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Economic Evaluation of Coupling APR1400 with a Desalination Plant in Saudi Arabia

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Abstract : Combining power generation and water production by desalination is economically advantageous. Most desalination projects use fossil fuels as an energy source, and thus contribute to increased levels of greenhouse gases. Environmental concerns have spurred researchers to find new sources of energy for desalination plants. The coupling of nuclear power production with desalination is one of the best options to achieve growth with lower environmental impact. In this paper, we will per-form a sensitivity study of coupling nuclear power to various combinations of desalination technology: {1} thermal (MSF [Multi-Stage Flashing], MED [Multi-Effect Distillation], and MED-TVC [Multi-Effect Distillation with Thermal Vapour Compression]); {2} membrane RO [Reverse Osmosis]; and {3} hybrid (MSF-RO [Multi-Stage Flashing & Reverse Osmosis] and MED-RO [Multi-Effect Distillation & Reverse Osmosis]). The Korean designed reactor plant, the APR1400 will be modeled as the energy production facility. The economical evaluation will then be executed using the computer program DEEP (Desalination Economic Evaluation Program) as developed by the IAEA. The program has capabilities to model several types of nuclear and fossil power plants, nuclear and fossil heat sources, and thermal distillation and membrane desalination technologies. The output of DEEP includes levelized water and power costs, breakdowns of cost components, energy consumption, and net saleable power for any selected option. In this study, we will examine the APR1400 coupled with a desalination power plant in the Kingdom of Saudi Arabia (KSA) as a prototypical example. The KSA currently has approximately 20% of the installed worldwide capacity for seawater desalination. Utilities such as power and water are constructed and run by the government. Per state practice, economic evaluation for these utilities do not consider or apply interest or carrying cost. Therefore, in this paper the evaluation results will be based on two scenarios. The first one assumes the water utility is under direct government control and in this case the interest and discount rate will be set to zero. The second scenario will assume that the water utility is controlled by a private enterprise and in this case we will consider different values of interest and discount rates (4%, 8%, & 12%).

Key Words : APR1400; DEEP; Desalination; discount rate; KSA

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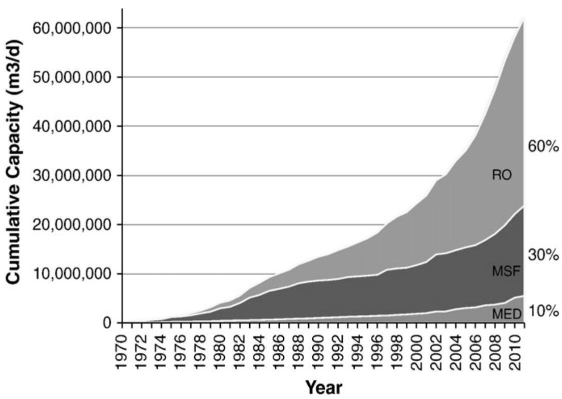
1. Introduction

Nearly three-quarters of the earth's surface is covered with water. The estimated total volume of water is 1.3x1018 m3. However, 97.5% of this water is contained in the oceans, which are highly saline and unfit for human consumption. Of the fresh water resources (i.e., the remaining 2.5%), a major portion is locked up in polar ice and glaciers. On balance, less than 1% is accessible for human use with about 9x1012 m^3 available as natural surface and ground water and another 3.5x1012 m^3 impounded by dams and reservoirs [1].

Desalination as a source of fresh water is the life blood for the economies of many countries and regions around the world (e.g., United Arab Emirates (UAE), Kingdom of Saudi Arabia (KSA)).

Over the last 20 years, construction of desalination plants has increased dramatically as illustrated in Figure 1. Recently, the relative shares of desalination technologies is 60% for RO, 30% for MSF and 10% for MED [2].

Most desalination projects employ fossil fuels as an energy source thus contributing to increased emissions of greenhouse gases. Environmental concerns associated with the use of fossil fuels have spurred researchers to find new sources of energy for desalination plants. The coupling of nuclear power production with desalination is one of the best options to achieve growth with lower environmental impact.



[Figure 1] Cumulative contracted capacity of desalination plants [1]

As driven by low fuel costs and low environmental impact, nuclear power has long been of interest for non-electricity energy production and use (e.g., hydrogen generation, district heating applications, and more recently, desalination). Nuclear desalination as defined by the IAEA is: "the production of potable water from sea water in a facility in which a nuclear reactor is used as the source of energy for the desalination process". Both electrical and thermal energy may be used in the desalination process. The co-generation facility may be dedicated solely to the production of potable water, or may be used for the generation of electricity and the production of potable water, in which case only a portion of the total energy output of the reactor is used for water production. In either case, the notion of nuclear desalination is taken to mean an integrated facility in which both the reactor and the desalination system are located on a common (or adjacent) sites and energy is produced on-site for use in the desalination sys-tem. It also involves at least some degree of common or shared facilities, services, staff, operating strategies, outage planning, and possibly controls facilities, along with seawater intake and outfall structures [1].

Nuclear energy for seawater desalination is used in Japan and Kazakhstan. Besides their experience, many other countries have shown a noticeable interest in nuclear desalination through several designs and studies including: The Republic of Korea, China, India, Morocco and the Russian Federation. High levels of international interest in nuclear desalination indicate the scale of the potential market for this technology [3].

Saudi Arabia has approximately 20% of the in-stalled salt water desalination capacity in the world. Domestically, the Saline Water Con-version Company (SWCC) has established pipeline systems with a total length of approximately 2000 km to transport fresh water to remote areas.

Treated wastewater supplies only 0.8% of cur-rent desalination plant makeup and is still considered to be in the early stages of devel-opment [3].

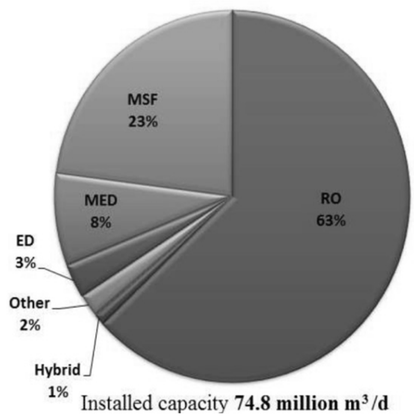
In the case study here, various combinations of desalination technology will be parametrically evaluated, including: (i) thermal (MSF, MED, & MED-TVC), (ii) membrane (RO), and (iii) hybrid (e.g., MSF-RO & MED-RO). These technologies will then be coupled to the Korean designed reactor plant, the APR1400 (Co-Generation), to evaluate overall feasibility and the optimal economic approach. The economical evaluation will be executed by using the computer program DEEP (Desalination Economic Evaluation Program) as developed by the IAEA. The program has capabilities to model several types of nuclear and fossil power plants, nuclear and fossil heat sources, and thermal distillation and membrane desalination technologies. The output of DEEP includes levelized water and power costs, break-downs of cost components, energy consumption and net saleable power for any selected option. Per state practice, economic considerations for these power and water utilities in the KSA do not consider or apply interest or carrying cost.

Therefore, evaluation results will be based on two scenarios, the first assuming the water utility is under direct government control and in this case the interest and discount rate will be set to zero. The second scenario will assume that the water utility is controlled by a private enterprise and in this case we will consider different values of interest and discount rates (4%, 8%, & 12%).

2. Desalination Coupled with NPP

2.1 Desalination Technologies

The major two types of desalination tech-nologies used around the world can be broadly classified as either: (i) a thermal desalination processes, in which feed is boiled and the vapor condensed as pure water (distillate), or (ii) a membrane desalination processes, in which semi-permeable membranes are used to filter out dissolved solids. Both technologies need energy to operate. Within these two types there are sub-categories (processes) using different techniques [4], as listed below and broken out per Figure 2. The thermal desalination processes



[Figure 2] Global desalination plant capacity [4] are: (i) Multi-Stage Flashing (MSF), (ii) Multi-Effect Distillation (MED), and (iii) the hybrid Multi-Effect Distillation and Thermal Vapour Compression (MED-TVC). The membrane desalination processes are: (i) Reverse Osmosis (RO) and (ii) Electro Dialysis (ED and EDR).

2.1.1 MSF Method

In the MSF process, seawater or 'feed', contained within finned tubes, is passed upstream through a series of 'cascading' stages. Each successive stage seen by the feed operates at a higher pressure and temperature than the previous one.

After passing through the 'first' or highest pressure stage, the feed is further heated by an external source of steam in the 'brine heater'. This heated feed then leaves the tubes to be introduced to the first stage. Here, a portion of the feed boils to be condensed on the outer surface of the tubes. In this manner, the feed is cascaded from stage to stage, with a portion of the feed boiling in each 'next' lower pressure stage. The steam which evolves is then condensed on the 'cold' surface of the tubes to be collected in a tray system as distilled water.

The first stage operates at a slightly elevated pressure relative to atmospheric pressure with a corresponding temperature in the range of 105 to 130°C. Water then passes from stage-to-stage as driven by gravity using differential operating levels between stages.

2.1.2 MED Method

In the MED process, in a typical arrangement, feed is only found on the outside of tubes. Feed is sprayed over the tubes with hot steam inside the tubes heating and boiling a portion of the feed. The steam inside the tubes is condensed and collected. The steam which evolves in each stage via boiling on the outside of the tubes is passed to the inside of the tubes on the next lower pressure effect. The hot steam in the first effect is generated by an external source of heat. The concentrated brine leaving the first effects is sent to the second effect maintained at slightly lower pressure than the previous effect. The process is repeated from effect to effect at successively lower pressures. The condensate is collected as product water [5].

2.1.3 RO Method

Reverse osmosis uses a series of specialized membranes to preferentially move water from stage to stage, leaving a concentrate to be bleed off without passing through the membrane. By standard chemistry, when two aqueous solutions of differing concentrations are separated by a semi-permeable membrane, water passes through the membrane in the direction of the more concentrated solution as a result of osmotic pressure. However, if enough counter pressure is applied to the concentrated solution to overcome the osmotic pressure, the flow of water will be reversed (giving rise to the description 'reverse' osmosis). To drive the water through the membranes requires differential pressure as supplied by a set of pumps.

Water molecules can form hydrogen bonds in the reverse osmosis membrane and fit into the membrane matrix. The water molecules that enter the membrane by hydrogen bonding can then be pushed through under pressure. Most organic sub-stances with a molecular weight over 100 are sieved out, (e.g., oils, and particulates including bacteria and viruses). The nominal rejection ratio of common ionic salts is 85–98% [6].

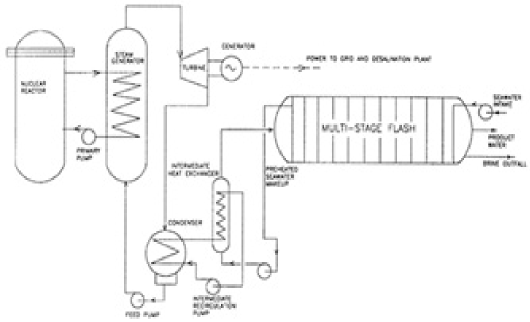
2.2 Desalination and Nuclear Power Reactor

While electricity is a fungible commodity with small losses associated with transmission, for best economy, to minimize losses, steam must be consumed near the source. The main benefit of coupling a desalination plant to an NPP is the availability of both electricity and steam to supply the MSF or MED process. Since steam produced by the Nuclear Steam Supply System (NSSS) has much higher energy than can be efficiently used by the thermal desalination processes, the coupling process involves steam extracted at lower pressures in the NPP turbine cycle.

An important aspect in selecting the cogeneration configuration is the final cost of power and water. Another important aspect is the method used to allocate various cost elements to power and water production [7].

Avoiding radionuclide contamination of the product water from the desalination plant is a key consideration. Despite very low levels of detectable radionuclides in secondary side water for the NPP, the standard approach considered for such a cogeneration project involves at least two mechanical barriers between reactor primary coolant loop and the desalination process. For the case of Pressurized Water Reactor (PWR) technology, the steam generator is counted as the first barrier.

Figure 3. facility shows an example of coupling between the MSF and the NPP, along with an intermediate heat exchanger (termed 'reboiler') as an additional isolation loop [1].



[Figure 3] Schematic diagram of a nuclear power reactor coupled to an MSF plant [1]

3. DEEP Software Tool

The potential benefits of using nuclear power to supply energy to desalination plants has led the International Atomic Energy Agency (IAEA) to develop and distribute freely the Desalination Economic Evaluation Program (DEEP). DEEP was originally derived from the desalination cost evaluation package developed in the eighties by General Atomics on behalf of the IAEA [8].

The DEEP software includes analysis and re-porting of the following [1]:

- Calculation of the levelized cost of electricity and desalted water as a function of quantity, site specific parameters, energy source, and desalination technology.
- Comparison of a large number of design alternatives on a consistent basis with common assumptions.
- Identification of the lowest cost options for providing specified quantities of desalted water and/or power at a given location.

DEEP has the capability to model nine (9) types of power plants (five (5) fossil plants, three (3) NPPs and one (1) renewable), and five (5) desalination technologies (two (2) thermal, one (1) electrical (RO) and two (2) hybrid)

<Table 1> Power and desalination plants in DEEP

Energy Source	
COAL	Steam Cycle — Coal (SSB)
OIL	OIL Steam Cycle — Oil
GT	GT Gas Turbine/HRSG
CC	CC Combined Cycle (Steam Turbine — Gas Turbine)
FH	FH Fossil Heat (Boiler)
RH	Renewable Heat
NSC	Nuclear Steam Turbine (PWR, PWHR, and SPWR)
NBC	Nuclear Gas Turbine (GTMHR)
NH	Nuclear Heat (HR)
Desalination	
MED	Multi Effect Distillation
MSF	Multi Stage Flash
RO	Reverse Osmosis
MED+RO	Hybrid: MED + RO
MSF+RO	Hybrid: MSF + RO

(see Table 1).

DEEP input variables are split into the following categories:

- User input data: Case specific input such as power and desalination plant capacity, discount rate, interest, fuel escalation, etc.,
- Technical parameters: Technology specific parameters such as efficiencies, temperature intervals etc. which depend only on the technology used, and
- Cost parameters: specific costs of various components (e.g. construction, fuel etc.), cost factors and other operational parameters (lifetime, availability, etc.).

3.1 DEEP economic model

DEEP output is presented in terms of cost per unit product ($/kWh for energy and $/m3 for water) broken down by cost components.

DEEP calculates the capital costs of the plant, by knowing the given plant capacity (plant type, electrical or thermal), and the estimated construction cost. These cost calculations consist of costs associated with engineering, procurement, and construction costs (EPC), owner, and contingency. Interest during construction is then calculated with an approximate formula. For the approximation, it is assumed that total construction costs are spent at mid-time of the construction period and that payments are equally apportioned throughout the construction period. Interest is then added to the total construction cost to obtain the total plant investment.

The capital recovery factor is calculated from the discount rate and the plant economic life. This fixed charge rate is multiplied by the total plant investment to obtain the annualized capital cost. In the case of NPP co-generation, plant decommissioning costs are added to the plant annualized capital cost [2].

4. Cost Breakdown in DEEP

DEEP apportions annual costs within the economic model for a single purpose power plant. Figure's 4 and 5 show the DEEP cost apportionment for a desalination plant. The default capital and operational economic parameters are specified along with their default values for each type of desalination technology per Table 2. Table 3 shows the power plant default model parameters [2].

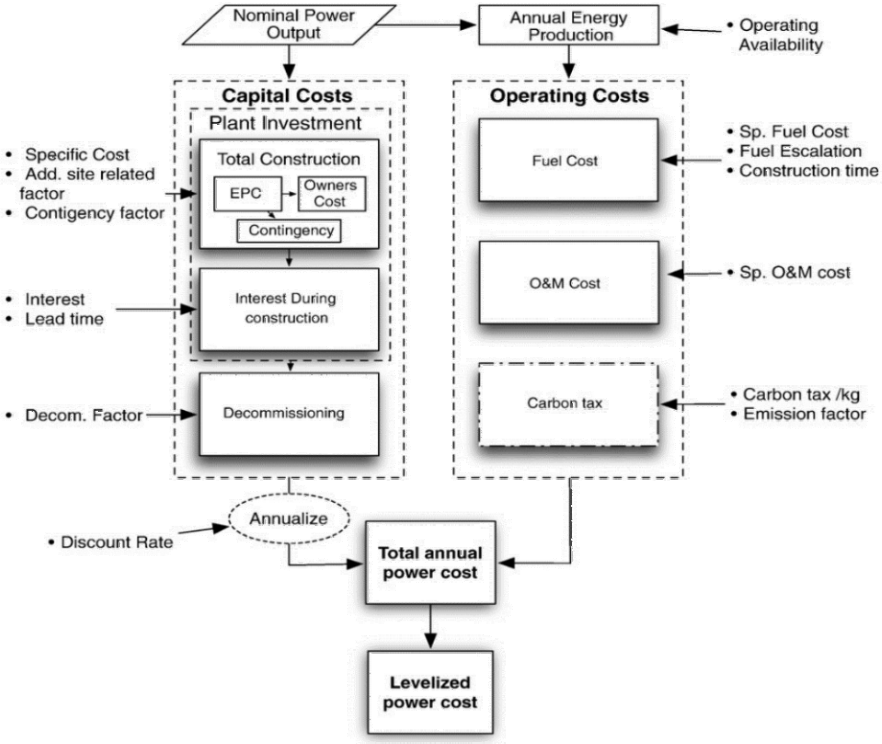
Economics of a single purpose nuclear or fossil fueled plant can be evaluated in DEEP using the well-known constant money levelized cost methodology. The levelized cost of energy is the dis-counted cost of all expenditures

<Table 2> Desalination plant default model parameters

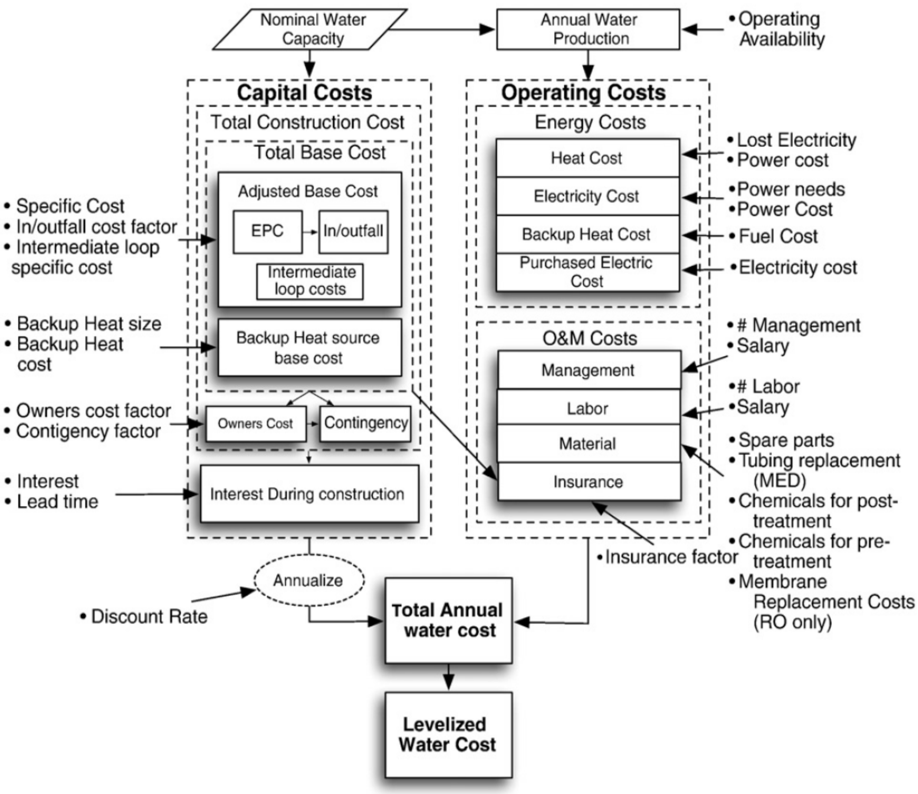
Desalination Plant Model		MED	MSF	RO
Operation	Units			
Water plant (WP) lead time	M	12	12	12
Lifetime of water plant	Yr.	20	20	20
Lifetime of backup heat	Yr.	20	20	
WP operating availability	%	90	90	90
Cost data				
Base unit cost	$/m^3/d	900	1000	900
Backup heat source	$/MW	55	55	–
Fossil fuel price for backup heat	$/bbl.	20	20	–
Purchased power cost	$/kWh	.06	.06	.06
Management salary	$/yr.	66	66	66
Labor salary	$/yr.	29	29.7	29.7
Specific O&M spare parts cost	$/m^3	.03	.03	.04
Tubing replacement cost (LT- MED)	$/m^3	.01	–	–
Specific O&M chemicals cost for pre-treatment	$/m^3	.03	.03	.03
Specific O&M chemicals cost for post-treatment	$/m^3	.02	.02	.01
O&M membrane replacement cost (RO)	$/m^3	–	–	.07
In/outfall sp. cost factor	%	7	10	7
Water plant owners cost factor	%	5	5	5
Water plant cost contingency factor	%	10	10	10
Water plant O&M insurance cost	%	0.5	0.5	0.5

<Table 3> Power plant default model parameters

Power Plant Model Parameters		Fossil					RH	Nuclear		
		OIL	COAL	FH	CC	GT		NH	NSC	NBC
Operation and performance Parameters	units									
Construction lead time	M	36	48	18	24	24	18	40	60	24
Lifetime of energy plant	Yr.	35	35	35	25	25	35	60	60	40
Operation Performance availability	%	85	85	85	85	85	85	90	90	90
Specific CO2 emissions	Kg/kWh	0.5	0.5	0.5	0.5	0.5	0	0	0	0
Cost parameters										
Specific construction cost	$/kW	1200	1300	50	700	700	50	200	1700	1500
Specific fuel cost	$/MWh	75.89	25.44	30.4	89.89	57	7.87	6	6	6
Primary fuel price	$/(bbl.)	50	75	50	50	50	30	–	–	–
Specific O&M cost	$/MWh	3.3	3.5	1	6.6	5.5	1	2	8.8	12
Carbon tax	$/t	20	20	20	20	20	0	0	0	0
Additional site construction cost factor	%	10	10	10	10	10	10	10	10	10
Energy plant contingency factor	%	0	0	0	0	0	0	0	0	0
NPP decommissioning cost factor	%	–	–	–	–	–	–	30	30	30



[Figure 4] Cost breakdown of power plant economic model [2]



[Figure 5] Cost breakdown of desalination plant economic model [2]

<Table 4> Input data for the desalination plants

Parameters	Units	MSF	MED	RO	MSF-RO	MED-RO
Water salinity	ppm	45000				
Feedwater temperature	℃	30				
Maximum Brine Temperature (Thermal)	℃	115	75	NA	115 (MSF)	75 (MED)
Maximum Brine Pressure	bar	NA	NA	69	69 (RO)	69 (RO)
Energy recovery efficiency (RO)	%	NA	NA	95	95 (RO)	95 (RO)
RO Percent Recovery	%	NA	NA	74	74 (RO)	74 (RO)
Water plant availability	%	90				
Product water salinity	ppm	25		199	75	75
Plant life time	years	30	20	20	20	20
Specific construction cost	$\$/m^3/day$	1000	900	900	1500	1500
Average management salary	$/year	66,000				
Average labor salary	$/year	30,000				

associated with the design, construction, operation, maintenance, and fuel cycle costs divided by the discounted values of the quantities of energy produced [9].

5. APR1400 coupled with various Desalination Plants

This study examines the economics of coupling different types of desalination plants (thermal, electrical, and hybrid) with the APR1400.

Specifically, circumstances specific to the KSA are considered based on government announce-ments indicating the intent to construct NPPs in the coming few years. In addition, the climate and site conditions for the Barakah Site, UAE, which have four (4) APR1400 units under-construction, are similar to those for the KSA.

The evaluation is done using DEEP 5.1 which gives the approximate cost of water and electricity. These parameters can be used for the comparison of different types of desalination technology.

As discussed earlier, results will include both cases with no applied interest or carrying costs, and cases which include these factors.

The technologies to be coupled to the energy source (i.e., the APR1400) include MSF, MED, RO, MSF-RO, and MED-RO.

Tables 4 and 5 list the input for the desal-ination plants and the APR1400, respectively. A desalination capacity of 350,000 m^3/day, is considered to be the suitable for the purpose of this study [10].

The data shown in this Table (Table 5) were based on references which are now considered

<Table 5> The Input data for APR1400 [11], [5]

Parameters	Units	APR1400
Net Electrical Power output	MWe	1450
Net thermal power input	MWth	4000
Efficiency	%	36.25
Plant Availability	%	91
Construction lead time	Months	48
Plant Life Time	Years	60
Specific Construction Cost	$/KWe	1556
Others, Construction Cost	$/KWe	155.6
Operation and maintenance	$/MWe	8.8
Nuclear Fuel Cost	$/MWe	6
Decommissioning Cost	$/KWe	233.4

to be historical. For new studies these data should be updated.

For desalination technologies, some important definitions are required as below:-

Salinity: The concentration of dissolved salts in water (ppm).

Total dissolved solids: (TDS) the weight per unit volume of all volatile and non-volatile solids dis-solved in a water or wastewater after a sample has been filtered to remove colloidal and suspended solids.

Top brine temperature: (TBT) The maximum temperature of the fluid being evaporated in an evaporator system.

RO Percent Recovery: The amount of water that is not sent to the drain as concentrate, but rather collected as permeate or product water. (%)

Gain output ratio: (GOR) measure of evaporator performance which represents the ratio of mass flow of distillate to steam input.

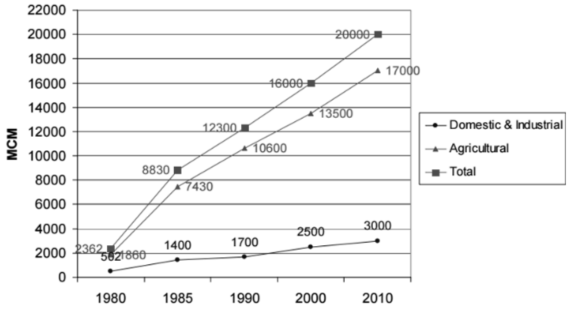
Latent heat: The heat required to cause a change of state at constant temperature, such as the vaporization of water, or the melting of ice.

Hybrid: A system incorporating multiple processes or technologies (e.g., a desalination facility incorporating both thermal and membrane processes).

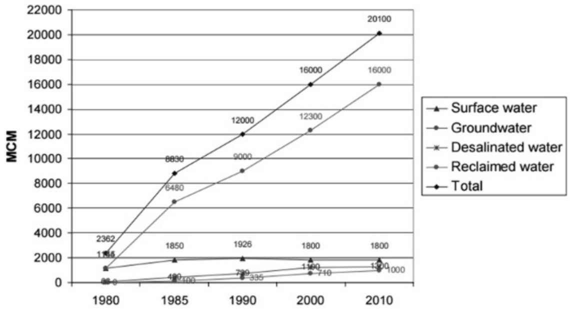
6. Water Supply & Demand, KSA

Fresh water resources in the KSA can be classified into four types: surface water, ground-water, desalinized water, and treated wastewater. Figure's 6 and 7 indicate the water demand and supply in the KSA, respectively.

From the data provided above, recent



[Figure 6] KSA water demands [12]



[Figure 7] KSA water supply [12]

contributions from desalination technology are in the range of 3~6% of total demand.

However, there are several challenges as-sociated with water demands. These include: (i) an increasing number of private and farming wells (26,000 in 1982, 85,000 in 1997), (ii) low water quality (high TDS levels), (iii) uncontrolled agricultural practices, and (iv) leakage from water supply systems (about 20% of water leaks from domestic water supply systems).

Water desalination technology has been em-ployed in the KSA since the 1970s. In order to meet current water demand, desalination plants produced 740x103 Mm3 of desalinated water in the year 2000 (Table 6) [3].

To minimize the gap between the demand and the supply of water in the KSA, future planning and construction of additional desal-ination capacity will have to be considered. In this paper, coupling of the APR1400 to de-

<Table 6> Quantity of water produced by desalination plants in KSA during 1990-2000 [3]

Year	Quantity in Mm^3	Year	Quantity in Mm^3	Year	Quantity in Mm^3
1990	635,178	1994	714,218	1998	733,780
1991	653,291	1995	715,605	1999	757,635
1992	673,103	1996	717,416	2000	740,475
1993	691,173	1997	735,485		

<Table 7> Water transportation input data

Parameters	unit	data	Parameters	unit	data
Pipeline length	km	30	Pipeline cost	M$/km	0.7
Pumping	MWe	1	investment	M$	0
lifetime	years	25	O&M Cost	%	7
Construction	Mont-hrs	60	Materials annual cost	M$/year	0

salination plants is examined as one of the best solutions to fill the gap between projected KSA water demands and supplies.

7. Results and Analysis

To investigate the best and most economical desalination technology coupled with the APR1400 based on KSA conditions, the DEEP 5.1 computer code was used with Table 4 and 5 data providing input. Results are based on a capacity of 350,000 m^3/day.

Results are based on two scenarios. The first assumes the water utility is under direct government control. In this case the interest and dis-count rate are set to zero.

The second scenario will assume that the water utility is controlled by a private enterprise. In this case different values of interest and discount rates are considered (4%, 8%, and 12%).

Output data from DEEP includes: (i) the specific construction cost, (ii) power plant total construction cost, (iii) power plant interest during construction, (iv) total power plant investment, (v) levelized electricity cost, (vi) total installed water plant capacity, (vii) interest during construction, (viii) total investment cost, (ix) specific investment cost, (x) GOR ratio, (xi) net saleable power, (xii) average daily water production, and (xiii) water cost.

Water cost is selected as the parameter for the evaluation of the best and cheapest desalination plant to be coupled with APR1400 based on KSA conditions.

Comparisons are based on the water cost be-tween different desalination technologies with zero interest and discount rates (Scenario No.1) and with a range of applied interest and discount rates (Scenario No.2). Transportation cost data is assigned per input data shown in Table 7.

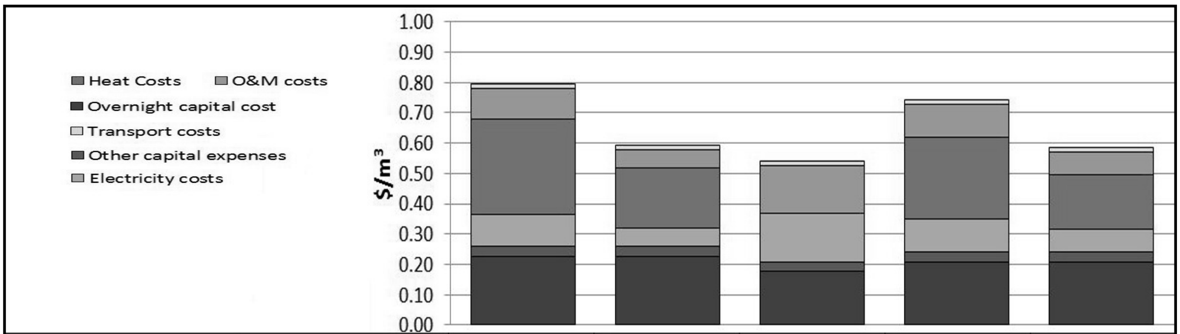
Results are presented in Tables 8 and 9, respectively.

Table 8 and Figure 8 indicate the most economical coupling of the APR1400 to desalination technology is for the RO and MED-RO processes.

It is noted here that for RO, the output water salinity is higher than considered to be suitable

<Table 8> 1st Scenario, comparison based on water cost $/$m^3$

Scenario1	MSF	MED	RO	MSF-RO	MED-RO
0% interest & discount rates	.804	.592	.550	0.742	0.583



		MSF	MED	RO	MSF-RO	MED-RO
Levelized Capital Costs	$/m3	0.26	0.26	0.21	0.24	0.24
Base plant overnight EPC	$/m3	0.23	0.23	0.18	0.21	0.21
Other	$/m3	0.04	0.04	0.03	0.03	0.03
Levelized operating costs	$/m3	0.54	0.33	0.34	0.50	0.34
Heat	$/m3	0.32	0.20	0.00	0.27	0.12
Electricity	$/m3	0.10	0.06	0.16	0.11	0.07
O&M	$/m3	0.11	0.11	0.20	0.14	0.14
Transport	$/m3	0.01	0.01	0.01	0.01	0.01
Lifecycle Emissions	Mtn/yr	224	224	246	246	246
Thermal Utilization		44%	43%	26%	41%	43%
Power lost	MWe	142	66	0	114	55
Power used for desalination	MWe	43	24	49	44	29
Power cost	$/MWh	32.5	32.5	32.1	32.1	32.1
Inputs Summary						
Power Plant Type		APR-1400	APR-1400	APR-1400	APR-1400	APR-1400
Fuel		Nuclear	Nuclear	Nuclear	Nuclear	Nuclear
Reference thermal output	MWth	4000	4000	4000	4000	4000
Reference electricity output	Mwe	1450	1450	1450	1450	1450
Desalination Type		MSF	RO	RO	MSF RO	MED RO
Total Capacity	m3/d	350000	350000	350000	350000	350000
Feed Salinity	ppm	35000	35000	35000	35000	35000
Combined Availability		81%	81%	81%	81%	81%

[Figure 8] KSA water demands [12]

〈Table 9〉 2nd Scenario, comparison based on water cost $/m^3$

Scenario2	MSF	MED	RO	MSF-RO	MED-RO
4% interest & discount	1.04	0.79	0.67	0.93	0.75
8% interest & discount	1.40	1.08	0.83	1.235	1.001
12% interest & discount	1.88	1.45	1.04	1.63	1.322

for potable water. While commonly acceptable for agriculture, the pure RO process should be combined with thermal process to 'blend' a portion of the product stream to produce potable water [Table 4].

Also, blending distillate (MED) and membrane permeate (RO) will reduce the requirements on boron removal by RO. Secondly, there are many advantages of hybrid MED with RO such as:

- RO reject and feed can be used as a cooling source for the heat rejection section of the MED.
- Blending the RO reject stream with warm seawater and blowdown from the MED or power plant (APR1400) reduces the heavy density plume from the RO outfall.
- Blending of the RO permeate reduces the temperature of distillate, and
- A smaller seawater intake and outfall can be employed for the combined process.

Finally, based on the simplified results from Scenarios Nos. 1 and 2, and the benefits citied above for the hybrid system, consideration of the hybrid desalination plant MED-RO coupled with APR1400 appears to have many advantages with-out a significant cost penalty.

Table 10 and Figure 9 provide additional details for the economic evaluation of coupling APR1400 with MED-RO desalination plant based on Scenario No. 1. Figure 10 illustrates the economic evaluation of co-generation using the APR1400 with MED-

<Table 10> Economic Evolution, MED-RO, Scenario #1

Capital Costs of Desalination Plant				
	MED	RO	Total	Share
Construction Cost	301	104	405	75%
Intermediate Loop	41	–	41	8%
Backup heat	–	–	–	0%
Infall / Outfall Cost	–	–	27	5%
Water plant Owners	17	5	22	4%
Water plant contingency	36	11	47	9%
Interest in Construction	–	–	–	0%
Annualized Capital Costs				
Sp. Annualized Cap Costs			0.24 $/m^3	
Operating Costs of Desalination Plant				
	MED	RO	Total	Share
Total Energy Cost	14	4	20	59%
Operation and Maintenance Costs				
Management Cost	–	–	0.33	1%
Labour Cost	–	–	1.13	3%
Material Cost	5.3	5.13	10.4	30%
Insurance Cost	2.0	0.60	2.6	7%
O&M cost	7	6	14	41%
Total Operating Cost	24	10	35	
Total Annual Costs			60.62M$	
Water Production Cost			0.569 $/m^3	
Water transport costs			0.014 $/m^3	
TOTAL WATER COST			0.583 $/m^3	

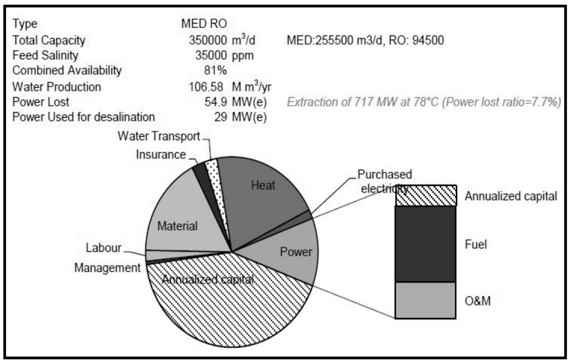
RO based on Scenario No.

8. Conclusion

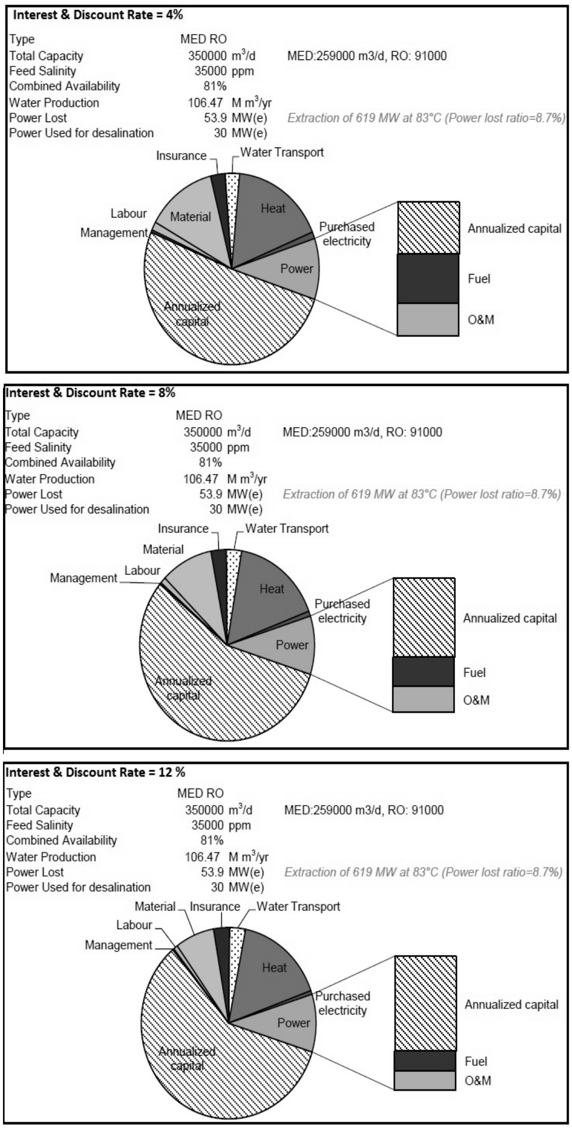
Current desalination technologies and economic evaluations of coupling the APR1400 with a desalination plant based on KSA conditions are presented in this paper.

The DEEP 5.1 computer code was used to compare the costs of various desalination technologies to be coupled with the APR1400.

As the current KSA practice is to construct



[Figure 9] Economic Evaluation, MED-RO, Scenario number 1



[Figure 10] Economic Evaluation, MED-RO, Scenario number 2 (4%, 8%, and 12%) interest and discount rate and operate desalination plants with an assignment of zero interest and discount rates, the evaluation here is divided into two scenarios. In the first the water utility is under direct government control and in this case the interest and discount rate will be zero. The second scenario will assume that the water utility is controlled by a private enterprise and in this case we will con-sider a range of values of interest and discount rates (4%, 8% & 12%).

Based on the analysis of Scenarios Nos. 1 and 2, and the benefits of hybrid system, results here indicate that hybrid desalination technology using MED-RO to be coupled with APR1400 appears to be attractive.

Since: (i) cost inputs are highly variable and local labor rates are highly dependent on the use of foreign workers, and (ii) the product quality is highly dependent on the end users (e.g., potable water needed?), this study primarily provides the methodology for the economics of the coupling.

Specific studies would employ a similar ap-proach using more recent and proprietary data and may likely show the same result, that hybrid technology is economically attractive.

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