Nisan Desalination Services

International Atomic Energy Agency

Comparison of DEEP versions 3.1 and 3.2

By

S. Nisan,(NDS)

I. Khamis (IAEA)

Nisan Desalination Services

International Atomic Energy Agency

CONTENTS

1. INTRODUCTION

The International Atomic Energy Agency (IAEA) has very recently issued the new version (3.2) of its Desalination Economic Evaluation Programme (DEEP).

The objective of this report is to compare the results of the new version of DEEP with those obtained previously with the version issued in july 2005.

The programme of comparison and interpretation of the differences between the results of the two versions will be based on two energy sources (The 610 MWe nuclear reactor AP600 and the 900 MWe gas turbine, combined cycle plant, CC900) and three desalination processes, MSF,MED and RO. Thus the real cases considered are:

- AP600+ MSF; AP600+MED; AP600+RO
- CC900+MSF; CC900+MED;CC900+RO;
- All the above calculations will be repeated for two water production capacities: 4500, and 50000 m^3/day as adopted in the DEEP benchmark problem.
- The reference cases for the previous DEEP version are taken from the corresponding reference calculations for the benchmark problem.

The correction in DEEP formulae for cases where the production capacity is >250 000 m3/day, has already been discussed in the context of DEEP benchmarking meetings.

2. METHODOLOGY

For the cases considered, comparisons are made with two different but complementary calculations:

- DEEP 3.2 version as it is (protected version, where only the allowed user input is modified).
- DEEP 3.2 calculations in which, after removal of the protection, some of the calculated parameters are changed so that the calculation data is made identical to the reference benchmark cases.

3. RESULTS

3.1. AP600 + MED

When comparing the results of version 3.2 and the benchmark case AP600+MED (4500 and 50000 m^3/day water production capacity), calculated with the previous version of DEEP (herefter referre to as DEEP3.1), we observe the differences as shown in table 1:

Table 1: Comparison of power and water costs versions DEEP 3.1 and 3.2 as it is **(AP600 + MED)**

Water production capacity (m3/day)	Item	Reference DEEP3.1 (1)	DEEP 3.2 (2)	Relative error = (2)-(1)/(1) %
4500	Power cost ($/kWh)	0.04434	0.04434	0
	Water cost ($/m3)	1.0722	1.5717	46.6
50000	Power cost ($/kWh)	0.04434	0.04434	0
	Water cost ($/m3)	0.8898	0.9597	7.9

It is observed that while the power costs are the same, the water costs between the two versions differ by nearly 8 and 47%, the relative error being the highest for the small capacity.

Now, according to the IAEA, the main difference between the two versions is the fact that in DEEP 3.1, the efficiency of the thermodynamic system is obtained by the Carnot cycle, where as in 3.2, the efficiency is calculated using the Rankine cycle, which is supposed to be more practical.

However, in the light of previous experience, we felt that the observed differences are much larger than they should.

It is for this reason that we examined all the parameters of the two systems which are influenced by the change.

The results are presented in Table 2:

Table 2: Parameters with different values in DEEP 3.1 and DEEP 3.2 (NSC + MED cases)

Parameter	DEEP3.1		DEEP3.2		Comments
	4500 m^3/day	50000 m^3/day	4500 m^3/day	50000 m^3/day	
Total heat to the water plant, Qcrm (MWt)	12.6	140.3	13.3	147.7	Calculated from the modified condensing temperature in 3.1, and from the difference of enthalpies in the Rankine cycle in 3.2; see DEEP for the full formulas
Efficiency, hcar	0.087	0.087	0.083	0.083	Carnot cycle in 3.1; Rankine cycle in 3.2
Power to heat ratio, Rpth	45.7		48.2		Same formula in both but depends on Qcrm
Steam flow to MED, FFs (Kg/s)	5.4	4.2	5.7	4.0	Same formula in both but depends on Qcrm
Maximum water production capacity, Wcd (m^3/day)	4500	50000	4738	52642	Same formula in both but depends on Ffs; this has important repercussions on parameters effecting cost
N° of modules, Ndu	1	5	2	6	Same formula in both but depends on Wcd; indirectly depends on the choice of the thermodynamic cycle; this has important repercussions on parameters effecting cost
Rejected brine flow, Wbd (Kg/s)	4500	50000	9000	60000	Same formula in both but depends on Ndu; this has important repercussions on parameters effecting cost
Make up water flow, wfd (Kg/s)	9000	100000	18000	120000	Same as above
Seawater flow, Fsd, (Kg/s)	104	1157	208	1389	Same as above
Total pumping power, qis (MWe)	0.461	0.264	0.923	0.293	Depends on Fsd
Total distillation plant power use, qdp (MW)	0.5	5.5	1.0	6.6	Depends on Fsd
Annual water production, Wpd, (m^3/a)	1348164	14979600	1419393	15771035	Depends on Ndu; very important for cost

3.2. AP600 + MSF

As for the previous case, the power and water costs are compared in table 3:

Table 3: Comparison of power and water costs versions DEEP 3.1 and 3.2 as it is **(AP600 + MSF)**

Water production capacity (m3/day)	Item	Reference DEEP3.1 (1)	DEEP 3.2 (2)	Relative error = (2)-(1)/(1) %
4500	Power cost ($/kWh)	0.04434	0.04434	0
	Water cost ($/m3)	1.4069	1.1063	-21.4
50000	Power cost ($/kWh)	0.04434	0.04434	0
	Water cost ($/m3)	1.2252	1.1878	-3.05

Here, the general tendency is the same but the signs of the relative errors have been inversed as compared to table 1

As before, to understand these differences, we compare the important parameters in table 4:

Table 4: Parameters with different values in DEEP 3.1 and DEEP 3.2 (AP600 +MSF)

Parameter	DEEP3.1		DEEP3.2		Comments
	4500 m^3/day	50000 m^3/day	4500 m^3/day	50000 m^3/day	
Total heat to the water plant, Qcrm (MWt)	12.3	136.7	14.0	155.8	Calculated from the modified condensing temperature in DEEP3.1, and from the difference of enthalpies in the Rankine cycle in 3.2; see DEEP for the full formulas
Efficiency, hcar	0.693	0.193	0.687	0.187	Carnot cycle in 3.1; Rankine cycle in 3.2
Power to heat ratio, Rpth	49.4	43.3	4.2	3.7	Same formula in both but depends on Qcrm
Steam flow to MED, FFs (Kg/s)	5.6	61.7	6.3	70.3	Same formula in both but depends on Qcrm
Maximum water production capacity, Wcd (m^3/day)	4500	50000	5120	56960	Same formula in both but depends on Ffs; this has important repercussions on parameters effecting cost
N° of modules, Ndu	1	5	2	6	Same formula in both but depends on Wcd; indirectly depends on the choice of the thermodynamic cycle; this has important repercussions on parameters effecting cost
Rejected brine flow, Wbd (Kg/s)	4500	50000	9000	60000	Same formula in both but depends on Ndu; this has important repercussions on parameters effecting cost
Make up water flow, wfd (Kg/s)	9000	100000	18000	120000	Same as above
Seawater flow, Fsd, (Kg/s)	437	4856	874	5827	Same as above
Total pumping power, qis (MWe)	0.092	1.025	0.185	1.230	Depends on Fsd
Total distillation plant power use, qdp (MW)		7.6		9.1	Depends on Fsd
Annual water production, Wpd, (m^3/a)	1348164	14979600	2696328	17975520	Depends on Ndu; very important for cost

4. DISCUSSION

4.1. The nuclear options:AP600+ MED and AP600 +MSF

Tables 1 to 4 clearly show that, whatever the thermal desalination process (MED or MSF), the total water cost is influenced by two types of parameters: 1)- the ones which are directly influenced by the choice of the thermodynamic cycles, Carnot or Rankine, and 2)- those which are influenced by the value of the maximum water production capacity, Wcd, This last parameter has a very significant impact on the water costs because in the example above it has doubled the number of modules, Ndu, which then leads to doubling of other parameters as shown in tables 2 and 4 above.

It is for this reason that we modified the formula for Wcd.

In both DEEP versions, Wcd is calculated as

$$Wcd = Ffs \times Gor \times 3600 \times 24/1000$$

Now Ffs is a direct function of $Qcrm$, which in turn depends on the choice of the Carnot or Rankine efficiency

$$Ffs = Qcrm/(598\text{-}0,6^*Tcm)/4,1868^*1000$$

We observe in Table 2 that the choice of the Rankine cycle in DEEP 3.2 leads to a higher value of Ffs.

Furthermore, the calculation of the number of modules, , depends on the value of Wcd:

$$Ndu = Ndd = If(Wdu0 > 0; INTEGER.SUP(Wcd/Wdu;0);1$$

where, $Wdu0$ is the selected unit size capacity. In our example, this was set equal to 4500 m^3/day. But because of the choice of the Rankine cycle, the value of Wcd is 4738 in DEEP 3.2 as compared to 4500 as imposed in DEEP3.1. The ratio 4738/4500 is thus equal to 1.0529 and the calculated number of modules becomes 2 instead of 1.

If we modify the formula for Wcd so that $Wcd = Wdrc$, the nominal water production capacity, then the ratio Wcd/Wdu is always equal to 1 and hence the number of modules is equal to 1 in this case.

With this modification, in DEEP3.2 cases, all the parameters depending on Wcd ***become identical to the corresponding ones in DEEP3.1 cases and we obtain the following tables for water cost:***

Table 5: Water costs with DEEP 3.1 and modified 3.2 **(AP600 + MED)**

Water production capacity (m3/day)	Item	Reference DEEP3.1 (1)	DEEP 3.2 (2)	Relative error = (2)-(1)/(1) %
4500	Water cost ($/m3)	1.0722	1.0730	0.07
50000	Water cost ($/m3)	0.8898	0.8906	0.09

We observe that in both the MED cases, the relative error between the two versions is thus only 0.07 to 0.09%! This is due to the choice of the thermodynamic cycle.

To verify these conclusions we repeated the calculations with the AP600 + MSF cases, as shown in table 6.

Table 6: Water costs with DEEP 3.1 and modified 3.2 **(AP600 + MSF)**

Water production capacity (m3/day)	Item	Reference DEEP3.1 (1)	DEEP 3.2 (2)	Relative error = (2)-(1)/(1) %
4500	Water cost ($/m3)	1.4069	1.4558	3.5
50000	Water cost ($/m3)	1.2252	1.2741	3.9

In these cases the relative errors show the same tendency as in the MED cases. The absolute value of the MSF cases is however higher than in the MED cases. This is comprehensible since the MSF cases involve much higher values of the lost shaft power which is more influenced by the choice of the Rankine or Carnot cycles.

4.2. The fossil fuelled options: CC+MED and CC+MSF

As its name indicates, the gas turbine combined cycle plant is a combination of steam cycle (to which the Rankine cycle can be applied) and a Brayton cycle for the gas turbine part.

At the moment, no Rankine cycle option has been incorporated in DEEP 3.2. However, it is useful to compare the two versions to ensure the consistency of DEEP 3.2 version.

We thus repeated the above calculations for the 900 MWe gas turbine combined cycle plant (CC900) coupled to MED and MSF. The gas price chosen was the equivalent of 100$/bbl and discount and interest rates were 8% as was done in the Benchmarking exercise.

First the direct comparison, with “as it is” cases, is given in table 7.

Table 7: Comparison of power and water costs versions DEEP 3.1 and 3.2 as it is **(CC900 + MED)**

Water production capacity (m3/day)	Item	Reference DEEP3.1 (1)	DEEP 3.2 (2)	Relative error = (2)-(1)/(1) %
4500	Power cost ($/kWh)	0.18029	0.18029	0
	Water cost ($/m3)	1.9862	1.9652	0
50000	Power cost ($/kWh)	0.18029	0.18029	0
	Water cost ($/m3)	1.8097	1.8097	0

This table shows that the results from the two versions are identical, as expected.

The results for the CC+MSF cases are presented in table 8:

Table 8: Comparison of power and water costs versions DEEP 3.1 and 3.2 as it is **(CC900 + MSF)**

Water production capacity (m3/day)	Item	Reference DEEP3.1 (1)	DEEP 3.2 (2)	Relative error = (2)-(1)/(1) %
4500	Power cost ($/kWh)	0.18029	0.18029	0
	Water cost ($/m3)	3.2967	3.2967	0
50000	Power cost ($/kWh)	0.18029	0.18029	0
	Water cost ($/m3)	3.1208	3.1208	0

Once again, we observe that with identical input data, there is no difference between the results of DEEP 3.1 and DEEP 3.2.

4.3. AP600+ RO and CC900 + RO cases

Results for AP600 + RO and CC900 +RO are given in Table 9.

Table 9: Comparison of DEEP 3.1 and 3.2; AP600+RO and CC900+RO cases

Water production capacity (m3/day)	Item	DEEP3.1		DEEP3.2		Relative error = (3)-(1)/(1) %	Relative error = (4)-(2)/(2) %
		AP600+RO (1)	CC900+RO (2)	AP600+RO (3)	CC900+RO (4)	AP600+RO	CC900+RO
4500	Power cost ($/kWh)	0.04434	0.18029	0.04434	0.18029	0	0
	Water cost ($/m3)	0.7861	1.1871	0.7861	1.1871	0	0
50000	Power cost ($/kWh)	0.04434	0.18029	0.04434	0.18029	0	0
	Water cost ($/m3)	0.6381	1.0391	0.6381	1.0391	0	0

Again, as expected, there is no difference between the results from the two DEEP versions.

5. CONCLUSIONS

When comparison is made between the results of DEEP3.1 and the new DEEP 3.2 versions, there is no difference in the water and power costs if the cases considered are RO, whatever their energy source.

On the other hand if the two versions are used as they are for the Nuclear options with MED and MSF, the relative errors could be between 4 and 47%, depending upon the water production capacity.

These errors arise for the following reasons:

- In DEEP 3.2, the Carnot cycle has been justly replaced by the Rankine cycle for the calculation of thermodynamic efficiencies.
- However, because of the choice of the Rankine cycle efficiency, the value of the Maximum water production capacity becomes higher than the nominal capacity, because the total heat transferred to the desalination plant and hence the value of the steam flow rate become higher than DEEP3.1 case.. This may lead to a doubling of the value of the number of modules, which results in much higher costs for DEEP3.2.
- If the value of the maximum water production capacity is taken to be equal to the nominal production capacity (and this seems logical to us), then the difference between the two versions is negligible indicating that finally the choice of the thermodynamic cycle is not crucial to water costs calculations.

We would thus suggest that in the forth coming versions of DEEP, two options should be programmed corresponding to the choice of Carnot or Rankine cycles.

The user should, however, be warned that while using the Rankine cycle, the value of the maximum water production capacity be put equal to the nominal capacity as selected by the user.

Alternatively, the formula for the maximum water production capacity be modified accordingly.

The choice of the thermodynamic cycles should be generalised to include fossil fuelled energy sources.