants in the Kingdom of Saudi Arabia and United Arab Emirates (UAE) are currently adopting a simple rather than a full integrated hybrid desalination configuration. The MSF and RO operate in parallel and entirely independent as shown in Fig. 2. The MSF and RO plants are having common intake and/or outfall facilities. The water product of the single pass RO unit is blended with the MSF product.

The Saline Water Conversion Corporation (SWCC) of Saudi Arabia introduced the concept of simple hybrid MSF/RO desalination concept to three of its large desalination plants: Jeddah, Al-Jubail and Yanbu plants. In 1989 Jeddah SWRO Phase-I desalination plant was built in the same site of Jeddah dual purpose MSF/Power plants. It consists of 1 stage plant and with a production capacity of 12.5 MIGD. In 1994, SWRO Phase-II of 12.5 MIGD production capacity was combined with Phase-I [14]. The two SWRO phases are having common intake system. The products from the two single SWRO plants are blended with product water from an MSF/Power dual purpose plant of 80 MIGD product water.

As the result of the increasing water demand in the two cities of Madina and Yanbu, Yanbu Phase-I MSF/Power cogeneration plant was extended. A simple hybrid configuration incorporating four MSF distillers each with 10 MIGD production capacity and a SWRO plant of total production of 28.16 MIGD, was adopted [15]. A single stage RO process was selected. The MSF and RO desalination plants share the intake/outfall facilities and the products of the two processes are blended.

Al-Jubail MSF/Power dual purpose plants which are located on the Gulf coast of Saudi Arabia were extended by including a 20 MIGD single stage SWRO desalination plant. The SWRO is sharing the intake/outfall facilities with the dual purpose MSF/Power Plant. The product of the SWRO and MSF desalination plants are blended

Recently in Fujairah, UAE, a large 100 MIGD desalination plant was originally designed and built based on the hybrid concept [16,17]. It combined a 62.5 MIGD MSF with 37.5 MIGD SWRO plant. The plant net electrical energy production is 500 MW. In UAE the demand of water is nearly constant throughout the whole year while the power demands drops by about 40 percent during the winter season. The hybrid concept was selected to provide a more flexible system as the RO system helps to sustain the electricity demand and eliminate the mismatch between the water and electricity demand [16]. The SWRO plant design incorporates a two stage system to obtain a product salinity less than 180 mg/l before being blended with the MSF product water.

## 3. PROSPECTS OF DEVELOPMENT OF HYBRID DESALINATION SYSTEMS

As has been described in the previous section, all the commercially-available hybrid desalination plants are applying the simple hybrid concept. It would be worthwhile to investigate the possibility of fully integrating the MSF and RO desalination plants. The prospects of utilizing the preheated seawater exiting the MSF heat rejection as a feed to the RO plant during the cooler seasons in existing plants, has to be considered. Such combination will result in the increase of plant productivity and reduce energy requirements of the RO process.

New dual-purpose power/water plants have to be designed on the basis of fully integrated hybrid concept. The MSF and RO designs are to be optimized in such away to take full advantage of blending the products of the two processes, utilizing part of the seawater leaving the heat rejection as a make-up to the RO process and combining the RO brine discharge with the MSF brine recycle.

The Research & Development Center (RDC) of SWCC of Saudi Arabia recently introduced a promising approach for pretreatment of seawater using nanofiltration (NF) membranes [18-27]. Application of nanofiltration technique for pretreatment of seawater resulted in the reduction of salt concentration and removal of most of the hardness ions ($Ca^{++}$, $Mg^{++}$) and co-ions ($SO_4^{--}$, $HCO3^-$) salts which are responsible for the formation of the alkaline and non-alkaline scale on the heat transfer surfaces of thermal desalination processes. Similarly, the NF pretreatment process removes the hardness ions and co-ions salts from SWRO feed. Pretreatment of raw seawater by nanofiltration opens the possibility to safely increase the top brine temperature (TBT) of thermal seawater desalination plants above their present TBT limit. Increase of TBT shall result in the increase of water production and performance ratio. Extensive evaluation tests were subsequently carried out by the RDC in Al-Jubail to establish the optimum operating conditions and to determine performance parameters of a 20 $m^3$/day multistage flash (MSF) pilot plant coupled with NF pretreatment system as shown in Fig.3.

The hybridized MSF pilot plant was operated successfully for the first time up to a top brine temperature (TBT) of 130$^{o}$C, which is the design TBT limit of the unit, without injection of scale control additive for a period of 1200 hours and the product recovery was increased up to 70% compared to 35 per cent obtained from conventional operated MSF desalination plants [27]. Successful evaluation tests were also performed at same TBT of 130$^{o}$C using a make-up to the MSF unit formed from a blend of nanofiltration product and seawater.

Evaluation tests which were carried out using the NF membrane for pretreatment of seawater feed to reverse osmosis desalination unit, revealed that the reject of RO unit consists of relatively low concentration of scale forming ions. Consequently, extensive evaluation tests were performed to establish the operating conditions of the trihybrid NF/RO/MSF system which is shown in Figure 3b. The MSF pilot plant was operated successfully for a period of 976 hours up to a TBT of 130 $^{o}$C with a make-up entirely formed from the reject of the RO unit. Successful evaluation tests were also performed using a make-up to the MSF unit formed from a blend of RO reject and appropriate proportions of seawater.

The pilot plant test results can be used as a basis to serve a two fold purpose:

(1) To explore the possibility of applying the NF pretreatment to an existing commercial MSF plant.

(2) To carry out a detailed techno-economic study for the design and construction of a gross-root MSF desalination plant operating at TBT higher than 120$^oC$ within the context of dihybrid (NF/MSF) and trihybrid (NF/RO/MSF) systems.

Research work is in progress to couple nanofiltration pretreatment with multi-effect distillation (MED) to form a dihybrid NF/MED desalination system. This is expected to allow operation at high top brine temperature (up to 125$^oC$). Conventional MED commercial plants are currently operating at TBT less than 65$^oC$. High temperature operation should significantly improve the MED thermal efficiency.

## 4. CONCLUSIONS

1. The state-of-the-art of hybrid desalination technology was reviewed.
2. A number of existing dual purpose MSF/Power plants were expanded by combining them with SWRO using the simple hybrid desalination concepts.
3. New membrane/thermal desalination plants are to be designed to take advantage of the fully integrated hybrid concepts.
4. Prospects for further developments of hybrid systems combining thermal desalination processes (MSF & MED) and reverse osmosis process with nanofiltration pretreatment, have to be pursued.

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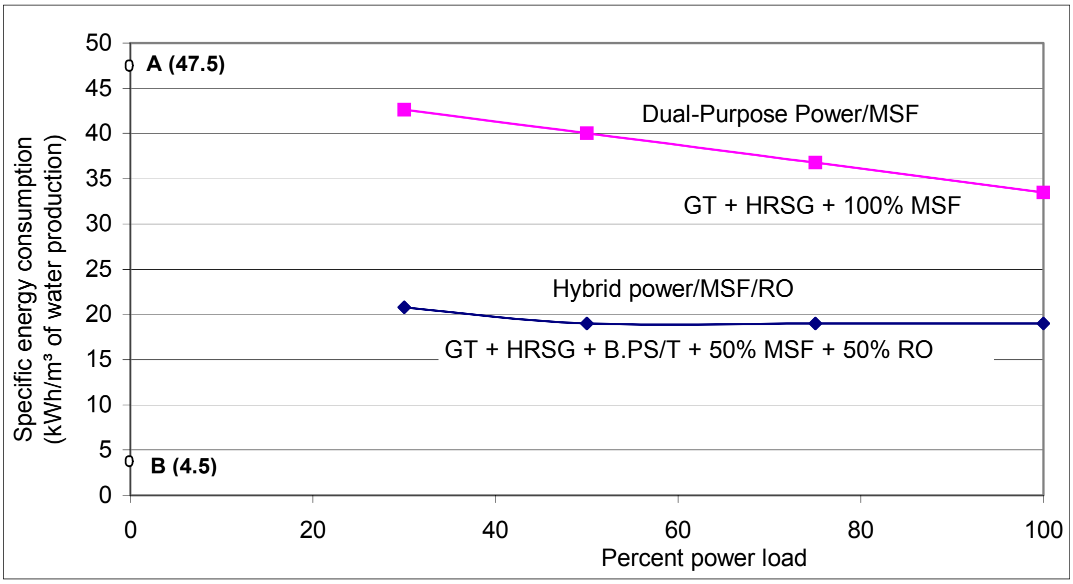


**Figure 1. Performance of MSF/Power dual purpose plant with variable power load**

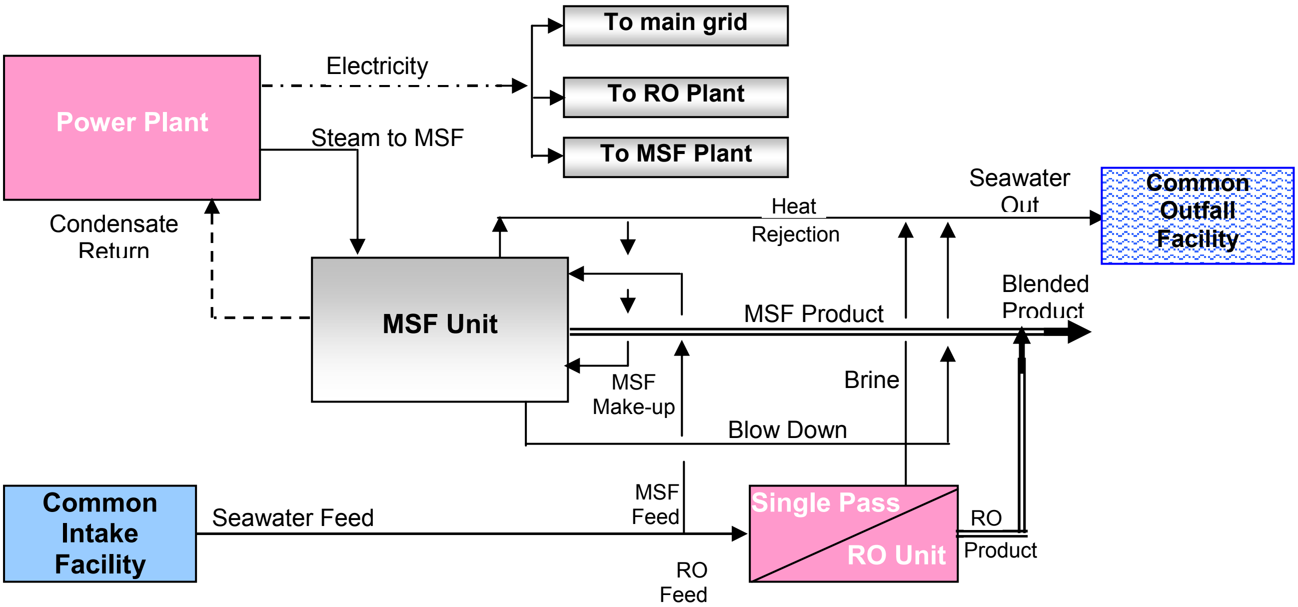


**Figure 2. Schematic diagram of commercially available simple hybrid desalination plants**

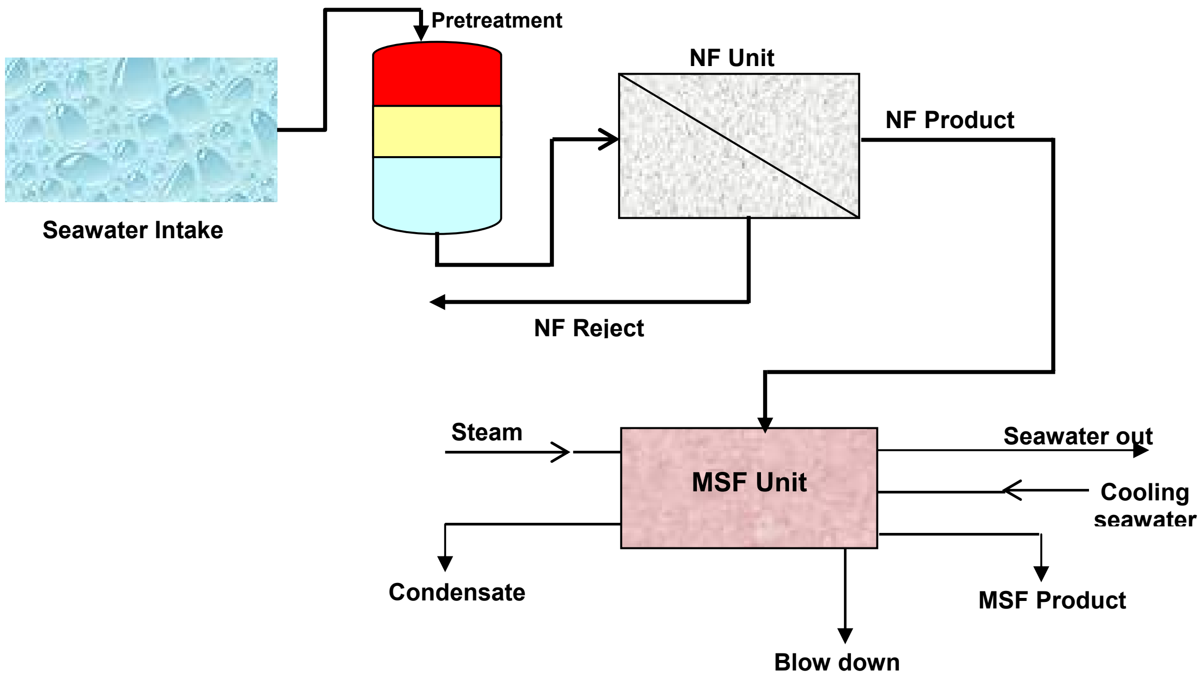


Figure 3(a). Schematic flow diagram of dihybrid NF/MSF desalination system

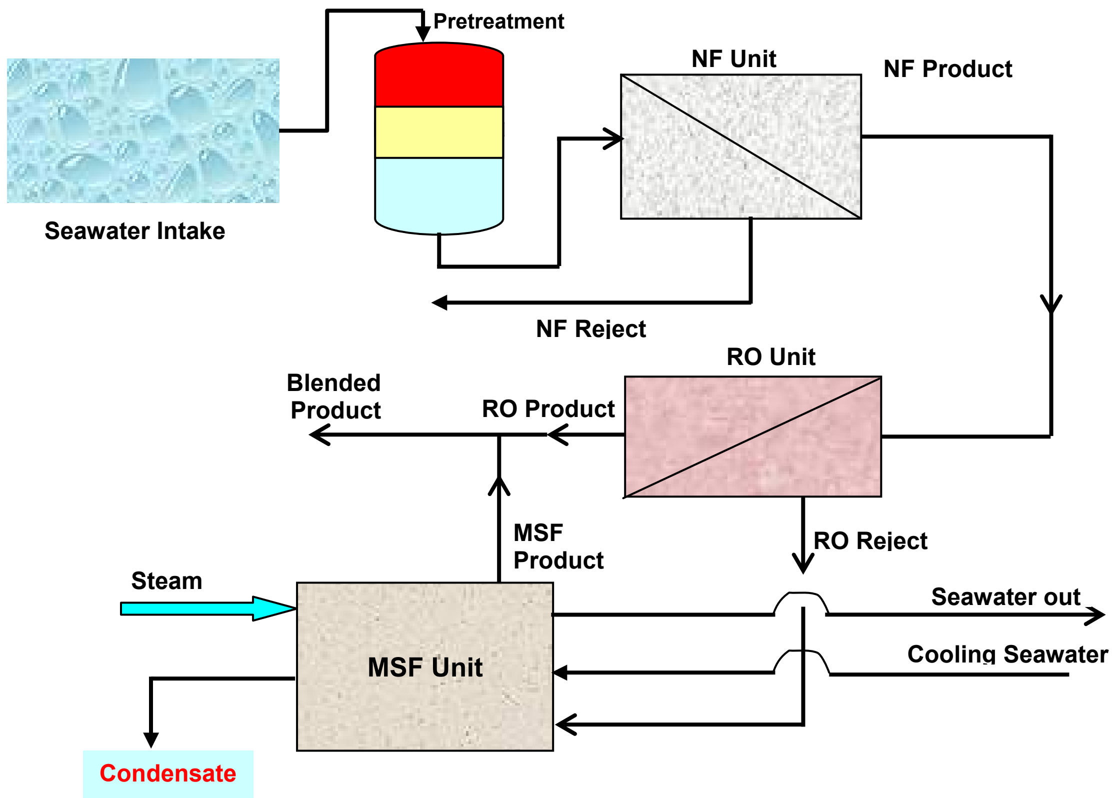


Figure 3(b). Schematic flow diagram of trihybrid NF/RO/MSF desalination system