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Development of Optimization Software of Ro Systems for Water Desalination: 'Desaltop'

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Abstract

DESALTOP is a optimization software of reverse osmosis systems for seawater and brackish water desalination, which we developed at European Membrane Institute (National Center of Scientific Research, Montpellier, France), in collaboration with Dr. John Palmeri of Toulouse University, and Ing. Patrice David (IEM, Montpellier). Like computer code of optimization, it allows to optimize RO system design for water desalination. The system design consists in choosing: stages and pass number, different blends and by-pass, modules number on each stage and pass, and also modules number per pressure vessel.

DESALTOP software is realized on the basis of:

- A physical modeling of various RO membranes performances.
- A modeling of various desalination costs.
- An optimization using a very powerful genetic algorithm.

Considering the complexity of the problems to be optimized (high number of equations to be solved, coupling and nonlinearity of equations, high number of linear and nonlinear constraints), this algorithm allows the code to converge towards the optimal solution (optimal design, optimal membrane choice, optimal operating parameters). The modification by the user, of algorithm genetic parameters, is also possible, in order to improve the results.

Our software DESALTOP, allows choosing: the optimal type of membrane to be used in RO plant. These membranes are much diversified: various technologies (spiral, hollow fibers), various marks (Toray, Hydranautics, Desal, Toyobo, Filmtec, Koch…) which is in various models, very variable performances (rejection rate, conversion, productivity, resistance…), and at various selling prices. The choice of optimal operating parameters of RO system is also assured by DESALTOP (pressure, conversion, flow rate).

The design and operation parameters optimization of desalination plant is made, according the desired quality of product water.

The software input data are: capacity and life plant, total concentration of salts, and Boron concentration of seawater or brackish water, like its temperature, and efficiencies of pumps and energy recuperation system (turbine or pressure exchanger).

The principal objective of DESALTOP, is to conceive a desalination system able to minimize desalted water cost.

Keywords: Design, Membrane, Optimization, RO Desalination, Water.

Introduction

RO membranes are very diversified through [1,2,3,4,5,6,7,8,9,10,11]: qualities (there are membranes for high salinity –seawater- and for low salinity -brackish water-), technologies (there are two dominant technologies for RO membranes; hollow fibers technology and spiral technology), diameters (who be able in 8", 4", et 2,5"), trademarks (there is the multitude of trademarks, the more utilized are: Filmtec, Hydranautics, Toray, Koch, Osmonics Desal, Toyobo, and Dupont -Dupont factory is closed since 2002, but a lot of plants who designed with this membrane continue to function-), models (for each trademark, there is a multitude of models). Each type of membranes is principally characterized by: permeat flow and salt reject rate, those are according to pressure and conversion. It's also characterized by maximum value of operating pressure.

Modeling of transport through RO membranes and modules attracts more and more the researcher attention in objective to make the reliable models for performances prediction [12-22].

Membrane prices are also very diversified: choice membrane at low price can lead to low economic efficiency, or to high power cost, while choice membrane at high price can lead to reduced total costs.

RO system design (stage number, pass number, number and rate of by-pass and blend), play an important role. Adequate design aims to search: firstly the best arrangement type, and secondly the best module positions.

Modeling of plant performances of water desalination has been the subject of the large research works [23-28]. The research of new designs remains the topical work in objective to create the more efficient designs [29-33].

Operating parameters (specially pressure and conversions _feed flows-) according to desirable objectives, are spreaded on the large domains, in the same time, the variables participant in theirs choices, are very numerous.

The combination of choices of all this elements is essential and decisive, for desalination costs and water price [34].

In view the complexity of problem to be optimize (very high number of coupled non- linear equations, high number of non- linear constraints), the best choice of algorithm for optimization is essential to converge toward the best solution.

The objective of this work is to introduce –through description and diversified applications- DESALTOP code for computation and optimization of RO desalination plants.

DESALTOP is an optimization software for RO systems, which we developed at European Membrane Institute (National Center of Scientific Research, Montpellier, France), in collaboration with Dr. John Palmeri of Theoretical Physical Laboratory (Toulouse University), and Ing. Patrice David (IEM, Montpellier).

This code is realized for to be able to treat a lot of questions: transport modeling through different membrane types, computation of seawater and brackish water desalination plants, Boron passage control, multi criteria and multi scale optimization (membrane, design, operating parameters), and economic calculation.

DESALTOP Description**:**

1- Code performances:

i) Modeling of transport and transfer through RO membrane.

ii) Modeling of Boron transfer.

iii) Computation of RO desalination systems for two cases: seawater and brackish water (one stage, two stage, and three stage system), with technical and economic calculate.

iv) Optimization of operating parameters for RO systems.

v) Optimization of design systems.

vi) Coupled optimization (parameters- design- membrane).

2- Elementary tools:

a- Membrane data base: includes 14 types with two free inputs for enrichment (one for seawater desalination membranes, and one of brackish water desalination membranes). Show table 1.

b- Rich and exhaustive data base of diagram for RO plant designs, show figure 1.

c- Evolutionary algorithm (the genetic type) endowed with a selection by the wheel of Goldberg, with adjustable genetic parameters according to desirable conditions (number of initial populations, number of generations, number of populations to evolve inter- generations, number of additional generations for control, crossing probability, mutation probability, scaling coefficient). Show figure 2.

d- Efficient algorithm for computation of membrane transport and transfer, show figure 3.

e- An algorithm for economic computations, show figure 4.

f- Input- Output units:

* Inputs:

i) Capacity of desalination plant.

ii) Characteristics of feed water (salinity, temperature, Boron concentration).

iii) Energy characteristics (energy price, pump efficiency, turbine efficiency).

iv) Economic parameters (plant life, load factor, interest rate, indirect investment cost rate, Average man- monthly salary).

v) Operating parameters: only for computation without optimization (pressure, conversion, rate of bypass or/and rate of blend on each stage).

Table 1: Membrane Trademarks and theirs models.

Marque	Models
Filmtec: for brackish water	BW30-440*i*, BW30-400/34*i*, BW30-400, BW30-365, BW30-4040, TW30-4040, BW30-2540, TW30-2540, TW30-4021, TW30-4014, TW30-2521, TW30-2514, TW30-2026.
Filmtec: for seawater	SW30XLE-400*i*, SW30HR LE-400*i*, SW30HR LE-400, SW30HR-370/34*i*, SW30HR-380, SW30HR-320, SW30-4040, SW30HR LE-4040, SW30-2540, SW30-4021, SW30-2521, SW30-2514.
Hydranautics: brackish water	ESPA1-4040, ESPA2-4040, ESPA3-4040, ESPA4-4040, ESPA1, ESPA2, ESPA2-365, ESPA2+*, ESPA3, ESPA4**, ESPA-B*, CPA2-4040, CPA2, CPA3, CPA4, LFC1, LFC3, LFC3-LD.
Hydranautics: seawater	SCW1-4040, SWC3+, SWC4+, SWC5.
Toray: brackish water	TM710, TM720-370, TM720-400, TM720-430.
Toray: seawater	TM810L, TM820L-370, TM820L-400, TM820-370, TM820-400, TM820E-400, TM820C-400, TM820H-370, TM820B-370.
Koch: brackish water	TFC-XR, TFC-XR Magnum, TFC-HR, TFC-HR Magnum, TFC-HR MegaMagnum.
Koch: seawater	TFC-SS, TFC-SS Magnum, TFC-HF, TFC-HF Magnum.
Osmonics: brackish water	Desal 1220978, Desal 1206799, Desal 1206802, Desal 1220979, Desal 1206812, Desal 1206816.
Osmonics: seawater	Desal 1206718, Desal 1206719, Desal 1206729, Desal 1206748, Desal 1206750, Desal 1206774.
Toyobo brackish water	HA3110, HA5110, HA5230, HA5330, HA8130.
Toyobo seawater	HR3155, HR5155, HR5255, HR5355, HR8355, HM8255, HM9255, HM10255, HB10255, HB10255FI, HB9155, HJ9155, HL10255.
DuPont brackish water	B9-0410, B9-0420, B9-0440, B9-0840, B9-0840R, B9-0880, B9-0880TBR, B9-0040, B9-0040R
DuPont seawater	B10-6410T, B10-6440T, B10-6835T, B10-6835TR, B10-6845T, B10-6845TR, B10-6880T, B10-6880TBR

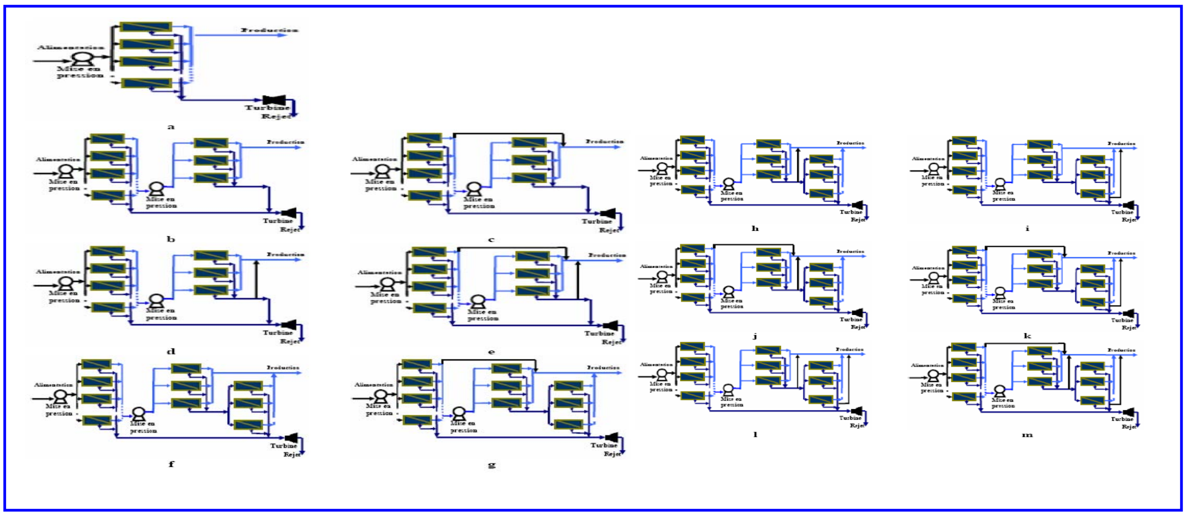

Figure 1: Different designs of RO systems

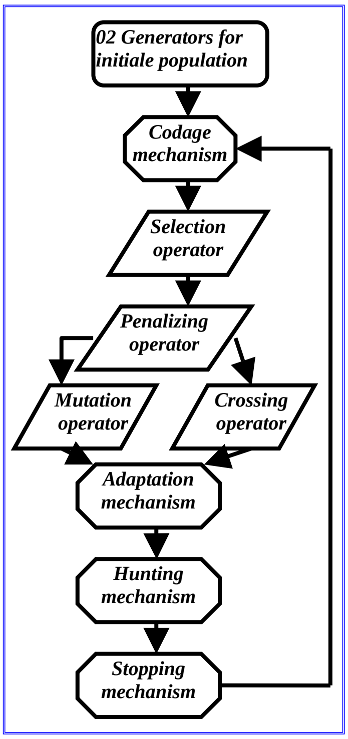

Figure 2: Components and functioning of the genetic algorithm

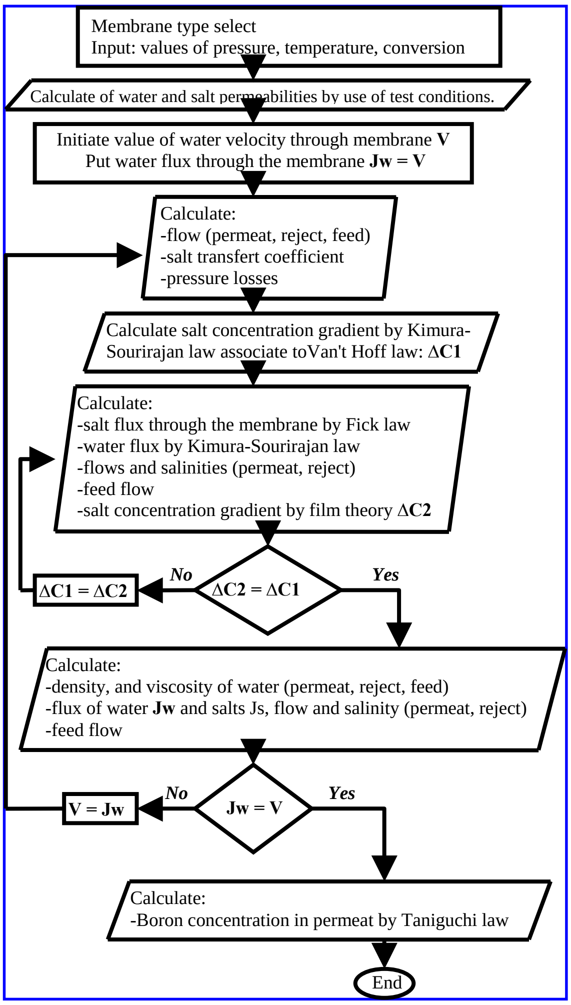

Figure 3: Computation algorithm for membrane transport and transfer

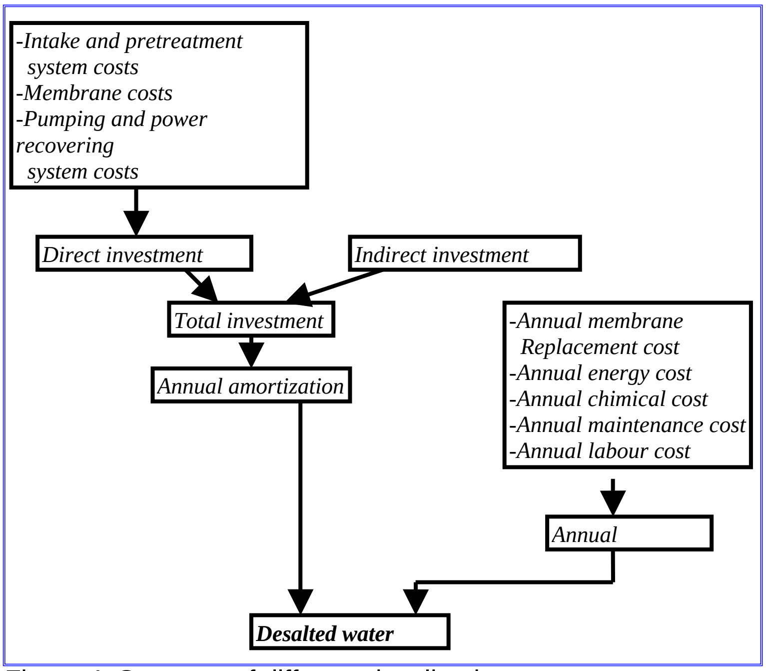

Figure 4: Structure of different desalination costs

vi) Objectives: only for computation with optimization (imposed limit on permeat salinity, imposed limit on permeat concentration of Boron, limit number of stages).

vii) Membrane characteristics –when use the non-existent membrane in data base-: membrane life, price, test conditions (salinity, temperature and Boron concentration of feed, permeat flow and salinity, conversion), for spiral membranes (average spacer thickness, average mesh size, length of membrane, active area of membrane, number of leaves), for hollow fibers membranes (inner fiber radius, outer fiber radius, inner bundle radius, outer bundle radius, fiber length, membrane area, porosity). Show figure 5.

** Outputs:

i) Technical parameters: total parameters (total product concentration of salt, total product concentration of Boron, total permeat flow, total plant recovery, total reject concentration of salt), parameters of each stage (number of modules, operating pressure, recovery, bypass/blend rate, product flow of module, product flow, reject flow, product concentration, Reject concentration).

ii) Economic parameters: unit price of water, unit power consumption, investment costs (intake and pretreatment costs, membrane costs, pumping and power recovering system costs, civil and electric work costs, total investment costs, annual amortization), annual operating costs (annual membrane replacement cost, annual energy cost, annual chemical cost, annual maintenance cost, annual labour cost).

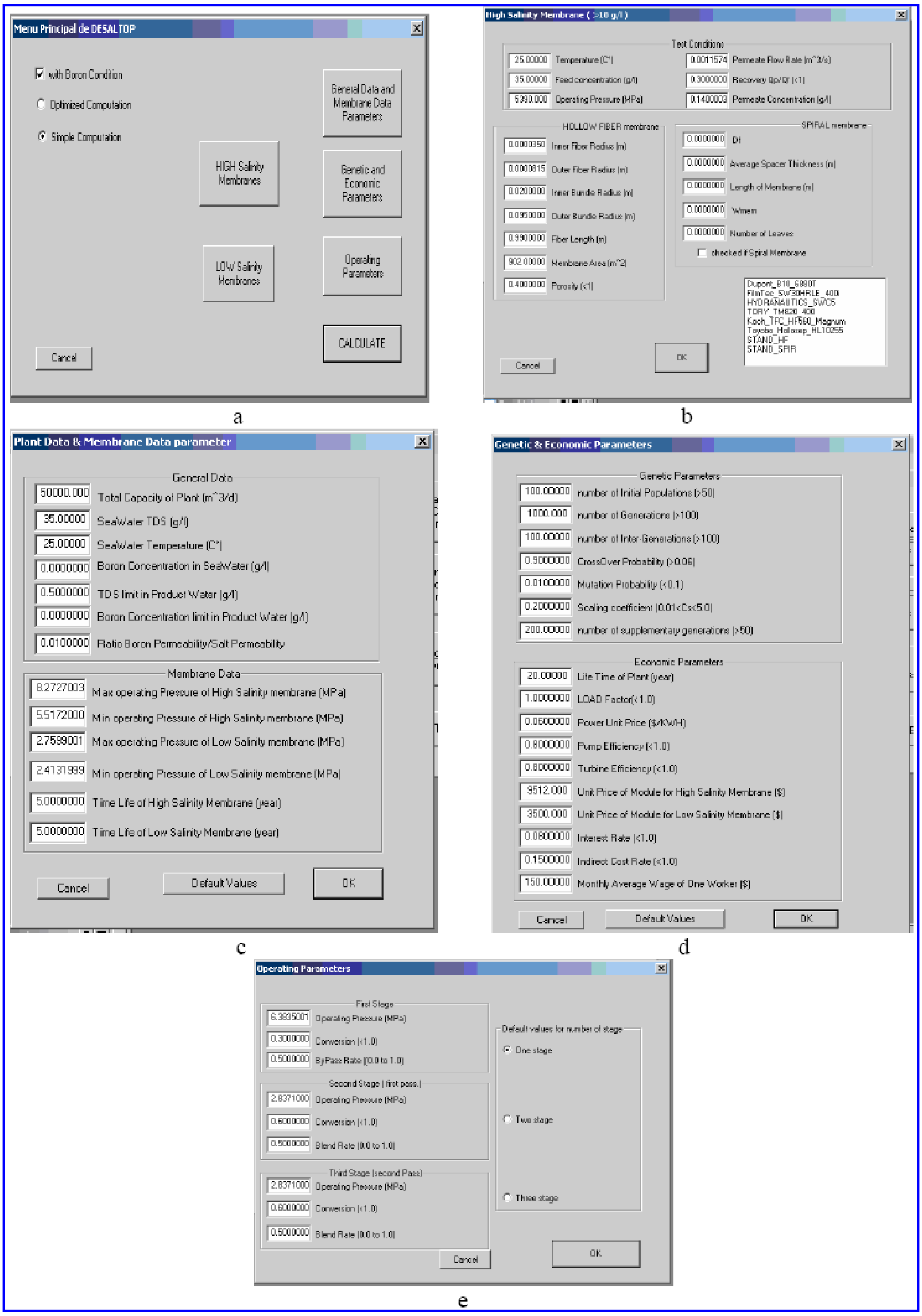

Figure 5: Different menus of Desaltop (a: principal menu, b: menu for membranecharacteristics, c: menu for general data, d: menu for economic andgenetic parameters, e: menu for simple computation parameters).

Applications:

1- Generalities:

We treat through this applications, the several diversified examples of desalination plants to show utility and efficiency of Desaltop code.
Eight desalination plants have been studied (seven for seawater desalination, and one for brackish water), those have very varied characteristics. Show table 2.

The objective is to introduce obtained results by Desaltop, and to show: i) modeling efficiency, ii) optimization utility through the comparison between prices of desalted water by real and optimized plants, iii) and power to calculate the different analytical elements of desalination costs.

The first six plants are designed by Dupont membranes, for this we kept the same used membrane type (DuPont-B10-6880T, DuPont-B9-0840) for show better the optimization utility. For all other cases, and for introduce the results of membrane type optimization, we used the models shown by table 3.

Table 2: Characteristics of desalination plants to be studied

N°	Plant	Capacity (m^3/d)	Water type	Temp. ˚C	Salinity (ppm)	Salinity limit on product water (ppm)
1	Marbella,Spain [35]	56 400	Eau de mer	18	38 750	400
2	Eilat1, Israel [36]	20 000	Eau de mer	23	36 000	400
3	Singapore1, Singapore [37]	4 500	Eau de mer	28	35 000	500
4	Tampa,FL,USA [36]	94 000	Eau de mer	23	24 500	100
5	Larnaca, Cyprus [36]	40 000	Eau de mer	23	40 500	500
6	Tajura, Libya [38]	38 000	Eau de mer	25	38 000	200
7	Skikda, Algeria [34]	100 000	Eau de mer	19	37 000	200
8	Ouargla, Algeria [34]	7560	Eau saumâtre	26	2 728	200

Table 3: Models of used membranes

Trademark	Models for brackish water	Models for seawater
Filmtec	BW30_440i	*SW30HRLE_400i*
Hydranautics	ESPA3	*SWC5*
Toray	TM720_430	*TM820_400*
Koch	HR_MegaMagnum	*TFC_HF560_Magnum*
Desal	AG8040F_400_CERT	*AD8040F*

2- Modeling of membrane transfer:

The comparison between experimental data of membrane transport and transfer, obtained by H.Ohya and al. in 1987 [39], with modeling results obtained by Desaltop, shows a very good reliability of model. Show figure 6.

3- Optimization of operating parameters:

The optimization of operating parameters (pressure and conversion) minimize water desalted price up to 47.26%. Show table 4 and figure 7.

4- Optimization of design:

Design optimization of RO plants, can reduce desalted water price up to 60.4% (with optimization of operating parameters). Show figure 8 and 9.

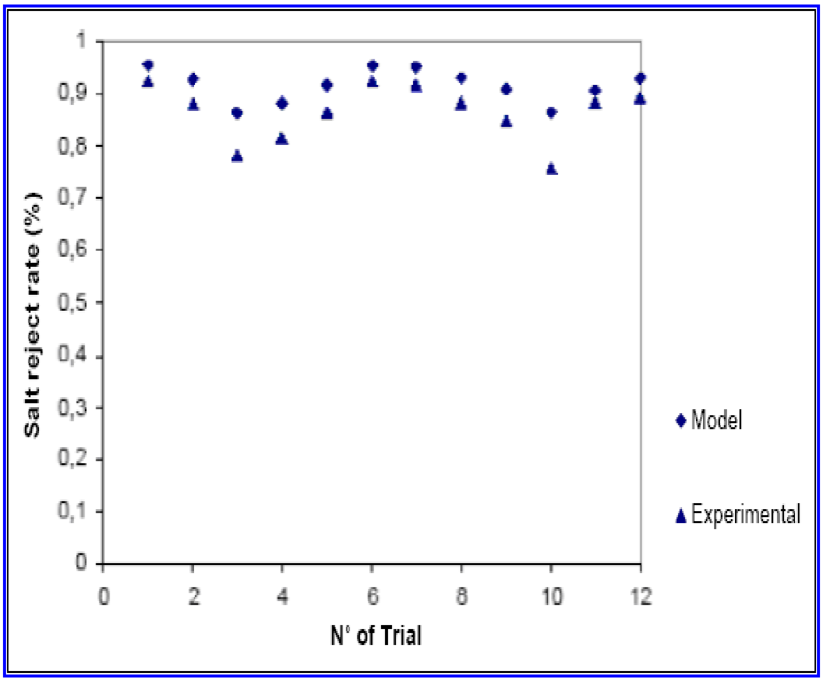

Figure 6: Correlation of model results with experimental data.

Table 4: Real and optimized operating parameters for the three plants: Marbella, Eilat1 and Singapore1

Parameter / Plant	Real conversion (%)	Optimised conversion (%)	Real Pressure (kPa)	Optimised pressure (kPa)
Marbella plant, Spain	45.0	40.0	6850	8273.7
Eilat 1 plant, Israel	50.0	40.0	-	8273.7
Singapore 1 plant, Singapore	32.0	40.0	6205	8273.7

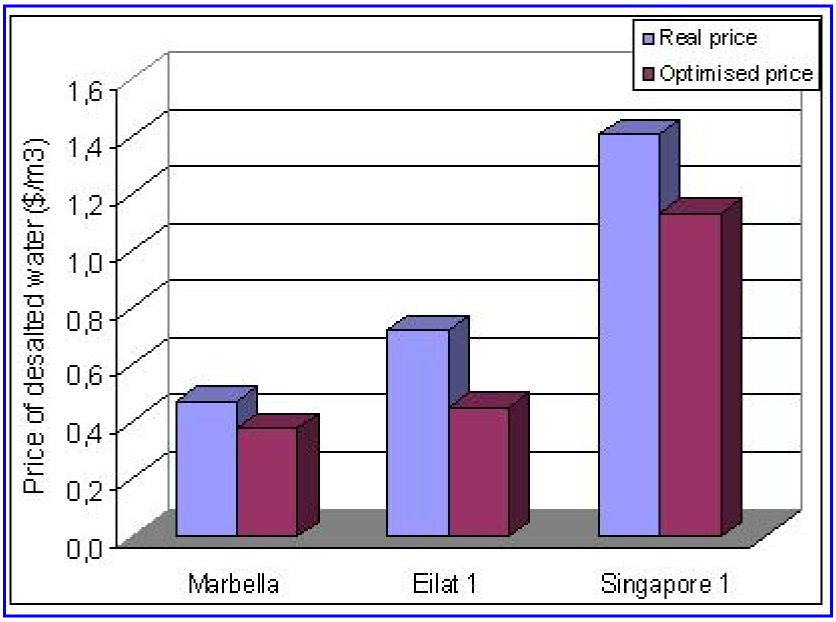

Figure 7: Comparison between real and optimized prices of desalted seawater for Marbella, Eilat1 and Singapore1 plants

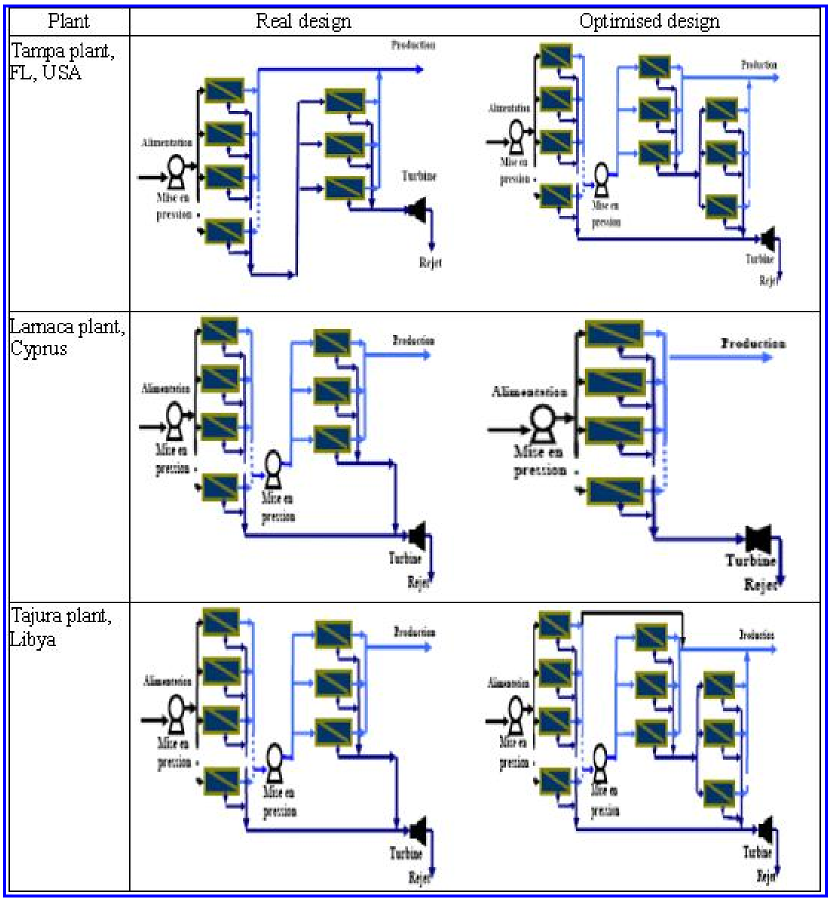

Figure 8: Comparison between real and optimized Designs for the three plants:Tampa, Larnaca and Tajura.

5- Optimization of membrane type:

5-1- Seawater case:

Optimization of membrane type for Skikda plant can reduce desalted water price up to 31% (with optimization of operating parameters). Show figure 10.

5-2- Brackish water case:

Optimization of membrane type for Ouargla plant can reduce water price up to 6% (with optimization of operating parameters). Show figure 11.

6- Optimization coupling of: parameters- design- membrane type:

Optimization through three coupled scales: parameters- design-membrane, for Skikda plant give a desalted water price reduction at 40%. Show figure 12 and 13.

The comparisons are realized in comparison with plants when operating parameters are already optimized. We can estimate that if the coupled optimization is perfect, the reduction of desalted water price can get up to 80%.

7- Economic Calculations:

The figure 14 and 15 show the structures of analytical elements of investment and annual charge costs for water desalination respectively.

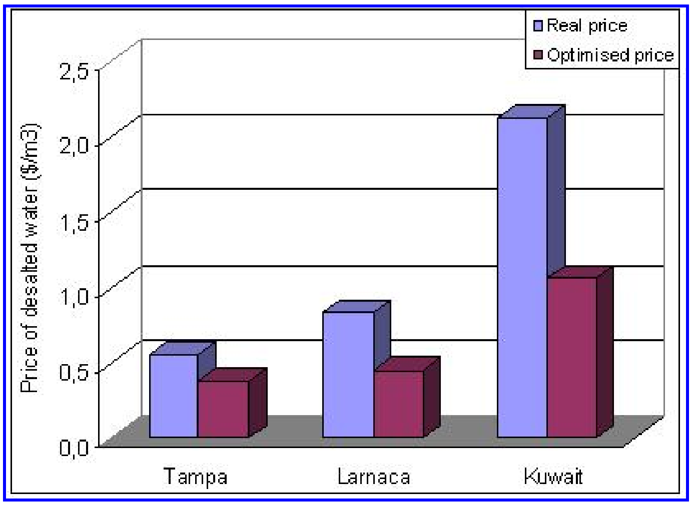

Figure 9: Comparison between real and optimized prices of desalted seawater for Tampa, Larnaca and Tajura plants

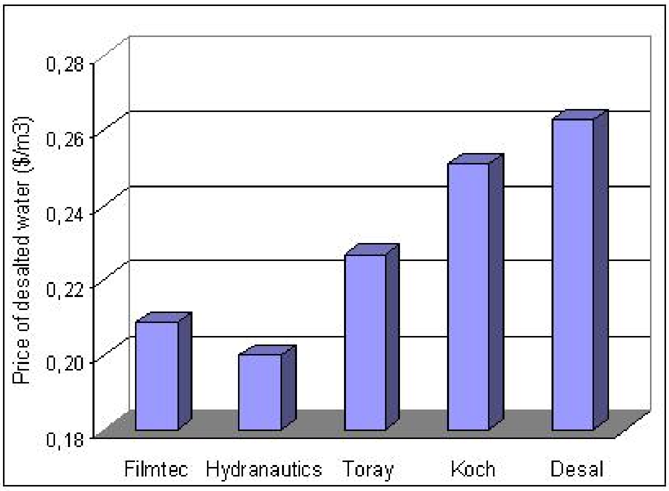

Figure 10: Prices of desalted seawater, using various membranes: case of one stage system (Skikda plant: 100 000 m^3/d)

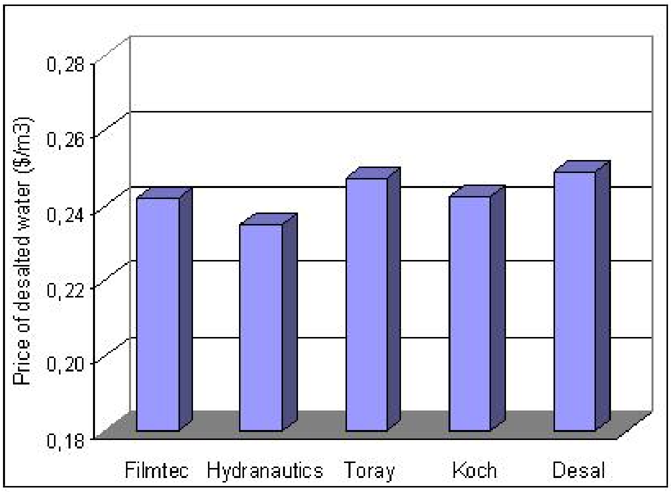

Figure 11: Prices of desalted brackish water, using various membranes: (Ouargla plant: 7 500 m^3/d)

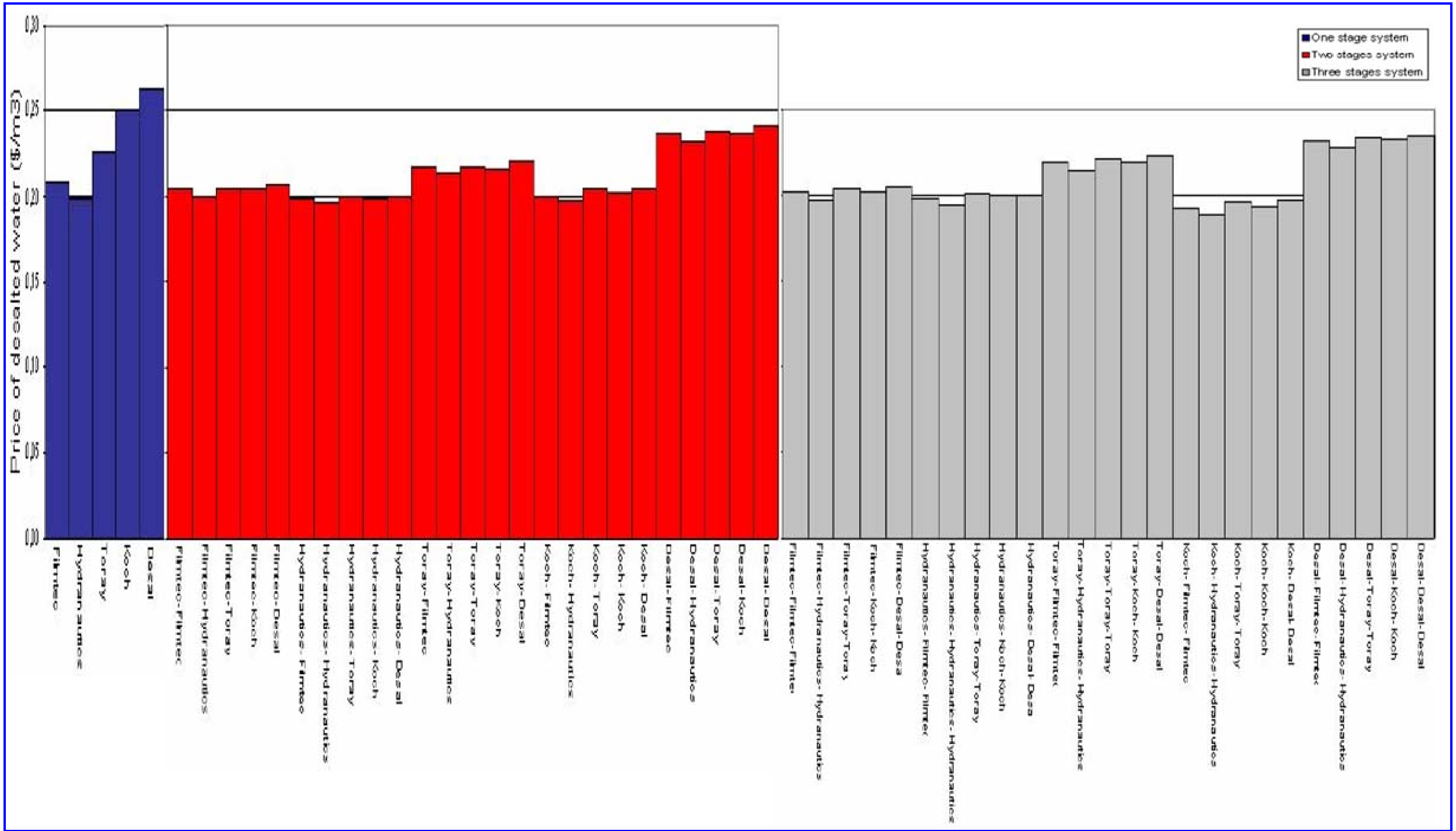

Figure 12: Prices of desalted seawater, using various membranes and various designs: (Skikda plant: 100 000 m^3/d)

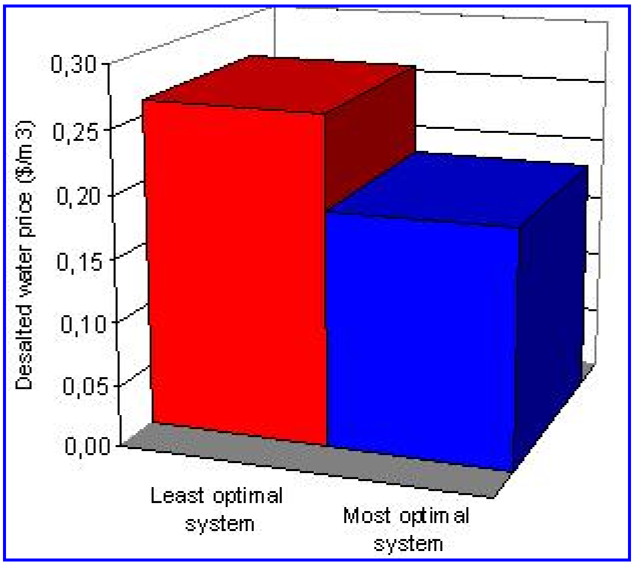

Figure 13: Comparison between desalted water prices of the most and the least optimal systems (Skikda plant)

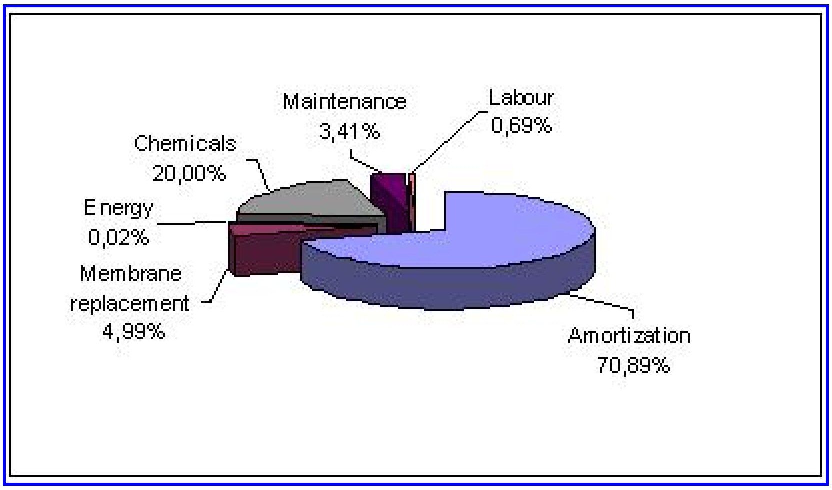

Figure 14: Repartition of annual charges (Skikda plant)

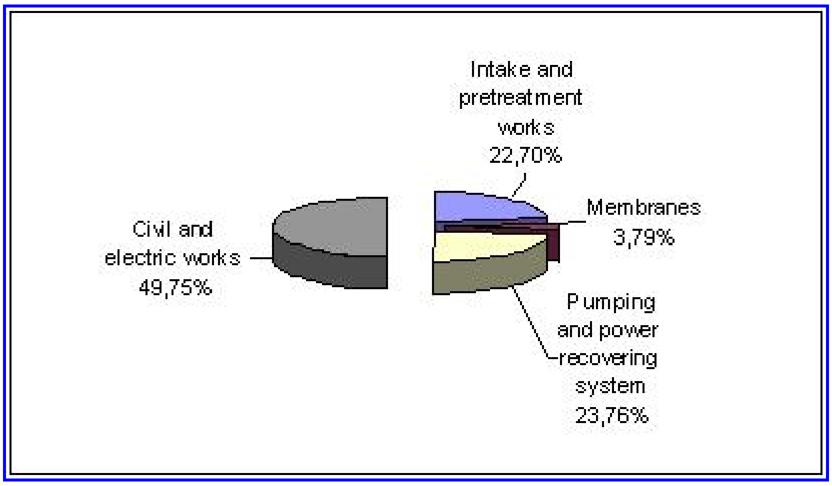

Figure 15: Repartition of Investment costs (Skikda plant)

Conclusions

The richness and diversity of introduced applications (lot of desalination plats, seawater and brackish water, very varied quality and temperature of water to be desalted, different sizes of plants, diversified quality limits –imposed for product water-, separated and coupled optimization scales -membrane type choice, plant design choice, operating parameter choices-), demonstrate clearly the utility, performance and power of Desaltop, like computation and optimization code for RO plants.

The DESALTOP code also forms: a strong element for decision and planning of financial tools in water desalination field.

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