An Optimized System for Advanced Multi-Effect Distillation (AMED) Using Waste Heat from Closed Gas Brayton Cycles

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SUMMARY

This report presents a novel Advanced Multi-Effect Distillation (AMED) method that can enable the production of substantial quantities of low-cost desalinated water using waste heat from high temperature reactors (HTRs). Conventional MED systems can currently compete with reverse osmosis desalination in areas where energy costs are relatively low, such as the Middle East. Because AMED can perform distillation without affecting the electricity generation efficiency of high temperature reactors (HTRs) using closed gas Brayton cycles, AMED can optimize to lower capital cost than conventional MED, while still producing large quantities of potable water. In examples presented here, a low-cost AMED system coupled to a 1200 MW(e) HTR plant (e.g., 4 GT-MHRs, 6 PBMRs, or 1 LS-VHTR) can produce 40,000 m^3/day of potable water. In locations where water costs are higher, additional effects may be added to increase water production up to 110,000 m^3/day or higher. AMED systems would use simple reconfiguration of current MED technology. While the additional AMED revenues (above electricity) are relatively modest (1 to 5%), the quantities of potable water generated as a byproduct of HTR electricity production are large, and could clearly be an important benefit for dry coastal regions.

INTRODUCTION

Closed gas Brayton cycles have an advantage over steam Rankine power cycles because closed Brayton cycles reject heat at substantially greater average temperature. Typical large steam-cycle power plants operate their condensers at pressures of around 0.043 bar, corresponding to a steam saturation temperature of 30°C. Large coolant flow rates are typically required to minimize the coolant temperature rise and the pinch-point temperature to reject heat from the condensing steam.

Conversely, the precoolers and intercoolers of closed gas cycles have gas inlet temperatures of around 85°C to 165°C, and exit temperatures of around 25°C to 35°C, giving average heat rejection temperatures of ranging from 55°C to 95°C, much higher than steam Rankine cycles. These larger temperature differences between the gas and cololant make it more attractive to use dry cooling, where heat is rejected from the cooling water to dry air. Dry cooling is particularly attractive for areas where water resources are scarce.

Where water is available, but is not potable due to brackishness or salinity, one potential use for waste heat from closed gas cycles is to desalinate water. Desalination is of particular interest in dry coastal areas, where abundant seawater is available but potable water is scarce or must be transported over long distances, as in California. This report presents two novel designs and economic analysis and optimization for a modified multi-effect distillation (MED) desalination system for producing potable water from seawater and other poor-quality water sources using waste heat from closed gas Brayton cycles.

The effectiveness of distillation-based desalination systems is commonly expressed as the Gain Output Ratio (GOR), that is, the ratio of the mass flow rate of clean water produced, to the mass flow rate of steam supplied to drive the distillation process. If a four-unit GT-MHR power plant, 6 unit PBMR plant, or an equivalent 2400 MW(t) AHTR (Advanced High Temperature Reactor), operating with 50% electricity production efficiency, were to be coupled to an advanced multi-effect distillation (AMED) system with a GOR of 2.5, it would be capable of producing

$$2.5\frac{0.5(2400\text{MWt})(3600\,\text{sec/hr})(24\text{hr/day})}{(2.4\text{MJ/kg})(1000\text{kg/m}^3)} = 110{,}000\text{m}^3\text{/day}$$

of clean water. This water production rate for a single 1,100 MW(e) nuclear plant would be impressive. Currently, a very large desalination plant would is 240,000 m^3/day (the capacity of Taweelah A1), and in 1995 the total, worldwide production of desalinated water was only 21 million m^3/day performed in a total of approximately 11,000 plants [5]. Put another way, in 2002 water consumption by the City of San Diego (population 1,256,000) was 800,000 m^3/day. Thus a nuclear power station the same size as the nearby 2,329 MW(e) San Onofre Nuclear Generating Station, using an AMED system, could provide a quarter of San Diego's current water supply if it used a closed Brayton cycle for power conversion.

Water delivered to San Diego from the Colorado River costs approximately \$0.29/m^3, while in Saudi Arabia thermal distillation of water is performed for approximately \$0.70/m^3. Thus desalination using waste heat from a 1,200 MW(e) nuclear plant with a GOR of 1 (40,000 m^3/day) could produce potable water revenues of approximately \$12,000 at the low water price, while a system with GOR of 2.5 (110,000 m3/day) could generate revenues of \$70,000 per day. This can be compared to electricity revenues of \$1.2 million per day at an electricity price of \$4/MWhr. Thus desalination could add 1 to 5 percent to plant revenues. Conventional MED systems typically operate at GOR = 14, so the potential exists to further increase the AMED GOR by adding surface area.

Figure 1 shows a conventional MED system flow diagram, where the heat source is steam. When this steam condenses in the first effect, it boils a mass of water from brine which is slightly smaller than the mass of condensed steam, because some of the latent heat is consumed in sensible heating of the rejected brine. The distilled vapor from the first effect flows into a heat exchanger in the second effect. Because the second effect operates at lower pressure than the first, brine in the second effect evaporates at a lower temperature. The steam entering the heat exchanger condenses, forming potable water, and a slightly smaller mass of brine is evaporated. Various flow patterns for brine are possible, with MED systems typically choosing either co-current or counter-current flow of brine and steam (Fig. 1 shows a counter-current configuration). The steam generated in this effect then flows into the next effect, where the process is repeated at yet lower pressure. Finally, steam generated in the last effect is condensed using seawater as the ultimate heat sink. Figure 2 shows a photo of a conventional MED plant.

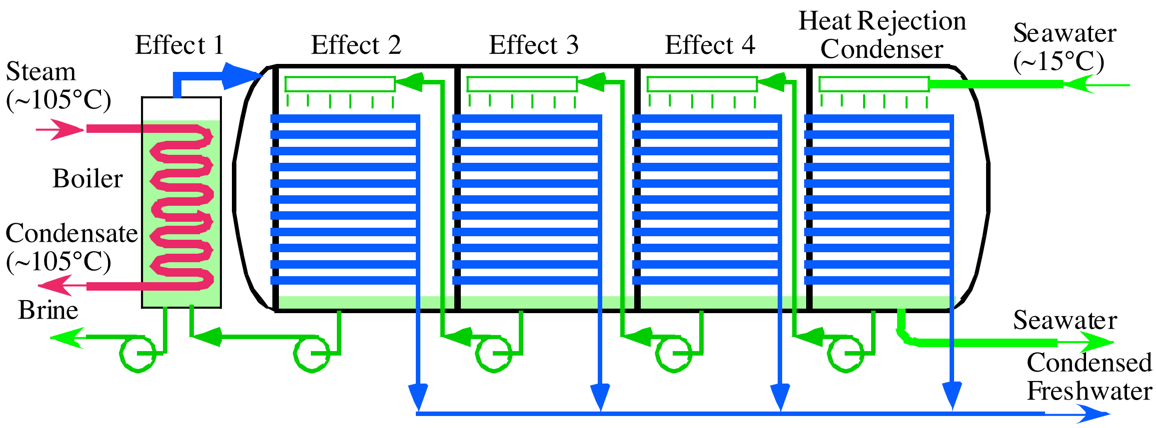

Fig. 1 Schematic of a conventional MED system, using steam as a heat source, with four effects stages.

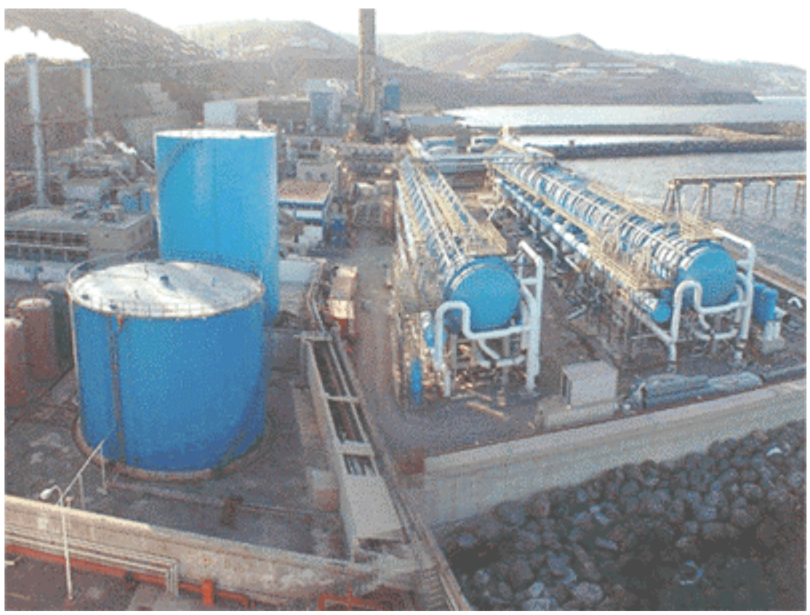

Fig. 2 A 2-unit MED plant built by IDE Technologies with total capacity of 35,000 m^3/day (http://www.ide-tech.com/code/what.html).

For conventional MED, the Gain Output Ratio, GOR, is the ratio of the mass of potable water generated to the mass of steam consumed. In the ideal limit where each effect evaporates a mass of steam equal to the mass condensed, the GOR value approaches the number of effects n, GOR $\rightarrow$ n. However, as the number of effects is increased, the heat exchanger surface area required increases as well. Because the log-mean temperature difference (LMTD) available to drive heat transfer drops inversely with the number of effects n+1, the total effective surface area UA required for evaporation and for the final condenser increases approximately proportional to $(n+1)^2$. The capital cost of MED systems is roughly proportional to the total heat exchanger area, so the optimal number of stages depends upon the relative cost of energy to generate steam, versus capital cost of the heat exchange equipment. As the cost of energy increases, the optimal value of the GOR also increases.

In contrast to a conventional MED system, the cooling water from a closed Brayton cycle intermediate loop delivers heat across a range of temperatures. Figure 3 shows a simple version of an AMED designed to use this heat optimally. As with conventional MED, the AMED system consists of multiple effects stages, each operating at different pressures and temperatures. In the first stage, which operates at the highest pressure, coolant from the intermediate cooling system is supplied to a heat exchanger that evaporates seawater sprayed into the effects vessel. The distilled vapor flows to the next effects vessel and is condensed, evaporating additional seawater. Likewise, the intermediate cooling water also flows into a heat exchanger that evaporates additional seawater into this effects stage. Because the intermediate coolant heat exchangers add additional steam to each effect, each effect condenser has progressively larger surface area. After the last effects stage, the resulting vapor is condensed using seawater. The intermediate coolant is also cooled further by seawater, so that it is returned to the closed gas cycle near the minimum temperature available in the ambient environment.

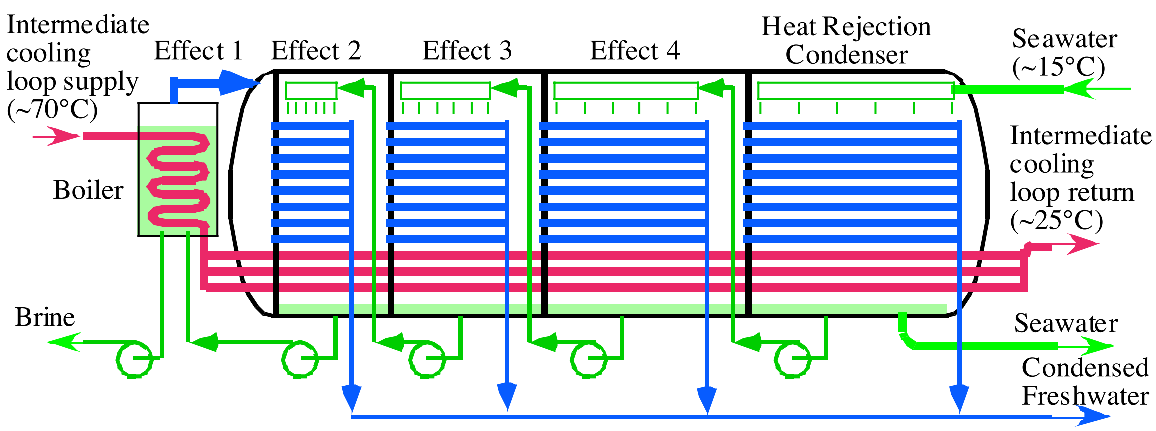

Fig. 3 Schematic of an AMED system with four effects stages and counter-current brine flow.

As shown in Fig. 4, the temperature distribution in the AMED differs substantially from a conventional MED system. In the AMED, the intermediate coolant temperature drops by approximately $\Delta T = (T_{in} - T_{out})/(n+1)$ over each effect. For the AMED, the GOR can be defined based upon the sensible heat provided by the intermediate fluid, so that the total mass of potable water produced is $m_T = GOR\ m_{IL}(T_{in} - T_{out})c_p/h_{fg}$, where m_{IL} is the mass flow rate of the intermediate coolant, c_p the coolant specific heat, and h_{fg} the latent heat of water. Neglecting sensible heating of the brine, the mass of steam evaporated in the first effect approaches $m \rightarrow m_{IL}\ \Delta T/(T_{in}-T_{out}) = m_{IL}/(n+1)$. In the second effect, steam is evaporated both by heat transfer from the intermediate coolant, and by condensing the steam generated in the first effect. Summing across all n effects, the total mass of potable water generated is then $m_T \rightarrow m_{IL} \sum_{i=1}^{n} i/(n+1) = m_{IL} n/2$, or equivalently GOR $\rightarrow$ n/2. Therefore to achieve the same GOR AMED requires roughly twice as many effects as MED. As can be seen in Figure 4, for the same GOR and Top Brine Temperature (TBT) the larger number of effects results in smaller temperature differences across the heat exchangers, and as a consequence the AMED system will also require approximately 80% more heat exchanger surface area to provide the same GOR.

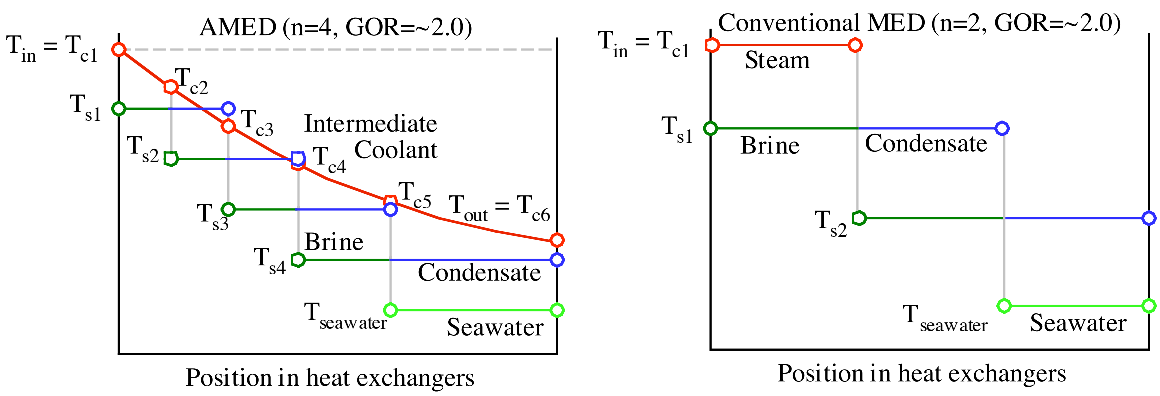

Fig. 4 Comparisons of temperature distributions in a three-effect AMED system (Fig. 3), versus conventional MED (Fig. 1).

In general, it is found that effects stages operating at a TBT above 62°C to 75°C can experience excessive fouling. This is not a problem for a typical intercooled closed Brayton cycle, where the intermediate coolant might have a maximum temperature of T_{in} = 70°C (for T_{out} = 25°C and T_{sea} = 15°C). However, in cases where desalinated water prices are sufficiently high, designers may choose to eliminate compressor intercooling, which would increase the maximum coolant temperature to approximately T_{in} = 120°C, and give rise to fouling concerns and reduced electricity generation efficiency.

To address high-temperature fouling a thermocompressor may be introduced, as shown in Fig. 5. In this case, the heat delivered at temperatures 10°C to 20°C or more above the TBT is used to boil water and drive a thermocompressor. The thermocompressor extracts low-pressure steam from the last effects stage or stages, increasing the steam mass flow and enthalpy delivered to the top effects stage, and thus increasing the mass flow of seawater evaporated in this stage. Because closed gas cycles deliver heat across a range of temperatures, more than one boiler may be used, operating at different temperatures, to reduce the LMTD between the water being boiled and the intermediate cooling water.

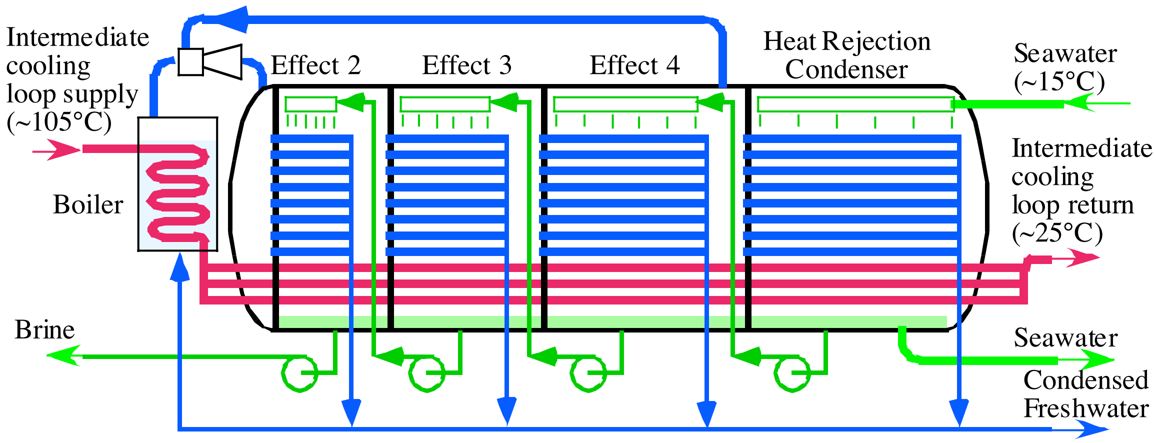

Fig. 5 Schematic of a MED system using a single boiler and thermocompressor. Additional boilers and thermocompressors, operating at lower pressures, may be added to increase the system GOR.

REVIEW OF MED

There are four different types of desalination plants in existence: multi-stage flash (MSF), multi-effect (ME), multi-effect vapor compression (MEV), and reverse osmosis (RO). In 1995 the MSF share of world capacity was 69%, whereas the RO share is about 23% and the ME is about 8% [1]. The conventional type of dual-effect plant normally consists of a steam supply, a number of effects, a series of preheaters, a train of flashing boxes, a condenser and a venting system. The motive steam is always extracted from a power generation turbine, a special boiler or by flashing steam from a waste energy source. ME plants have many limitations, i.e., as a top brine temperature (TBT) of 120°C by calcium sulfate scaling, and the temperature at the bottom end condenser is limited to the normal temperature of seawater used as a cooling water. The plant effects must be operated at specific vacuum pressure according to boiling point elevation, saturation pressure, salt concentration and others parameters. The number of effects in ME is restricted by the temperature difference between the condensing temperature at the first hot plant effect and the condensing temperature at the final condenser.

Low temperature (LT) and high temperature (HT) ME plant configurations are dictated by TBT. A high temperature is greater than 90°C and a low temperature is less than 90°C. Operating at high TBT results in a decrease in the specific heat transfer area because of the increase in temperature driving force per effect and the heat transfer coefficient, but the GOR value of a ME system is independent of the TBT. Operation at low temperature will avoid scaling and corrosion problems that might cause a serious problem in a HT-ME plant. TBT is limited to about 75°C with antiscalant treatment, but by using acid treatment of the feed water, one can operate at a higher brine temperature.

General Atomics' past research explored, in a preliminary way, the application of high temperature helium cooled reactors in either electricity or hydrogen production modes for desalination [2]. Three desalination technologies are discussed: RO and thermal processes using either MSF or ME. For the latter, it is found that the waste heat rejected from a high temperature reactor comes in power levels and temperatures reasonably well suited for desalination. An economic comparison was made using the best available data and scaling to compare the processes. Reverse osmosis and thermal distillation possess comparable costs within the error bars of the analysis, but RO generally resulted in slightly lower costs. Thus the choice between them can be made with other criteria such as feed salinity and product quality. It was also found that desalinated water co-produced with either electricity (RO and ME) or hydrogen (ME) are expected to cost about the same. Since hydrogen and desalinated water can be produced off the grid, this co-production architecture appears attractive for the early deployment of high temperature helium cooled reactors.

In the GA study, though, the waste heat was used to boil water, which did not take advantage of the fact that closed gas cycle waste heat is delivered across a range of temperatures. In the economic analysis, the authors also kept the same desalination system GOR value as commercial thermal plants would use, where the energy used must be paid for. However, with free heat from a closed gas Brayton cycle, one would want to look at lower GOR to lower capital cost, since capital cost will dominate the cost of the desalinated water. Because RO and MED distillation were found to be roughly competitive in the GA study, it can be expected that an optimized AMED system could be more attractive than RO for producing water, and that desalination could provide an attractive product for closed gas Brayton cycle systems that also produce electricity.

AMED USING PLATE-TYPE HEAT EXCHANGERS

Plate-type heat exchangers have significant advantages for lower-temperature applications, because plates can be fabricated at low cost by stamping processes using corrosion resistant materials like titanium, and plate heat exchangers are compact and have high surface area to volume ratios, which can reduce the size of vacuum vessels required for MED.

Fig. 6 Alfa-Laval MED desalination unit using plate type heat exchangers.

Figures 6 and 7 show photos of a recently developed commercial plate type MED system. The design can be readily and simply adapted to function as an AMED, with the coolant and condensation heat exchangers integrated into single units. Figure 8 shows the flow configuration for a plate-type AMED system. Figure 9 shows a plate gasket system for directing the flow of the coolant, evaporating brine, and condensing fresh water.

Fig. 7 Alfa-Laval titanium stamped plates for MED desalination.

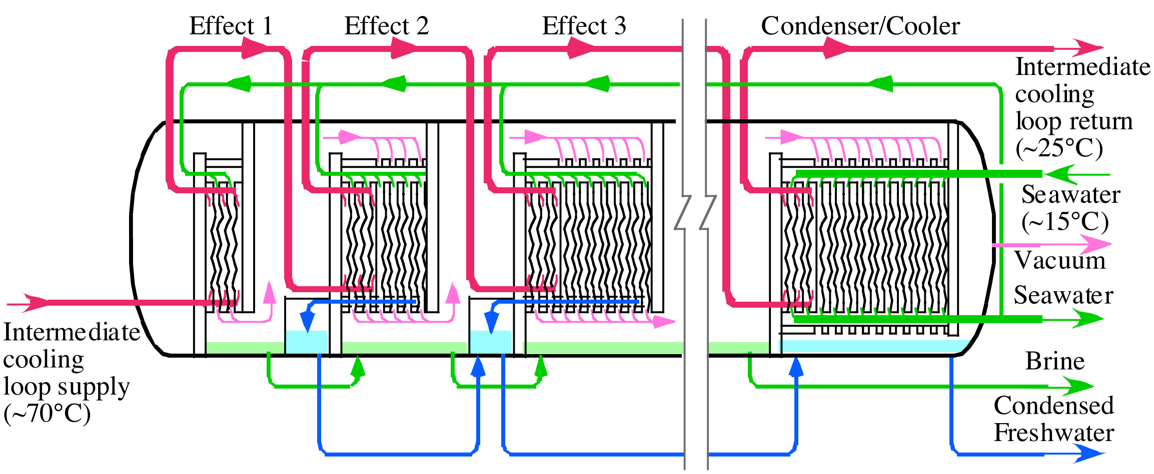

Fig. 8 Schematic diagram of flow inside a plate-type AMED system..

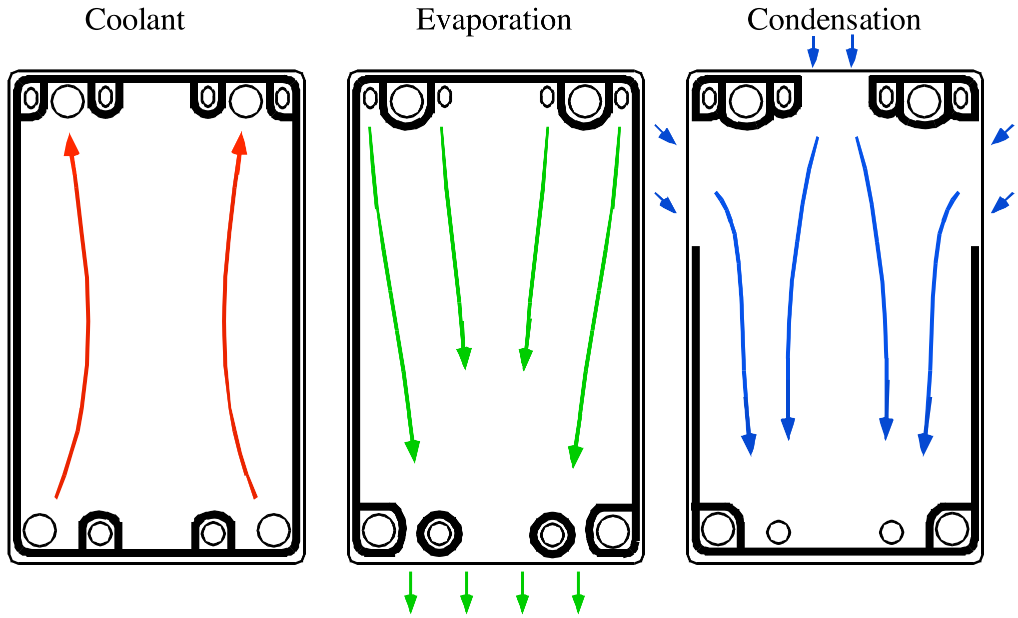

Fig. 9 Schematic gasket configurations for AMED with plate-type heat exchangers.

ECONOMIC ANALYSIS OF COUPLING MULTIPLE REHEAT GAS CYCLES WITH MED

Closed gas Brayton cycles are being developed for high-temperature gas cooled reactors, including the GT-MHR and PBMR. U.C. Berkeley is also developing concepts of multiple reheat Brayton cycle power conversion systems using heat from high temperature molten salts or liquid metals systems (MCGC) [3]. Figure 10 shows the schematic flow diagram for one reference three-expansion-stage MCGC, using three PCU modules (HP, MP, and LP) each containing a generator (G), turbine (T), compressor (C), and heater and cooler heat exchangers, with a recuperator (R) located in a fourth vessel. The reference thermal power is 2400 MW. For a turbine inlet temperature of 900°C, the net thermal efficiency is 54% for this configuration with one compression and intercooling for each reheat and expansion stage. The helium outlet and inlet temperatures in the coolers are 35°C/142°C. Additional intercooling can further increase the efficiency. With two stages of compression and intercooling for each reheat and expansion stage, the net thermal efficiency is 56%. The intercooler helium inlet temperature for this case is 86°C. The low efficiency MCGC system can couple with HT-MED desalination system with TBT about 120°C. The high efficiency MCGC system can couple with LT-MED system with TBT about 70°C. All the heat transferred to the desalination plant is waste heat. The cooling water coming out of the intercoolers can directly go to desalination heating lines to boil brine water as shown in Figure 1 and 2. The design goal here is trying to use this waste heat to generate maximum net revenue (net electricity revenues plus net water revenues) without affecting the electricity production.

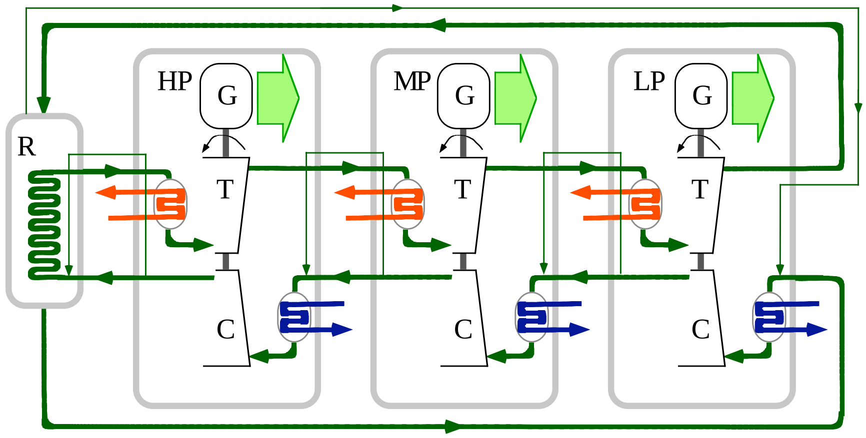

Fig. 10 Schematic flow diagram for the reference three-expansion-stage MCGC, using three PCU modules (HP, MP, and LP) each containing a generator (G), turbine (T), compressor (C), and heater and cooler heat exchangers, with a recuperator (R) located in a fourth vessel.

The cost of water (COW) from a MED desalination plant varies significantly with design, size, location, brine water type and other factors. For modern large MED desalination plant, \$0.70 per m^3 water production can be achieved [2, 4]. The COW includes water plant installation, thermal energy cost, capital cost, maintenance cost, electricity cost, and others. For a MED plant, the electricity cost in COW is only 1% and can be ignored. For a tower type MED, the water plant cost is about 37% and the thermal energy cost is 27% [5]. For a MED plant coupling with a closed gas cycle, the thermal energy cost can be zero if the system is optimized.

As a first-order approximation, the MED water plant cost can be assumed proportional to the total heat transfer area. According to reference [6], a function of relative specific heat transfer area with the number of effects and TBT can be obtained through multivariate regression. The range of number of effects is from 4 to 18 and the range of TBT is from 80ºC to 105ºC. Figure 11 shows the specific heat transfer area relative to the value for a plant with 14 effects and 105ºC TBT. With the increase of the number of effects, more specific heat transfer area is needed for one effect. Each effect has larger temperature difference with higher TBT, therefore less heat transfer area. If we assume \$0.70/m^3 COW for a regular MED plant with 14 effects and 105ºC TBT, the specific water cost except for thermal energy for an AMED system can be estimated by the following equation:

$$c_o(n_e, TBT) = c_w(1 - r_e - r_i) + c_w \cdot r_i \cdot \frac{(n_e+1)^2}{(14+1)^2} \cdot 1.8 \cdot p\left(n_e, \frac{TBT}{273.15K + 105K}\right), \qquad (1)$$

where n_e is the number of effects, c_w = \$0.70/m^3 the reference COW for a regular MED plant, r_e the fraction of thermal energy cost in the COW, r_i the fraction of installation's capital cost in the COW, 1.8 an area multiplier for the AMED area requirement compared to MED area, and p the relative specific heat transfer area for each effect as a function of the number of effects and TBT. For an AMED plant using waste heat as for the cases we are considering for closed gas cycle plants, c_o is the actual COW. Figure 12 shows COW for the LT-AMED case and the HT-AMED case. As the number of effects increases, the COW increases because more heat transfer area is needed for each effect. But this does not mean that the net revenue from desalination will decrease with the increase of number of effects because this is only the unit water cost ($ per m^3).

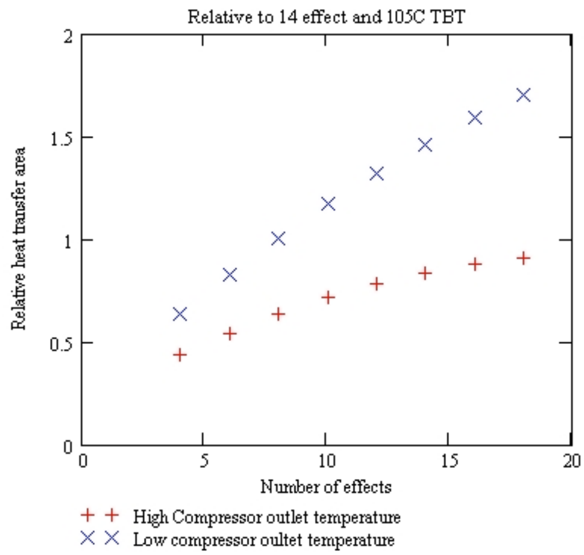

Fig. 11 Relative specific heat transfer area per effect as the function of number of effects and TBT (142°C for HT-MED and 86°C for LT-MED).

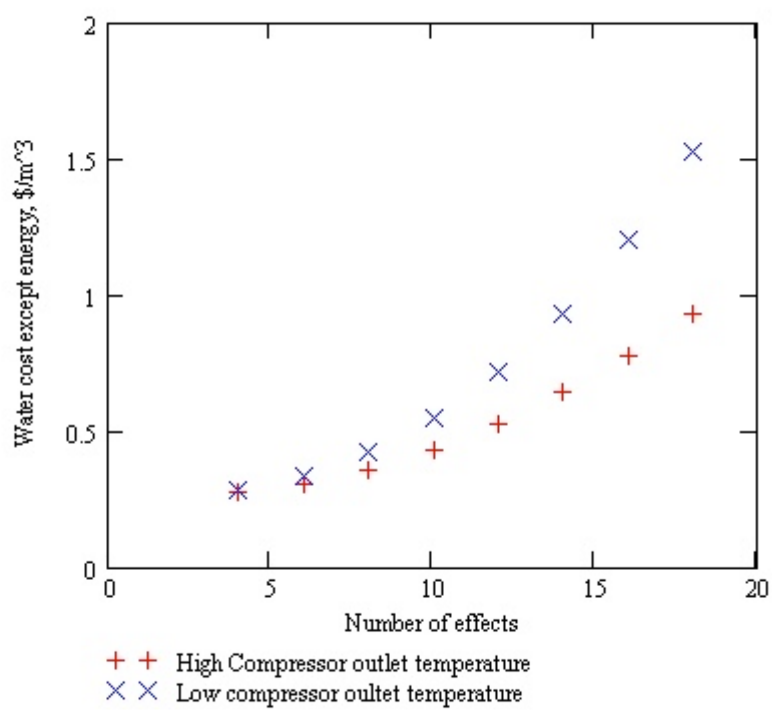

Fig. 12 COW as the function of number of effects and TBT.

The GOR for a modern large MED plant is directly related to the number of effects and weakly related with TBT [6]. Here we assume that GOR is only related to the number of effects to simplify the analysis. According to reference [6], for conventional MED the GOR as a function of the number of effects can be correlated using regression methods as shown in Figure 13. The water production rate can then be calculated as:

$$Q_w(n_{gor}, \eta) = \frac{0.5 n_{gor} \cdot Q \cdot (1-\eta)}{h_{fg} \cdot 1000 \frac{kg}{m^3}}, \tag{2}$$

where n_{gor} is the GOR, η the power cycle efficiency, Q the total thermal power, and h_{fg} the specific heat of evaporation for water. Figure 14 shows the water production rates for two cases as a function of number of effects. The water production rate increases with the number of effects.

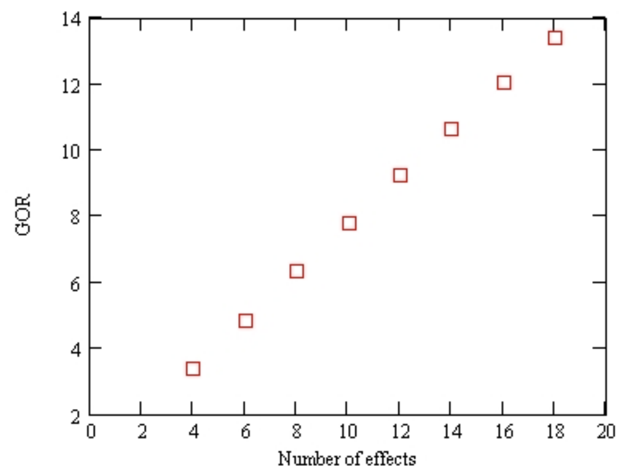

Fig. 13 GOR for conventional MED as a function of number of effects.

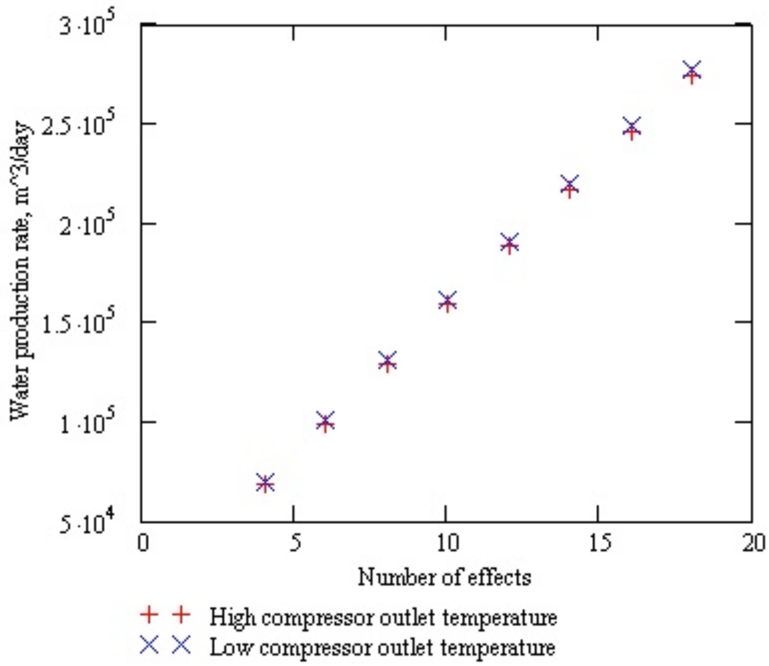

Fig. 14 Water production rate for a 2400 MW(t) HTR as a function of number of AMED effects.

The net daily desalination revenues from combined AMED and electricity production can be calculated from the following equation:

$$E_w(n_e,\eta,TBT,v_w) = Q_w(n_{gor},\eta)\cdot day\cdot(v_w - c_o(n_e,TBT)), \tag{3}$$

where v_w is the water price [$/m^3]. Assuming that the electricity price is $0.04 per kWh and the generation cost is $0.03, the net electricity earnings per day from a large MCGC power cycle can be calculated by:

$$E_e(\eta) = \frac{Q\cdot\eta\cdot day}{kW\cdot hr}\cdot(0.04-0.03), \tag{4}$$

The total earning per day for a combined power and MED desalination plant then is

$$E(n_e,\eta,TBT,v_w) = E_w(n_e,\eta,TBT,v_w) + E_e(\eta), \tag{5}$$

With Eq. (5), we can find optimal number of effects for different water prices. Water prices vary with location. Three cases are considered in this paper: the first one is $0.29/m^3 which is the water cost delivered to southern California from the Colorado river; the second one is $0.70/m^3 which is the typical desalination water cost for Middle Eastern countries; and the third one is $0.50/m^3 which is the average of the first two. Figures 15 to 17 show the net revenues per day for the combined plants with different assumptions. Tables 1 to 3 summarize the optimized results for different water prices.

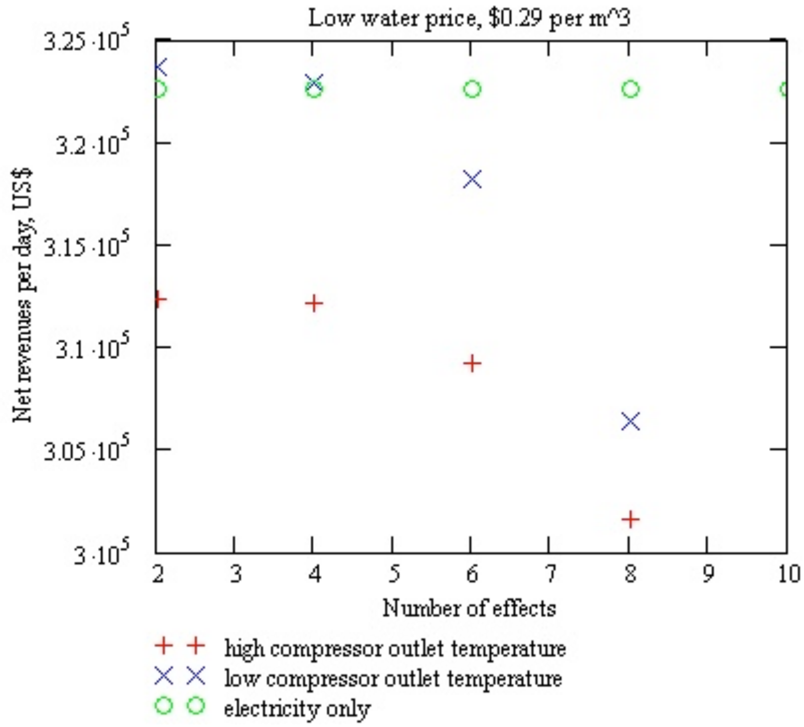

Fig. 15 Net revenues per day for a combined power and AMED desalination plant for a water price of $0.29/m^3.

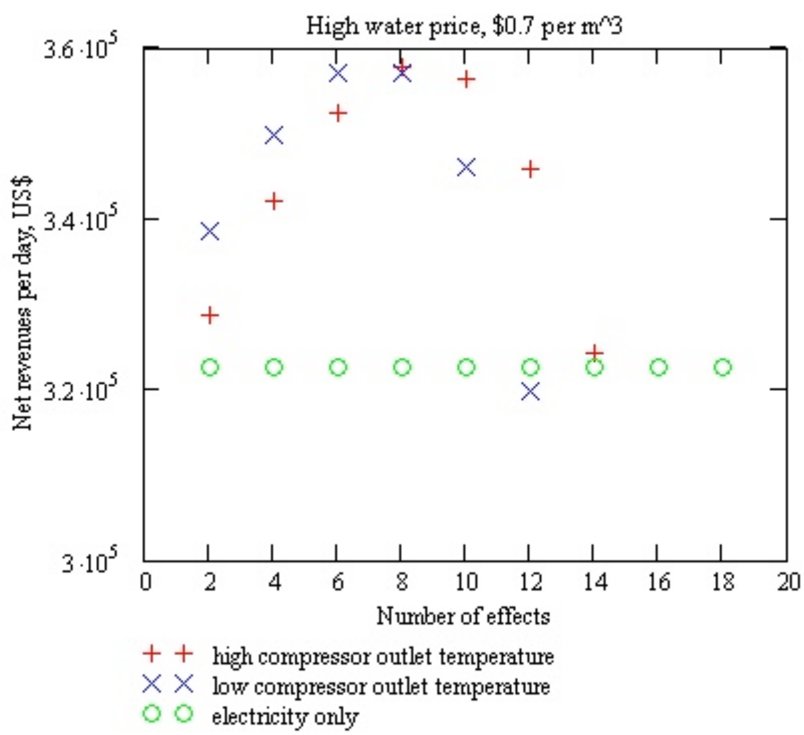

Fig. 16 Net revenues per day for a combined power and AMED desalination plant for a water price of $0.70/m^3.

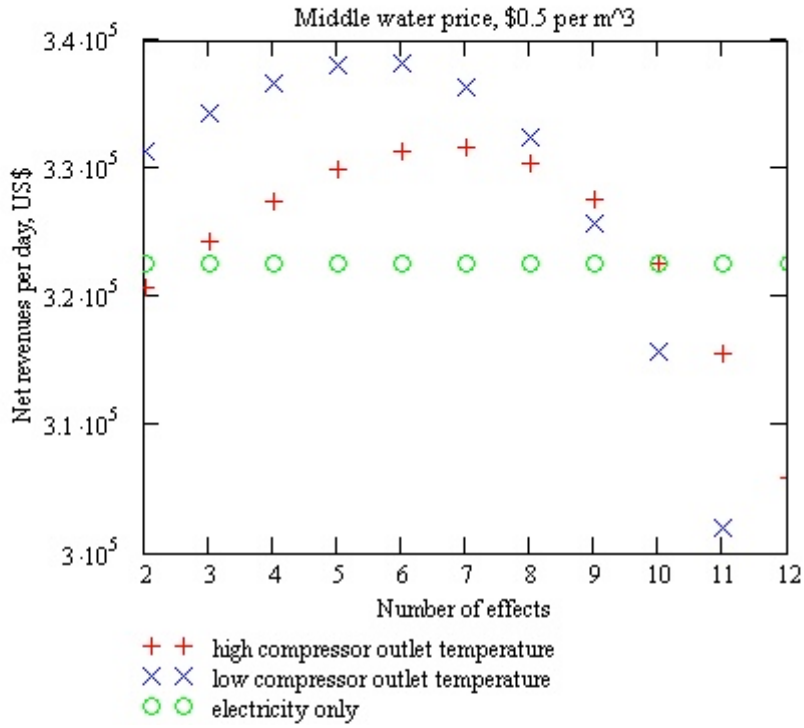

Fig. 17 Net revenues per day for a combined power and AMED desalination plant for a water price of $0.50/m³.

Table 1 Maximum net revenue increase and water production rates for a 2400 MW(t) HTR with water price of $0.29

	LT-AMED	HT-AMED
TBT, [°C]	70	120
Optimal number of effects, [-]	2	N/A
Maximum net revenue increase relative to the maximum electricity net revenue, [-]	0.3%	<0
Water production rate, [m^3/day]	$3.6x10^4$	N/A

Table 2 Maximum net revenue increase and water production rates for a 2400 MW(t) HTR with water price of $0.70

	LT-AMED	HT-AMED
TBT, [°C]	70	120
Optimal number of effects, [-]	7	8
Maximum net revenue increase relative to the maximum electricity net revenue, [-]	11%	11%
Water production rate, [m^3/day]	1.1×10^5	1.4×10^5

Table 3 Maximum net revenue increase and water production rates for a 2400 MW(t) HTR with water price of $0.50

	LT-AMED	HT-AMED
TBT, [°C]	70	120
Optimal number of effects, [-]	6	7
Maximum net revenue increase relative to the maximum electricity net revenue, [-]	4.8%	2.8%
Water production rate, [m^3/day]	0.95×10^5	1.2×10^5

Based on this approximate analysis, for the low water price cases (Table 1), only the LT-AMED case can produce a small net revenue from seawater desalination. Maximizing the electricity generation should be pursued. Although the energy is free, the relative high water plant cost and cheap water make the cogeneration not economically competitive. For the high water price (Table 2), LT-MED and HT-MED can generate 10% higher net revenue than pure electricity generation. For the middle water price (Table 3), LT-MED and HT-MED can increase net revenue by roughly 5% and 3%, respectively. For LT-MED, the number of effects tends to optimize at lower number while for HT-MED the number of effect optimizes at a higher number, as expected because the high compressor outlet temperature reduces the electricity production efficiency. HT-MED tends to have experienced excessive fouling problems and higher operational cost. Under similar net revenues, LT-MED is preferred.

While the increase in the net plant revenues is relatively small for the lowest water price, still the water production rates for all the cases studied (40,000 to 140,000 m^3/day) are substantial and comparable to the largest current desalination plants. Therefore, economies of scale may further reduce the cost of AMED systems coupled to high-temperature nuclear power plants. In this study, the AMED with vapor compression (VC) is not considered. Vapor compression could further increase GOR, and potentially the COW could be further decreased. Clearly, if AMED technology can be developed and coupled to high-temperature nuclear reactors like the GT-MHR, PBMR and AHTR, these plants could produce large quantities of potable water in addition to electricity in arid coastal regions, as in California.

CONCLUSIONS

By using an advanced multi-effect distillation (AMED) system, the waste heat from closed gas Brayton cycles could be fully utilized to desalinate brackish water and seawater without affecting the power cycle thermal efficiency. For higher water prices, the net revenues from a combined electricity and LT-AMED plant, could be as much as 10% greater than the production of electricity alone, without affecting the electricity efficiency. Even at relatively low water prices, where the optimal GOR is relatively small, with an AMED system HTR power stations would still generate large quantities of desalinated water (40,000 m^3/day for a 1200 MW(t) station)

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REFERENCES

1. M. A1-Shammiri and M. Safar, "Multi-effect distillation plants: state of the art", Desalination 126 (1999) 45-59.
2. S. L. Bogart and K. Schultz, "Water Desalination as a Possible Opportunity for the GT and H2-MHR", Proceedings of ICAPP '04, Pittsburgh, PA USA, June 13-17, 2004.
3. H. Zhao and P.F. Peterson, "Optimization Of Advanced High-Temperature Brayton Cycles With Multiple Reheat Stages," The 11th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-11), Popes' Palace Conference Center, Avignon, France, October 2-6, (2005).
4. IAEA-TECDOC-666, "Technical and Economic Evaluation of Potable Water Production through Desalination of Seawater by Using Nuclear Energy and Other Means", ISSN 1011-4289, September 1992.
5. R. Semiat, "Desalination: Present and Future", Water International, Volume 25, Number 1, Pages 54–65, March 2000.
6. Narmine H. Aly, Adel K. El-Fiqi, "Thermal Performance of Seawater Desalination Systems," Desalination 158 (2003) 127-142.