COMPUTER MANUAL SERIES No. 19

Desalination Economic Evaluation Program (DEEP-3.0)

User's Manual

IAEA
International Atomic Energy Agency

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FOREWORD

DEEP is a Desalination Economic Evaluation Program developed by the International Atomic Energy Agency (IAEA) and made freely available for download, under a license agreement (www.iaea.org/nucleardesalination). The program is based on linked Microsoft Excel spreadsheets and can be useful for evaluating desalination strategies by calculating estimates of technical performance and costs for various alternative energy and desalination technology configurations. Desalination technology options modeled, include multi-stage flashing (MSF), multi-effect distillation (MED), reverse osmosis (RO) and hybrid options (RO-MSF, RO-MED) while energy source options include nuclear, fossil, renewables and grid electricity (stand-alone RO) .

Version 3 of DEEP (DEEP 3.0) features important changes from previous versions, including upgrades in thermal and membrane performance and costing models, the coupling configuration matrix and the user interface. Changes in the thermal performance model include a revision of the gain output ratio (GOR) calculation and its generalization to include thermal vapour compression effects. Since energy costs continue to represent an important fraction of seawater desalination costs, the lost shaft work model has been generalized to properly account for both backpressure and extraction systems. For RO systems, changes include improved modeling of system recovery, feed pressure and permeate salinity, taking into account temperature, feed salinity and fouling correction factors. The upgrade to the coupling technology configuration matrix includes a re-categorization of the energy sources to follow turbine design (steam vs. gas) and co-generation features (dual-purpose vs. heat-only). In addition, cost data has also been updated to reflect current practice and the user interface has been refurbished and made user-friendlier.

The IAEA officers responsible for this publication were M. Methnani and B. Misra of the Division of Nuclear Power.

EDITORIAL NOTE

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1. INTRODUCTION

Desalination is known to be an energy intensive process, requiring mainly low-temperature steam for distillation and high-pressure pumping power for membrane systems. Traditionally, fossil fuels such as oil and gas have been the major energy sources. However, fuel price hikes and volatility as well as concerns about long-term supplies and environmental release is prompting consideration of alternative energy sources for sewater desalination, such as nuclear desalination [1] and the use of renewable energy sources[2]. If we add to this the fact that the coupling methods between power and desalination units can also vary, the need for a performance and cost analysis tool to assist in design selection and optimization becomes clear.

The Desalination Economic Evaluation Program (DEEP) is a spreadsheet tool originally developed for the IAEA by General Atomics[3] and later expanded in scope by the IAEA, in what came to be known as the DEEP-2 version [4]. Recently, the models have been thoroughly reviewed and upgraded and a new version, DEEP-3.0, has been released[5]. The program allows designers and decision makers to compare performance and cost estimates of various desalination and power configurations. Desalination options modeled include MSF, MED, RO and hybrid systems while power options include nuclear, fossil and renewable sources. Both co-generation of electricity and water as well as water-only plants can be modeled. The program also enables a side-by-side comparison of a number of design alternatives, which helps identify the lowest cost options for water and power production at a specific location. Data needed include the desired configuration, power and water capacities as well as values for the various basic performance and costing data.

2. DESALINATION PROCESSES

Desalination systems fall into two main design categories, namely thermal and membrane types [6]. Thermal designs including multi-stage flash (MSF) and Multi-effect distillation (MED), use flashing and evaporation to produce potable water while membrane designs use the method of Reverse Osmosis (RO), shown in Fig. 1. With continuing improvements in membrane performance, RO technology is increasingly gaining markets in seawater desalination and hybrid configurations, combining RO with MED or RO with MSF have also been considered (Fig. 2.).

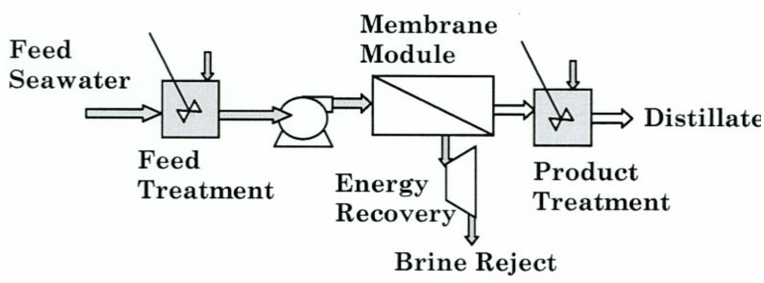

Fig. 1. Sketch of RO layout.

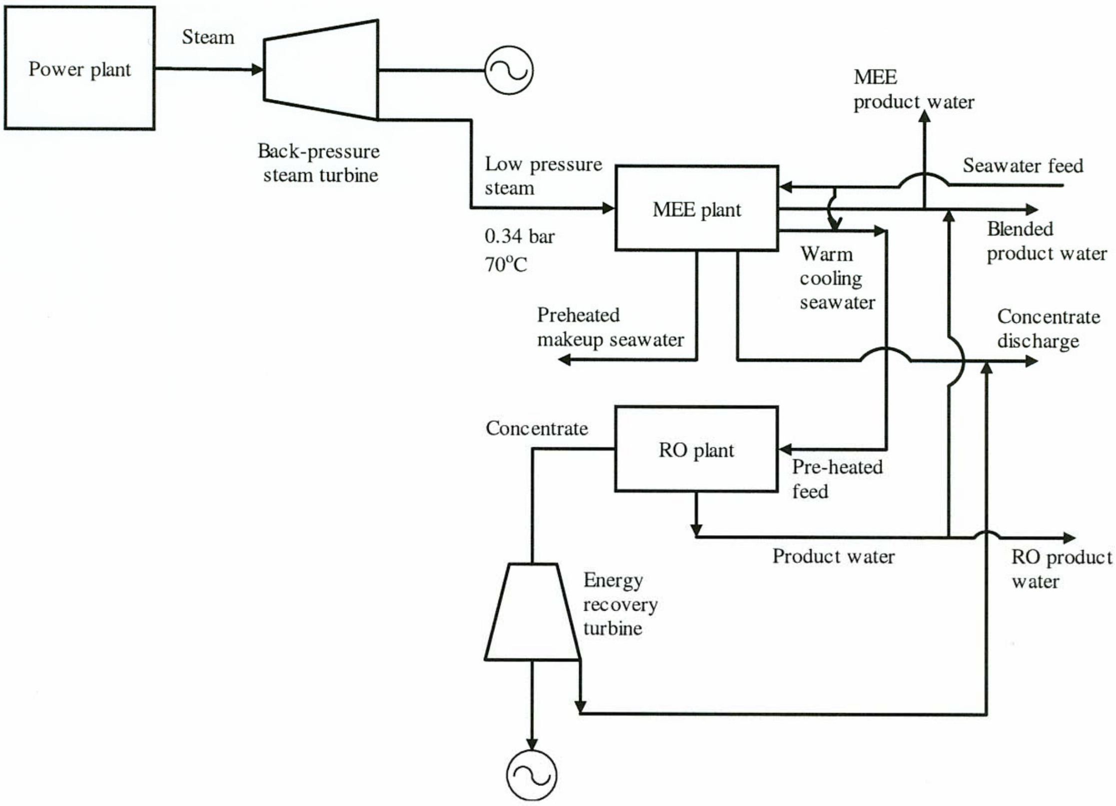

Fig. 2. Sketch of hybrid MED-RO layout.

2.1. Multi stage flash (MSF) distillation

Figure 2 shows the schematic flow diagram of an MSF system. Seawater feed passes through tubes in each evaporation stage where it is progressively heated. Final seawater heating occurs in the brine heater by the heat source. Subsequently, the heated brine flows through nozzles into the first stage, which is maintained at a pressure slightly lower than the saturation pressure of the incoming stream. As a result, a small fraction of the brine flashes forming pure steam. The heat to flash the vapour comes from cooling of the remaining brine flow, which lowers the brine temperature. Subsequently, the produced vapour passes through a mesh demister in the upper chamber of the evaporation stage where it condenses on the outside of the condensing brine tubes and is collected in a distillate tray. The heat transferred by the condensation warms the incoming seawater feed as it passes through that stage. The remaining brine passes successively through all the stages at progressively lower pressures, where the process is repeated. The hot distillate flows as well from stage to stage and cools itself by flashing a portion into steam which is re-condensed on the outside of the tube bundles.

MSF plants need pre-treatment of the seawater to avoid scaling by adding acid or advanced scale-inhibiting chemicals. If low cost materials are used for construction of the evaporators, a separate deaerator is to be installed. The vent gases from the deaeration together with any non-condensable gases released during the flashing process are removed by steam-jet ejectors and discharged to the atmosphere.

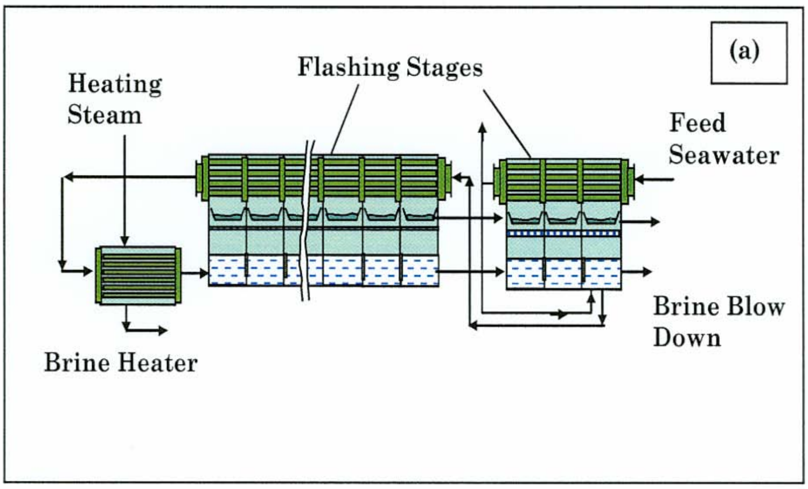

Fig. 3. Sketch of MSF layout.

2.2. Multiple effect distillation (MED)

Figure 3 shows the schematic flow diagram of MED process using horizontal tube evaporators. In each effect, heat is transferred from the condensing water vapour on one side of the tube bundles to the evaporating brine on the other side of the tubes. This process is repeated successively in each of the effects at progressively lower pressure and temperature, driven by the water vapour from the preceding effect. In the last effect at the lowest pressure and temperature the water vapour condenses in the heat rejection heat exchanger, which is cooled by incoming seawater. The condensed distillate is collected from each effect. Some of the heat in the distillate may be recovered by flash evaporation to a lower pressure. As a heat source, low pressure saturated steam is used, which is supplied by steam boilers or dual-purpose plants (co-generation of electricity and steam).

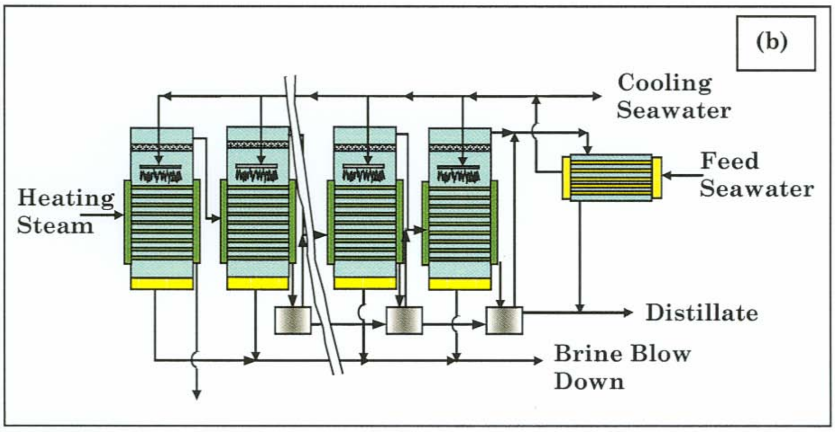

Fig. 4. Sketch of MED layout.

Currently, MED processes with the highest technical and economic potential are the low temperature horizontal tube multi-effect process (LT-HTME) and the vertical tube evaporation process (VTE).

In LT-HTME plants, evaporation tubes are arranged horizontally and evaporation occurs by spraying the brine over the outside of the horizontal tubes creating a thin film from which steam evaporates. In VTE plants, evaporation takes place inside vertical tubes.

2.3. MED plants with vapour compression (VC)

In some MED designs, a part of the vapour produced in the last effect is compressed to a higher temperature level so that the energy efficiency of the MED plant can be improved (vapour compression). To compress the vapour, either mechanical or thermal compressors are used.

2.4. Reverse osmosis (RO)

Reverse osmosis is a membrane separation process in which pure water is "forced" out of a concentrated saline solution by flowing through a membrane at a high static transmembrane pressure difference. This pressure difference must be higher than the osmotic pressure between the solution and the pure water. The saline feed is pumped into a closed vessel where it is pressurised against the membrane. As a portion of the water passes through the membrane, the salt content in the remaining brine increases. At the same time, a portion of this brine is discharged without passing through the membrane.

RO membranes are made in a variety of modular configurations. Two of the commercially successful configurations are spiral-wound modules and hollow fibre modules. The membrane performance of RO modules such as salt rejection, permeate product flow and membrane compaction resistance were improved tremendously in the last years. The DEEP performance models cover both the effect of seawater salinity and the effect of seawater temperature on recovery ratio and required feedwater pressure.

A key criterion for the RO layout is the specific electricity consumption, which should be as low as possible. That means, the recovery ratio has to be kept as high as possible and the accompanying feedwater pressure as low as possible fulfilling the drinking water standards as well as the design guidelines of the manufactures. Since the overall recovery ratios of current seawater RO plants are only 30 to 50%, and since the pressure of the discharge brine is only slightly less than the feed stream pressure, all large-scale seawater RO plants as well as many smaller plants are equipped with energy recovery turbines.

3. DEEP-3.0 PROGRAM CHANGES

Version three features important changes from previous versions, including upgrades in thermal and membrane performance and costing models, the coupling configuration matrix and the user interface, as well as a thorough review of the configuration templates.

- The thermal model upgrade includes:

    1. A generalization of the lost shaft work to model both extraction and backpressure coupling configurations.

    2. Improvements in the distillation thermal balance model and Gain Output Ratio (GOR) calculation.

    3. Adding a new Thermal Vapor Compression (TVC) option.

- The RO model, upgrade includes:

    1. New and validated correlations for feed pressure and permeate salinity, accounting for the effects of feed salinity, temperature and fouling.

    2. A new correlation for recovery ratio estimates.

- The coupling configuration upgrade includes a re-categorization of the energy sources to follow current practice. The coupling scheme selection follows turbine design (steam vs. gas) and co-generation features (dual-purpose vs. heat-only). The energy source categorization includes nuclear, fossil and renewable options, with the latter being a new addition.

4. DEEP-3.0 MODEL DESCRIPTION

A flow chart for the overall programme layout is shown in Fig. 5.

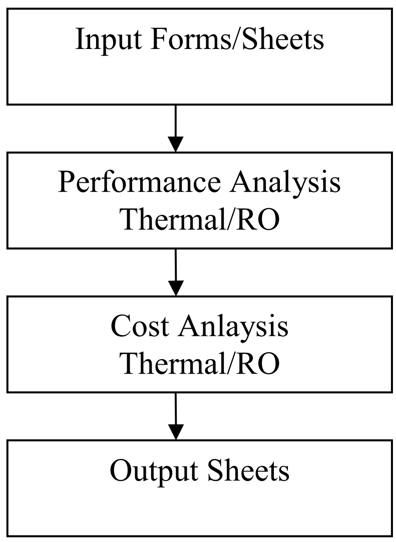

Fig. 5. General DEEP program layout.

This section gives a brief overview of the models, including the thermal and RO performance models as well as the costing model.

4.1. Thermal performance model

The flow chart for this model is shown in Fig. 6.

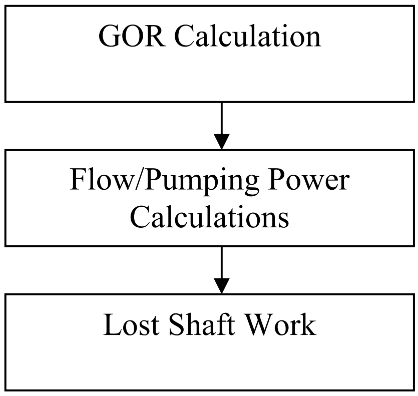

Fig. 6. Flowchart for thermal performance model.

GOR Model

In the DEEP-3.0 model, the user has the choice of specifying the GOR as a design parameter or letting the program calculate an estimate.

For MSF systems, the GOR is calculated as follows:

$$\mathbf{GOR = \lambda_h / c_h / (dT_{bh} + dT_{bpe}) * (1 - exp(-c_{vm} * dT_{ao} / \lambda_m)} \quad \mathbf{(1)}$$

And for MED systems, the GOR is calculated as follows:

$$\mathbf{GOR = \lambda_h / (\lambda_m * dT_{ae} / dT_{do} + c_h * (dT_{ph} + dT_{bpe}))} \quad \mathbf{(2)}$$

Where

λ_h = latent heat of heating vapour, kJ/kg
λ_m = average latent heat of water vapour in MSF stages, kJ/kg
T_{mb} maximum brine temperature, °C
T_{sw} seawater temperature, °C
DT_{dls} brine to seawater temperature difference in last stage, °C
c_h = specific heat capacity of feedwater in brine heater, kJ/kg/K
c_{vm} = average specific heat capacity of brine in MSF plant, kJ/kg/K
dT_{ao} = overall working temperature range, °C
dT_{ae} average temperature drop per effect, °C
dT_{bh} brine heater feed temperature gain for MSF, °C
dt_{bpe} boiling point elevation, °C
dT_{ph} Preheating feed temperature gain, °C

For the case of thermal vapor compression units coupled to MED or MSF systems, the GOR model is generalized as follows:

$$\mathbf{GOR_{tvc} = GOR(1+R_{tvc})} \quad \mathbf{(3)}$$

Where R_{tvc} is defined as the ratio of entrained vapour flow to motive steam flow, an input design parameter.

The top brine temperature $\mathbf{T_{mb}}$ is also retained as a design parameter and as such, can be input by the user or alternatively, calculated given an input steam temperature.

Given as input the salt concentration factor CF, the cooling seawater temperature gain ΔT_c and the product water flow rateW_p, estimates for reject brine flow W_b , make-up feed flow W_f and condenser cooling water flow W_c, could also be calculated as follows,

$$\mathbf{W_b = W_p / (CF-1)} \quad (4)$$
$$\mathbf{W_f = CF.W_b} \quad (5)$$
$$\mathbf{W_c = Q_c / (c_c \Delta T_c)} \quad (6)$$

Where Q_c refers to the net condenser heat load and $\mathbf{c_c}$ refers to the specific heat capacity of cooling water.

While specific heat transfer areas could also be calculated in DEEP in a straightforward manner, the current approach, where user input is expected for specific capital costs ($/m^3/d), is considered adequate for the purposes of DEEP and is therefore retained.

Lost Shaft Work Model

In DEEP-3.0, the lost shaft work is calculated as follows (except for the heat-only case, where it is set to zero, as follows:

For the backpressure case,

$$\mathbf{Q_{ls} = (Q_{st} /(1-\eta)).\eta} \quad (7)$$

With $\mathbf{Q_{st} = Q_{cr}}$
Where Q_{cr} refers to the condenser heat load,

$$\mathbf{\eta = \eta_{lpt} .(T_{cm}-T_c)/(T_{cm} + 273)} \quad (8)$$

η_{lpt} refers to low pressure turbine isentropic efficiency, and
T_c and T_{cm} refer to the condenser reference and modified temperatures in °C.

For the extraction case,

$$\mathbf{Q_{ls} = Q_{st}.\eta} \quad (9)$$

With $\mathbf{Q_{st} = W_{st}.h_{fg}}$

Where $\mathbf{h_{fg}}$ is the steam latent heat, assuming saturation conditions.

and η is redefined as,

$$\mathbf{\eta = \eta_{lpt} .(T_{st}-T_c)/(T_{st} + 273)} \quad (10)$$

Where $T_{st} = T_{extracted\ steam}$ in °C

Note that the cases involving available waste heat, such as gas cooled reactors correspond to a backpressure configuration with

$$\mathbf{T_{cm} = T_c}$$

And

$$\mathbf{Q_{ls} = 0}$$

Which implies free available heat and no lost shaft work.
For the backup pressure cases, the heating steam is limited by the heat exchanger or condenser load. For extraction cases, it is limited by the available heat source. The following expression is used:

$$\mathbf{Q_{st} < (Q_t - Q_e)/(1-\eta)} \qquad \mathbf{(11)}$$

Where Q_t refers to the available thermal power and Q_e refers to the produced electric power.

4.2. RO performance model

The flow chart for the Reverse Osmosis (RO) model is shown in Fig. 7:

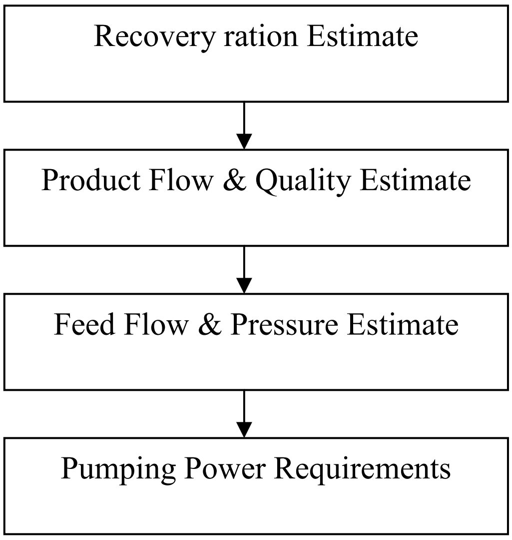

Fig. 7. Flowchart for RO performance model.

Here, again, the user can either specify the system recovery ratio, or have it estimated by DEEP, as follows:

$$\mathbf{R = 1 - CNS \, . \, S_f} \qquad \mathbf{(12)}$$

Where
S_f refers to the feed salinity in ppm and C is a constant defined as

$$\mathbf{CNS = 1.15E\text{-}3/P_{max}} \qquad \mathbf{(13)}$$

P_{max} refers to the maximum design pressure of the membrane in bars.

Note that as feed salinity becomes small, the recovery ratio approaches unity and as it approaches the numerical equivalent of maximum membrane pressure (in millibars), recovery goes to zero, as would be expected in practice.

For permeate salinity and feed pressure, we use the expressions given by Wilf [7], which take into account feed temperature and salinity correction factors and have been verified against commercial design data.

Feed pressure $\mathbf{P_f}$ is calculated as follows:

$$\mathbf{P_f = \Delta p_d + P_{osm} + \Delta p_l} \tag{14}$$

Where

$$\mathbf{\Delta p_d = \varphi_d / \varphi_n . \Delta p_n . c_t . c_s . c_f} \tag{15}$$

And

$\mathbf{P_{osm}}$ is the average osmotic pressure across the system;
$\mathbf{\Delta p_l}$ is the corresponding pressure loss;
$\mathbf{\Delta p_d}$ and $\mathbf{\varphi_d}$ are the design net driving pressure and flux;
$\mathbf{\Delta p_n}$ and $\mathbf{\varphi_n}$ are the nominal net driving pressure and flux; and
$\mathbf{c_t}$, $\mathbf{c_s}$ **and** $\mathbf{c_f}$ are correction factors related to temperature, salinity and fouling.

Permeate salinity $\mathbf{S_p}$ on the other hand, is calculated as follows:

$$\mathbf{S_p = (1-r_m). S_f. \varphi_n / \varphi_d. c'_r. c'_t} \tag{16}$$

Where

$\mathbf{S_f}$ refers to feed salinity; and
$\mathbf{c'_r}$ and $\mathbf{c'_t}$ are correction factors related to recovery and temperature.
$\mathbf{r_m}$ refers to the membrane salt reject fraction.

For the calculation of energy recovery Q_{er}, given the energy recovery efficiency ξ_{er} , both Pelton-type and work exchanger designs are modeled as follows:

For the Pelton design,

$$\mathbf{Q_{er} = (1-r_m) . \xi_{er} Q_{hp}} \tag{17}$$

Where Q_{hp} refers to the available high pumping power, adjusted for system losses.

4.3. Hybrid performance model

Hybrid methods refer to the use of a combined configuration, usually an RO + MED or an RO + MSF configuration. These configurations have been designed with an eye on improving product water quality and operational flexibility [8] and DEEP allows their simulation, through a combination of the thermal and RO models described above.

4.4. Cost model

Cost calculations in DEEP are done for both power and water plants and are case-sepcific. Capital costs as well as fuel, operation and maintenance and other costs are taken into consideration. Water capacity scaling is taken into account in cost calculations if specified by the user.

DEEP uses the power credit method [9] to estimate the value of steam in co-generation systems. The essence of this method is that the cost of the low-pressure steam $\mathbf{C_{st}}$ per unit volume of produced water is determined by the lost value of the additional electric power $\mathbf{\Delta Q_e}$, (KWh), which could have been produced instead. This is sometimes alternatively referred to as the lost shaft work.

$$\mathbf{C_{st} = C_e \cdot \Delta Q_e / W_p} \qquad \mathbf{(18)}$$

Where $\mathbf{C_e}$ is the base electricity cost per KWh and W_p is the volumetric water production rate per hour. While there are other methods available, for high power-to-water ratios, the power credit method is considered adequate.

5. DEEP-3.0 PROGRAM INSTRUCTIONS

The DEEP programme structure is based on the linking of macro-enabled Excel spreadsheets. The linking procedure enables the separation of the calculation and presentation parts of the software.

Performance and cost estimates of co-generated electricity and water, or alternatively, water for water-only plants, are calculated by the programme engine, DEEP.xls and saved in separate case files under the “User Files/Cases” subfolder. In the process, the programme makes use of pre-composed configuration templates (subfolder templates). DEEP also includes features allowing a comparative result presentation of up to nine pre-run cases and results are saved under the “User Files/CPs” subfolder.

5.1. Installing DEEP

The installation of DEEP has been tested under Windows 2000 and Windows XP. A minimum free disk size of of 11 Mbytes is needed, including about 3 MB for the executable file “DEEP3.xls” and 7 MB for the template folder. The user should make sure that the DEEP3 folder is not write-protected and that the Excel security level is not set to “high”, in order to enable macros.

5.2. Running a DEEP case

The programme is executed by double-clicking on the DEEP3.xls icon in the root folder. At startup, the user is prompted to enable macros and is presented with the main program window. Options available to the user include the following options:

New case

This option is selected to start a new case. A Case Input Form is presented for input of the main case parameters.

View case

This option is selected to load an existing case file.

Edit input data

This option is selected to edit input for an active case. All data can be edited, with the exception of the configuration options, which can only be changed from the Case Input Form. Double-clicking on any cell marked in green, allows the user to modify its content.

Show case results

This option is selected to show results for an active case. The output summary includes main case parameters and configuration options as well as performance and cost results. It can be printed on a single sheet.

New/edit CP

This option is selected to start a new Comparative Presentation (CP) case, for side-to-side comparison of existing cases. The user may be prompted to update reference links to the "CPnull" template located in the DEEP-3.0 root directory and is then prompted to specify the name of the CP save file and to select the cases to be compared.

View CP

This option is selected to load an existing CP presentation file.

Show CP results

This option is selected to show contents of an active CP presentation.

View directories

This option is selected to view the DEEP-3.0 directory structure.

5.3. Case input form

The flowchart for input data is shown in Fig. 8.

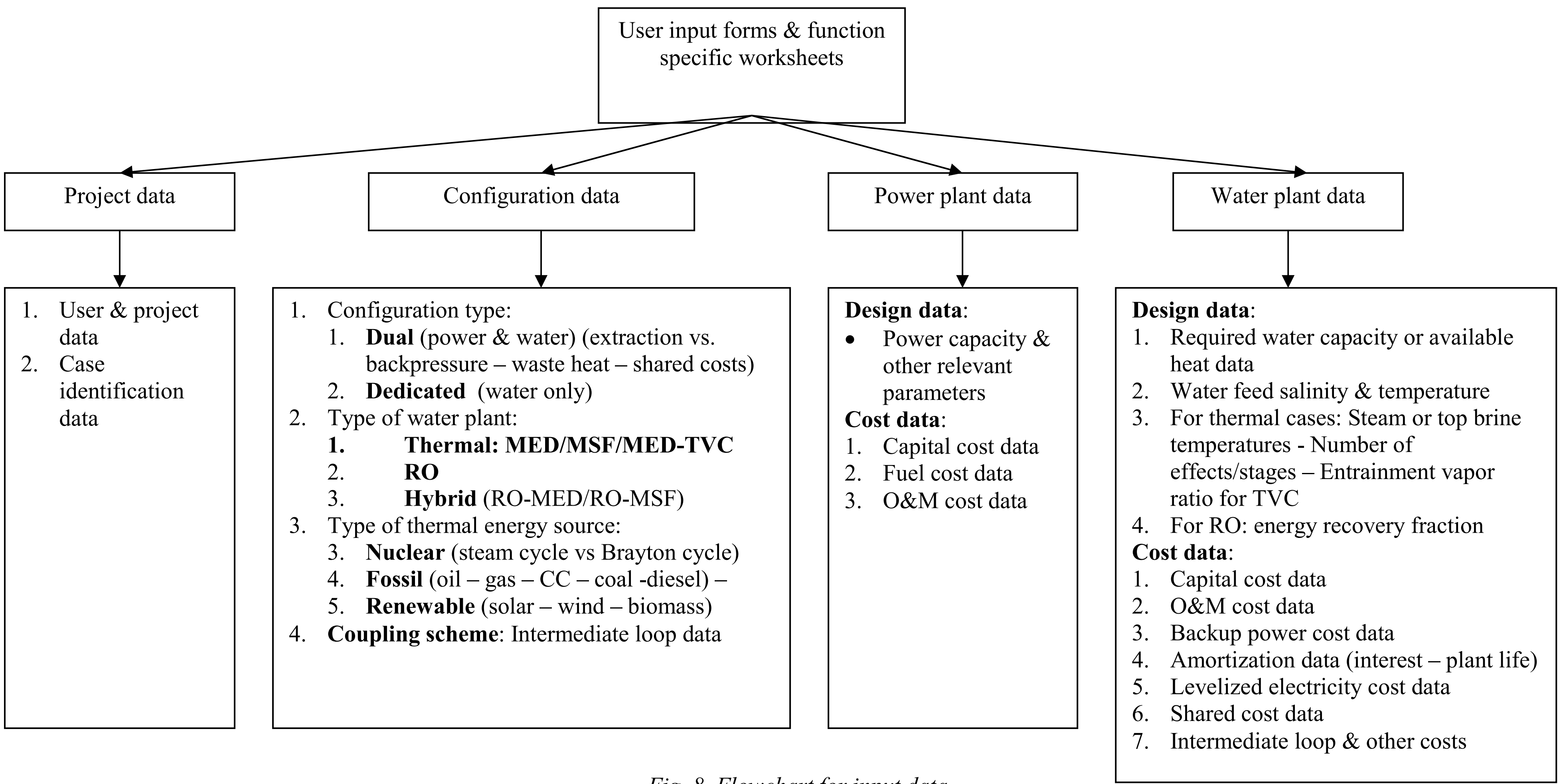

Fig. 8. Flowchart for input data.

When starting a new case, the user is presented with a Case Input form, to allow data entry, as shown in Fig. 9.

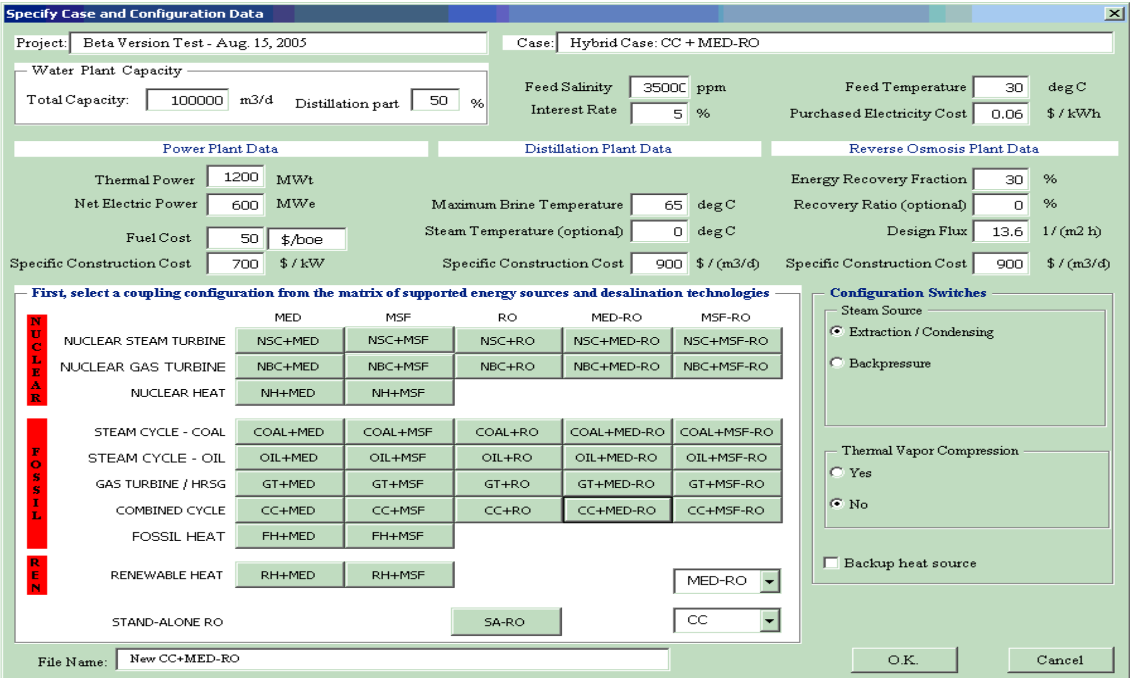

Fig. 9. View of case input form.

The user is expected to first select the desired coupling configuration from the matrix of supported energy and desalination coupling options and also specify the name of the case save file. Default values for the main parameters are then presented to the user, who can edit them, as approprate for the case. Because error checking in DEEP is minimal, the user is cautioned to check the accuracy of the input data entered. Upon selecting the OK button, spreadsheet calculations are automatically performed and the user could then look at the case results. Upon closing the output sheet, the user can then further edit the input and run a follow up case, if desired. The user has then the possibility of setting up a comparative presentation (CP), to compare main cost results from two or more cases, as explained above. An example of a CP comparison sheet view is shown in Fig. 10.

When quitting the program, the user should make use of the exit button, and in any case, is cautioned against saving the executable file DEEP3.xls, which may cause problems. All user data are designed to be stored in the case files and not in the executable file. It is also adviasable to keep a backup copy of the executable file DEEP3.xls, just in case the original is unintentionally corrupted.

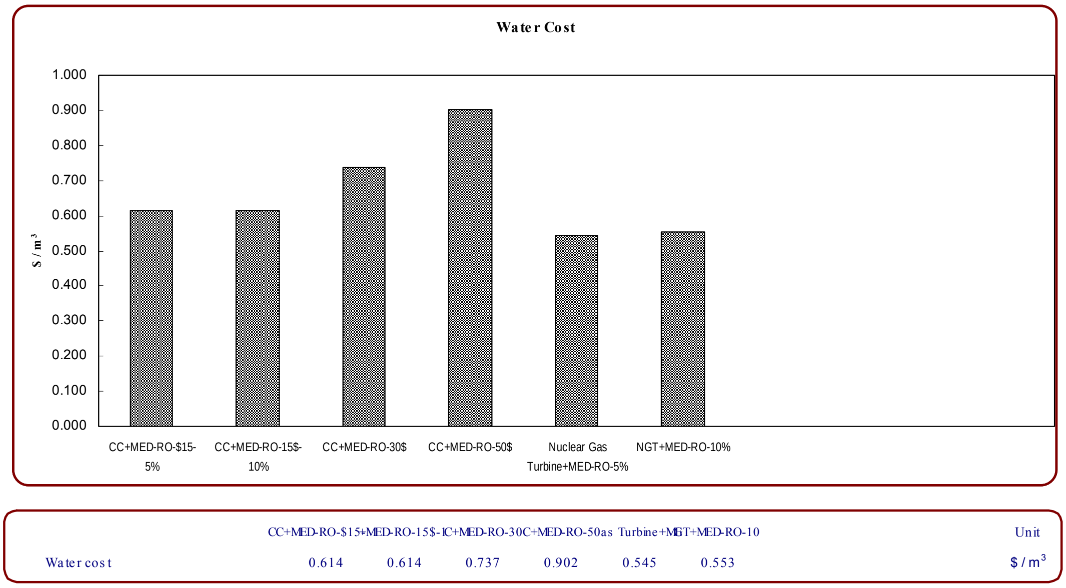

Fig. 10. View of a comparative DEEP-3.0 presentation.

6. DEEP-3.0 INPUT OUTPUT DESCRIPTION

6.1. Input sheet

Case Identification & Basic Configuration

Input Variable	Description	Unit	Default	Remarks
Project	Project identification	text		
Case	Case identification	text		
EnPlt	Energy plant type	text		
DslpType	Desalination plant type	text		
RefDiag	Reference coupling diagram	#		

Energy Plant Performance Data

Input Variable	Description	Unit	Default	Remarks
Qtp	Ref. thermal power	MWt		
Pen	Ref. net electric power	Mwe	600 or 0 (RH,NH,FH)	
opp	Planned outage rate		0,100	
oup	Unplanned outage rate		0,110	
Appo	Operating availability		if 0, value is calculated	
Lep	Lifetime of energy plant	a		
kec	Energy plant contingency factor		0	
Le	Construction lead time	m		
Tair	Site specific inlet air temp	°C	28	for GT/CC cases
DTca	Condenser-to-Interm. loop approach temp.	°C		
TurType	Turbine type (ExtrCon / BackPr)			
DTft	Interm. loop temperature drop	°C		
DT1s	Difference between feed steam temp. and max brine temp.	°C		
DPip	Intermediate loop pressure loss	bar		
Eip	Intermediate loop pump efficiency			

Energy Plant Cost Data

Input Variable	Description	Unit	Default	Remarks
Ce	Specific construction cost	$/KW		
Ceom	Specific O&M cost	$/MW(e).h		
eff	Fossil fuel annual real escalation	%/a	2	
Cff	Specific fossil / renewable fuel cost	$/ton or OE		
Cnsf	Specific nuclear fuel cost	$/MWh		
ir	Interest rate	%		
Ycr	Currency reference year			
Ycd	Initial construction date			
Yi	Initial year of operation			
Lwp	Lifetime of water plant	a		
LBKo	Lifetime of backup heat source	a		
cpe	Purchased electricity cost	$/Kwe		
kdcopp	Decommissioning cost	% of Ce	30	for nuclear cases

Distillation Plant Performance Data

Input Variable	Description	Unit	Default	Remarks
Wc_t	Required capacity	m^3/d	100000	
Tsdo	Seawater feed temp	°C	30	
TDS	Feed salinity	ppm		
GORo	GOR		if 0, value is calculated	
Wduo	Distillation plant modular unit size	m^3/d	0	
DTdcr	Condenser range	°C	10	
DTdca	Condenser approach	°C	5	
Tcmo	Steam temperature	oC	if 0, value is calculated	
Tmbo	Max. brine temperature	°C	if 0, value is calculated	
TVC	Thermal vapor compression option	Y/N		
Rtvco	TVC vapor entrainment ratio		1	
DPsd	Seawater pump head	bar	1,7	
Esd	Seawater pump efficiency		0,85	
Qsdp	Specific power use	$kW(e)h/m^3$		
opd	Planned outage rate		0,030	
oud	Unplanned outage rate		0,065	
Adpo	Plant availability		if 0, value is calculated	
BK	Backup heat source option flag	Y/N		
opb	Backup heat planned outage rate			
oub	Backup heat unplanned outage rate			

Distillation Plant Cost Data

Input Variable	Description	Unit	Default	Remarks
Wdur	Reference modular unit size for cost adjustment	m^3/d		
Cdu	Plant base unit cost	$\$/(m^3/d)$		
Csdo	Infall/outfall cost	%		% of construction cost
Cil	Intermediate loop cost	$\$/(m^3/d)$	0	
kdc	Plant cost contingency factor		0,1	
kdo	Plant owners cost factor		0,05	
Ldo	Plant construction lead time	m	if 0, value is calculated	
Sdm	Average management salary	$/a	66000	
Sdl	Average labor salary	$/a	29700	
csds	Specific O&M spare parts cost	$\$/m^3$	0,03	
cdtr	Tubing replacement cost			
cdcpr	Specific O&M chemicals cost for pre-treatment	$\$/m^3$	0,03	
cdcpo	Specific O&M chemicals cost for post-treatment	$\$/m^3$	0,02	
kdi	Plant O&M insurance cost	%	0,5	
Cbuo	Backup heat source unit cost	$/MW(t)	55000	
Cffb	Fossil fuel price for backup heat source at startup	$/bbl	20	
effb	Fossil fuel real escala. for backup heat source	%/a	2	
Ndmo	Num. of management personnel		if 0, value is calculated	
Ndlo	Number of labor personnel		0	

RO Plant Performance Data

Input Variable	Description	Unit	Default	Remarks
Wct	Required capacity	m^3/d		
Tsmo	RO feedwater inlet temperature	°C	30	
Wmuo	RO plant modular unit size	m^3/d		
DPsm	Seawater pump head	bar		
Esm	Seawater pump efficiency			
TDS	Feed salinity	ppm		
Rro	Recovery ratio			
Dflux	Design flux	l/(m2.h)		
Eer	Energy recovery efficiency			
EerType	RO energy recovery device type			PLT / PEX
DPbm	Booster pump head	bar		
Ebm	Booster pump efficiency			
DPhm	High head pump pressure rise	bar		
Ehm	High head pump efficiency			
Ehhm	Hydraulic pump coupling efficiency			
Qsom	Other specific power use	$kW(e)h/m^3$		
opm	Planned outage rate			
oum	Unplanned outage rate			
Ampo	Plant availability			if 0, value is calculated

RO Plant Cost Data

Input Variable	Description	Unit	Default	Remarks
Cmu	RO plant base unit cost	$\$/(m^3/d)$		
Csmo	Infall/outfall cost	%		% of construction cost
kmc	Plant cost contingency factor			
kmo	Plant owners cost factor			
Lmo	Plant availability		if 0, value is calculated	
Smm	Average management salary	$/a		
Sml	Average labor salary	$/a		
cmm	O&M membrane replacement cost	$\$/m^3$		
cmsp	O&M spare parts cost	$\$/m^3$		
cmcpr	Specific chemicals cost for pre-treatment	$\$/m^3$		
cmcpo	Specific chemicals cost for post-treatment	$\$/m^3$		
kmi	Plant O&M insurance cost	%		
Nmmo	Num. of management personnel		if 0, value is calculated	
Nmlo	Number of labor personnel			
Lho	Hybrid plant lead time	m	if 0, value is calculated	

Hybrid Plant Data

Input Variable	Description	Unit	Default	Remarks
Wc_t	Required total desalination capacity	m^3/d		
Wc_dst	Hybrid dist. capacity	m3/d		
Wc_RO	Hybrid RO capacity	m3/d		
Lho	Hybrid plant lead time	m	0	

6.2. Output sheet

Performance Results

Description	Unit	Remarks
Lost Electricity Production	MW	
Power-to-Heat Ratio	MWe/MWt	
Plant Thermal Utilization	%	

Distillation Performance

Description	Unit	Remarks
# of Effects/Stages	MW	
GOR	MWe/MWt	
Temperature Range	°C	
Distillate Flow	m3/d	
Feed Flow	m3/d	
Steam Flow	kg / s	
Brine Flow	m3/d	
Brine salinity	ppm	
Specific Heat Consumption	kWh / m3	

RO Performance

Description	Unit	Remarks
Recovery Ratio	MW	
Permeate Flow	m3/d	
Feed Flow	m3/d	
Feed Pressure	bar	
Product Quality	ppm	
Brine Flow	m3/d	
Brine salinity	ppm	
Specific Power Consumption	kWh / m3	

Cost results

Specific Power Cost

Description	Unit	Remarks
Fixed charge cost	$ / kWh	
Fuel cost	$ / kWh	
O&M cost	$ / kWh	
Decommissioning cost	$ / kWh	
Levelized Electricity Cost	$ / kWh	

Specific Water Cost

Description	Unit	Remarks
Fixed charge cost	$ / m3	
Heat cost	$ / m3	
Plant electricity cost	$ / m3	
Purchased electricity cost	$ / m3	
O&M cost	$ / m3	
Total Specific Water Cost	$ / m3	

7. DEEP-3.0 SAMPLE CASES

Summary of Performance and Cost Results

Main Input Parameters

Project DEEP Version 3.0 - Sep. 2005 **Case** CC+MED

Power Plant Data			**Water Plant Data**		
Type	CC		Type	MED	
Ref. Thermal Power	1,200	MW	Required capacity	100,000	m^3/d
Ref. Net Electric Power	600	MW	Hybrid Dist. Capacity	N/A	m^3/d
Construction Cost	700	$ / kW	Dist. Construction Cost	900	$ / (m^3/d)
Fuel Cost	50	$/BOE	Maximum Brine Temp.	65.0	°C
Purchased Electricity Cost	0.037	$/kWh	Heating Steam Temp.	0.0	°C
Interest Rate	5	%	Dist. Feed Temp.	30	°C
			Seawater Feed Salinity	35000.0	ppm
Configuration Switches			Hybrid RO Capacity	N/A	m^3/d
Steam Source	ExtrCon		RO Construction Cost	N/A	$ / (m^3/d)
Intermediate Loop	N/A		RO Recovery Ratio	N/A	
TVC Option	N		RO Energy Recovery Efficiency	N/A	
Backup Heat	N		RO Design Flux	N/A	l / (m^2 hour)
RO Energy Recovery Device	N/A		RO Feed Temp.	N/A	°C

Performance Results

Lost Electricity Production	20.0	MW
Power-to-Heat Ratio	1.7	MWe/MWt
Plant Thermal Utilization	75.5	%

Distillation Performance			**RO Performance**		
# of Effects/Stages	9				
GOR	8.0		Recovery Ratio	N/A	
Temperature Range	20	°C	Permeate Flow	N/A	m^3/d
Distillate Flow	100,000	m^3/d	Feed Flow	N/A	m^3/d
Feed Flow	200,000	m^3/d	Feed Pressure	N/A	bar
Steam Flow	144.39	kg / s	Product Quality	N/A	ppm
Brine Flow	100,000	m^3/d	Brine Flow	N/A	m^3/d
Brine salinity	70,000	ppm	Brine Saliniy	N/A	ppm
Specific Heat Consumption	80.67	kWh / m^3	Specific Power Consumption	N/A	kWh / m^3

Cost Results

Specific Power Costs			**Specific Water Costs**		
Fixed charge cost	0.008	$ / kWh	Fixed charge cost	0.328	$ / m^3
Fuel cost	0.075	$ / kWh	Heat cost	0.424	$ / m^3
O&M cost	0.006	$ / kWh	Plant electricity cost	0.204	$ / m^3
Decommissioning cost	N/A	$ / kWh	Purchased electricity cost	0.000	$ / m^3
			O&M cost	0.139	$ / m^3
Levelized Electricity Cost	**0.088**	$ / kWh	Total Specific Water Cost	**1.093**	$ / m^3

Summary of Performance and Cost Results

Main Input Parameters

Project	**DEEP Version 3.0 - Sep. 2005**		**Case**	**CC+MED-RO**	

Power Plant Data			**Water Plant Data**		
Type	CC		Type	MED-RO	
Ref. Thermal Power	1,200	MW	Required capacity	100,000	m^3/d
Ref. Net Electric Power	600	MW	Hybrid Dist. Capacity	50,000	m^3/d
Construction Cost	700	$ / kW	Dist. Construction Cost	900	$ / (m^3/d)
Fuel Cost	50	$/BOE	Maximum Brine Temp.	65.0	°C
Purchased Electricity Cost	0.037	$/kWh	Heating Steam Temp.	0.0	°C
Interest Rate	5	%	Dist. Feed Temp.	30	°C
			Seawater Feed Salinity	35000.0	ppm
Configuration Switches			Hybrid RO Capacity	50,000	m^3/d
Steam Source	ExtrCon		RO Construction Cost	900	$ / (m^3/d)
Intermediate Loop	N/A		RO Recovery Ratio	0.00	
TVC Option	N		RO Energy Recovery Efficiency	0.95	
Backup Heat	N		RO Design Flux	13.6	l / (m^2 hour)
RO Energy Recovery Device	PEX		RO Feed Temp.	30.0	°C

Performance Results

Lost Electricity Production	10.0	MW
Power-to-Heat Ratio	3.5	MWe/MWt
Plant Thermal Utilization	62.8	%

Distillation Performance			**RO Performance**		
# of Effects/Stages	9				
GOR	8.0		Recovery Ratio	0.42	
Temperature Range	20	°C	Permeate Flow	50,000	m^3/d
Distillate Flow	50,000	m^3/d	Feed Flow	120,000	m^3/d
Feed Flow	100,000	m^3/d	Feed Pressure	56.1	bar
Steam Flow	72.20	kg / s	Product Quality	279	ppm
Brine Flow	50,000	m^3/d	Brine Flow	70,000	m^3/d
Brine salinity	70,000	ppm	Brine Saliniy	60,000	ppm
Specific Heat Consumption	80.67	kWh / m^3	Specific Power Consumption	2.91	kWh / m^3

Cost Results

Specific Power Costs			**Specific Water Costs**		
Fixed charge cost	0.008	$ / kWh	Fixed charge cost	0.301	$ / m^3
Fuel cost	0.075	$ / kWh	Heat cost	0.195	$ / m^3
O&M cost	0.006	$ / kWh	Plant electricity cost	0.213	$ / m^3
Decommissioning cost	N/A	$ / kWh	Purchased electricity cost	0.007	$ / m^3
			O&M cost	0.158	$ / m^3
Levelized Electricity Cost	**0.088**	$ / kWh	Total Specific Water Cost	**0.873**	$ / m^3

Summary of Performance and Cost Results

Main Input Parameters

Project	DEEP Version 3.0 - Sep. 2005		Case	NBC+MED-RO	

Power Plant Data			**Water Plant Data**		
Type	NBC		Type	MED-RO	
Ref. Thermal Power	1,570	MW	Required capacity	100,000	m^3/d
Ref. Net Electric Power	660	MW	Hybrid Dist. Capacity	50,000	m^3/d
Construction Cost	1,500	$ / kW	Dist. Construction Cost	900	$ / (m^3/d)
Fuel Cost	6	$/MWh	Maximum Brine Temp.	65.0	°C
Purchased Electricity Cost	0.06	$/kWh	Heating Steam Temp.	0.0	°C
Interest Rate	5	%	Dist. Feed Temp.	30	°C
			Seawater Feed Salinity	35000.0	ppm
Configuration Switches			Hybrid RO Capacity	50,000	m^3/d
Steam Source	ExtrCon		RO Construction Cost	900	$ / (m^3/d)
Intermediate Loop	Y		RO Recovery Ratio	0.00	
TVC Option	N		RO Energy Recovery Efficiency	0.95	
Backup Heat	N		RO Design Flux	13.6	l / (m^2 hour)
RO Energy Recovery Device	PEX		RO Feed Temp.	30.0	°C

Performance Results

Lost Electricity Production	0.0	MW
Power-to-Heat Ratio	3.9	MWe/MWt
Plant Thermal Utilization	52.4	%

Distillation Performance			**RO Performance**		
# of Effects/Stages	9				
GOR	8.0		Recovery Ratio	0.42	
Temperature Range	20	°C	Permeate Flow	50,000	m^3/d
Distillate Flow	50,000	m^3/d	Feed Flow	120,000	m^3/d
Feed Flow	100,000	m^3/d	Feed Pressure	56.1	bar
Steam Flow	72.20	kg / s	Product Quality	279	ppm
Brine Flow	50,000	m^3/d	Brine Flow	70,000	m^3/d
Brine salinity	70,000	ppm	Brine Saliniy	60,000	ppm
Specific Heat Consumption	80.67	kWh / m^3	Specific Power Consumption	2.91	kWh / m^3

Cost Results

Specific Power Costs			**Specific Water Costs**		
Fixed charge cost	0.013	$ / kWh	Fixed charge cost	0.311	$ / m^3
Fuel cost	0.009	$ / kWh	Heat cost	0.000	$ / m^3
O&M cost	0.012	$ / kWh	Plant electricity cost	0.097	$ / m^3
Decommissioning cost	0.004	$ / kWh	Purchased electricity cost	0.006	$ / m^3
			O&M cost	0.157	$ / m^3
Levelized Electricity Cost	**0.037**	$ / kWh	Total Specific Water Cost	**0.571**	$ / m^3

Summary of Performance and Cost Results

Main Input Parameters

Project	**DEEP Version 3.0 - Sep. 2005**		**Case**	**Stand-Alone RO**	
Power Plant Data			**Water Plant Data**		
Type	N/A		Type	RO	
Ref. Thermal Power	N/A	MW	Required capacity	100,000	m^3/d
Ref. Net Electric Power	N/A	MW	Hybrid Dist. Capacity	N/A	m^3/d
Construction Cost	N/A	$ / kW	Dist. Construction Cost	N/A	$ / (m^3/d)
Fuel Cost	N/A	$/MWh	Maximum Brine Temp.	N/A	°C
Purchased Electricity Cost	0.037	$/kWh	Heating Steam Temp.	N/A	°C
Interest Rate	5	%	Dist. Feed Temp.	N/A	°C
			Seawater Feed Salinity	35000.0	ppm
Configuration Switches			Hybrid RO Capacity	N/A	m^3/d
Steam Source	N/A		RO Construction Cost	900	$ / (m^3/d)
Intermediate Loop	Y		RO Recovery Ratio	0.00	
TVC Option	N/A		RO Energy Recovery Efficiency	0.95	
Backup Heat	N/A		RO Design Flux	13.6	l / (m^2 hour)
RO Energy Recovery Device	PEX		RO Feed Temp.	30.0	°C

Performance Results

Lost Electricity Production	N/A	MW
Power-to-Heat Ratio	N/A	MWe/MWt
Plant Thermal Utilization	N/A	%

Distillation Performance			**RO Performance**		
# of Effects/Stages	N/A				
GOR	N/A		Recovery Ratio	0.42	
Temperature Range	N/A	°C	Permeate Flow	105,000	m^3/d
Distillate Flow	N/A	m^3/d	Feed Flow	252,000	m^3/d
Feed Flow	N/A	m^3/d	Feed Pressure	56.1	bar
Steam Flow	N/A	kg / s	Product Quality	279	ppm
Brine Flow	N/A	m^3/d	Brine Flow	147,000	m^3/d
Brine salinity	N/A	ppm	Brine Saliniy	60,000	ppm
Specific Heat Consumption	N/A	kWh / m^3	Specific Power Consumption	2.97	kWh / m^3

Cost Results

Specific Power Costs			**Specific Water Costs**		
Fixed charge cost	N/A	$ / kWh	Fixed charge cost	0.278	$ / m^3
Fuel cost	N/A	$ / kWh	Heat cost	N/A	$ / m^3
O&M cost	N/A	$ / kWh	Plant electricity cost	0.000	$ / m^3
Decommissioning cost	N/A	$ / kWh	Purchased electricity cost	0.110	$ / m^3
			O&M cost	0.173	$ / m^3
Levelized Electricity Cost	**N/A**	$ / kWh	Total Specific Water Cost	**0.562**	$ / m^3

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