DROPS : *The first Data Reconciliation and OPtimization System for MSF distillers has been installed on Al Taweelah B*

FIRST FEEDBACK DATA AND RESULTS AFTER SOME MONTHS OF OPERATION ON THE WORLD LARGEST MSF DESALINATION PLANT

E. Ghiazza - FISIA / ITALIMPIANTI
B. Fumagalli - TECHINT / ITALIMPIANTI
G. Odicino - DEMAG / ITALIMPIANTI

Abstract

Looking to the shortage of available energy all over the world, one of the main topics today is energy saving. This issue must be taken into account also in the field of MSF desalination, to produce water following a wise policy as far as energy and environment are concerned. Therefore, the aim of a desalination plant should be not only the production of the required amount of distillate water, but also the reduction of the operational and maintenance costs, in order to minimize the unit cost of the produced distillate.

The paper presents an overview on a new Data Reconciliation and OPtimization System which has been installed, for the first time in the world, on the six MSF units of Al Taweelah B (United Arab Emirates), in operation since June 1996 producing twelve million of gallons of fresh water per day each. After the overview, the paper shows some preliminary results and feedback data gathered during the commissioning and first operational period of the Data Reconciliation and OPtimization System.

Generally speaking, the three main operational costs influenced by the set points of an MSF distiller are 1) the cost for the energy input by <u>steam</u>, 2) the cost for <u>chemicals</u> additives, and 3) the cost for <u>electrical energy</u> consumption by the plant equipment (pumps, etc.). As an example, for a fixed distillate production, a plant operation at higher top brine temperature will decrease the steam cost, but it will increase the chemicals cost for unit of water produced. On the other hand, a plant operation at lower top brine temperature for the same distillate production will increase the steam cost, but it will decrease the

chemicals cost for unit of water produced. The best compromise should be found on the basis of the relevant values of the three costs, taking into account also the operational limits for the process variables (temperatures, flowrates, etc.). We are in front of a typical problem of *constrained optimization*, and the paper shows how it is solved by the system in different cases.
As far as the Data Reconciliation is concerned, it has two main tasks: 1) the evaluation of the "*non measured*" variables (such as plant fouling factors) necessary to keep the mathematical model of the OPtimization System aligned with the actual plant status; 2) the evaluation of a set of "*true*" variables giving a picture of the actual plant behavior much more precise than the rough measurement can do. As an example, a rough sea water or brine temperature measurement in a pipe is representative (apart from noise and systematic errors) only of the point where the measurement device is placed, while the "*true*" value from Data Reconciliation is the one representative of the whole stream. In addition to this, Data Reconciliation has also a function of *gross errors* detection, giving an help in finding out faulty or not tuned measurement devices. It's worth mentioning, in the end, that it is the first time that such a system is applied to MSF desalination.

The cost of water

The distillate water produced by a desalination plant has a specific cost depending on many different items, also including the particular kind of plant. First of all we can distinguish between *fixed costs* and *operating costs*, being the first related to the money investment for the plant, and the second related to the production of the distillate.
Not considering the costs of the distillate post-treatments, storage and distribution, related to the installations and operations necessary to go from the raw distillate out from the desalination unit to the potable water distributed by a town water pipeline, a rough splitting of the different items constituting the specific cost of the distillate is given in Fig. 1 for an MSF plant [1].
The data in Fig. 1 are referred to a 10 MIGD MSF unit with a total capital cost of 100 M$, considering a life of 25 years and an average operability of 90%.
However, as far as the plant operating conditions are concerned, not all the costs outlined in Fig. 1 can be "optimized": the fixed charge is not influenced by the plant process parameters, and the maintenance costs can be better reduced with a wise maintenance program. The focus of this paper is instead on how the costs depending on the operating conditions of the plant can be minimized, and on how it has been achieved on the desalination units of the plant in Al Taweelah B. These costs are represented by the *steam* cost, the *electrical power* cost, and the *chemicals consumption* cost.

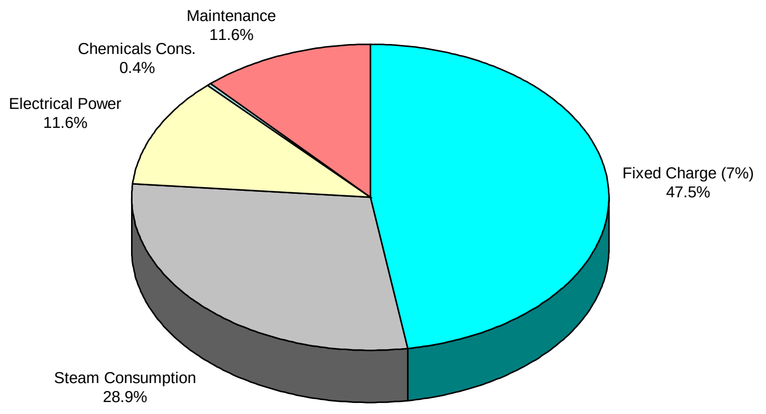

Fig. 1 - Distribution of costs for MSF distillate production

Approach

The DROPS software package has been installed and tested and is now in operation on the MSF units in Al Taweelah B for the first time in the world. Aim of the package is to minimize the part of the distillate cost related to the *steam* cost, the *electrical power* cost, and the *chemicals consumption* cost, automatically adjusting the plant operating conditions (*set points*). The influenced costs are distributed as in Fig. 2.

The plant set points adjusted by the optimization software in order to minimize the sum of the costs in Fig. 2, are the following:

1. Top brine temperature
2. Brine recycle flow
3. Sea water to reject temperature (winter only)
4. Sea water to reject flow
5. Make up flow
6. Antiscale dosing rate
7. L.p. steam to brine heater temperature

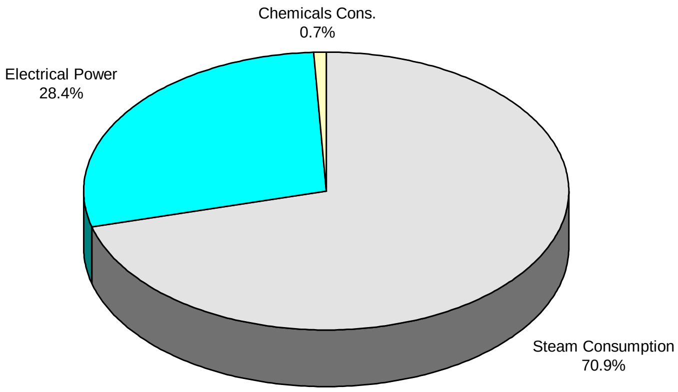

Fig. 2 - Distribution of costs influenced by MSF plant set points

The costs of the other chemicals (Antifoam and Sodium Sulphite) are not considered here since their dosing rate is not changing at different operating conditions of the plant.

The principles on how the overall cost is minimized can be well explained by a simple example, involving only two (top brine temperature and brine recycle flow) of the seven set points listed above, and only two (steam and antiscale) of the three considered costs.

The same distillate production can be reached on one MSF unit at higher top brine temperature and lower brine recycle flow, or at lower top brine temperature and higher brine recycle flow. As shown in Fig. 3, the steam cost is decreasing with the top brine temperature (due to an increase in the plant performance ratio), while the antiscale cost is increasing (due to an increase in the necessary antiscale dosing rate); therefore, an “optimum” value of top brine temperature exists that minimize the overall cost.

Hence, if the plant is for instance running under the operating condition 1, a decrease in the cost of the distillate will be achieved lowering the brine recycle flow and increasing the top brine temperature, while the opposite will be required if the plant is running under the operating condition 2.

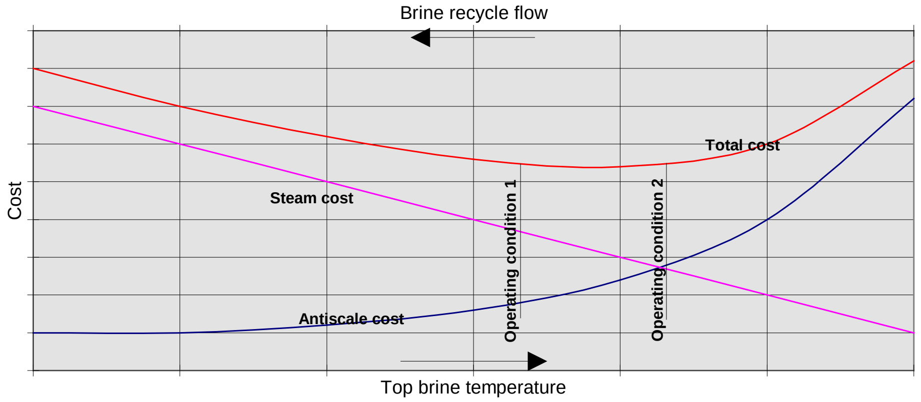

Fig. 3 - Influence of tbt / R on steam and chemicals costs at constant production

The problem would be simple in a case like in the example above, but gets more and more complicated when more set points and more costs are taken into account. In fact, every cost component is influenced by more set points, considering for example that the electrical costs are relevant to all the process pumps and change in accordance to different flows. A summary of the situation on the plant in Al Taweelah B is outlined in Table 1.

	tbt	R	swt	F	Mu
Steam cost	X	X	X	X	
Chem. cost	X				X
SW pump			X	X	
R pump		X			
C pump	X	X	X		
BD pump					X

Tab. 1 - Influences of different set points on cost items

Finding the optimum group of set points constitutes therefore a complex multidimensional non-linear constrained minimization problem, solved by the optimization software using a well proven quasi-Newton non-linear algorithm, whose details can be found in [2].

<u>The need for Data Reconciliation</u>

The schematic functional structure of the **D**ata **R**econciliation and **Op**timization **S**ystem, developed by FISIA/ITALIMPIANTI, is outlined in Fig. 4.
The heart of the package, represented by the block "**Op**timization **S**ystem", is essentially working in this case on a problem where:

- Targets: desired distillate production rate
  minimum specific distillate cost
- Parameters: plant set points
- Constraints: set points allowed values
  in tubes velocity allowed values
  brine salinity allowed values
  process pumps capacity allowed values

Since it is mandatory that the mathematical model used by the optimization algorithm is kept constantly aligned with the actual status of the plant, a function of "parameters estimation" (mainly corresponding to fouling factors) is included in the system; this estimation is significant <u>only when based on reliable measurement from the plant</u>, hence the need for an internal function of data treatment represented in Fig. 4 by the block "**D**ata **R**econciliation", carried out by mean of proper sophisticated mathematical algorithms (for "true" values evaluation) and of modern redundancy-based data treatment techniques (for error detection features). Details for Data Reconciliation algorithms can be found in [3].
The knowledge of the plant fouling trend in time and of the presence of faulty or not tuned measurement devices can give useful hints to the plant management about the best plant operating policy. If this could in the end positively affecting the overall life of the plant even only for a few percentage points, this would reduce the fixed charge slightly. But, since the fixed charge constitutes almost one half of the overall cost of distillate (see Fig. 1), the global money saving could be in the end not negligible.

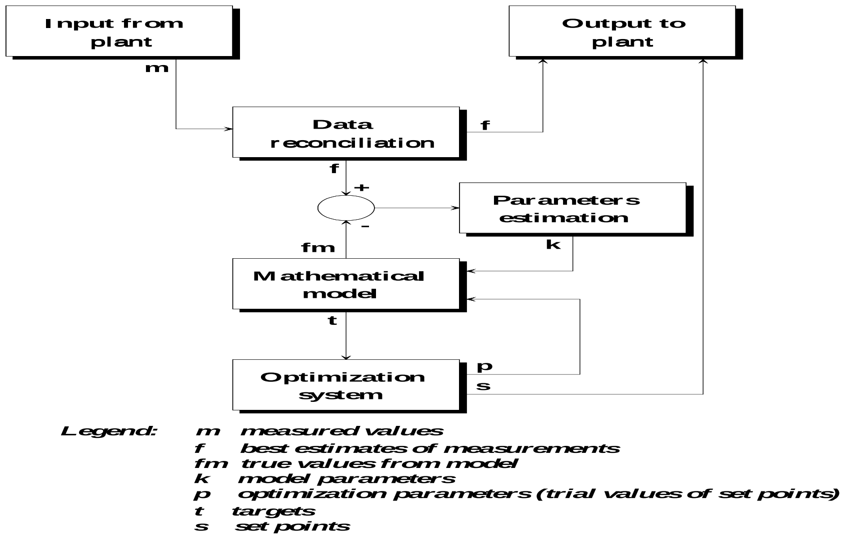

Fig. 4: The functional structure of DROPS

Operational results

The system has been tested on all the six MSF units of Al Taweelah B desalination plant at three different loads:

- Minimum load (7.4 MIGD, 84 °C tbt)
- Nominal load (10.5 MIGD, 100 °C tbt)
- Maximum load (12.7 MIGD, 112 °C tbt)

For each case, a first evaluation of the produced water unit cost (US$/m^3) has been carried out with the plant running under D.U.C. (automatic) control mode.
With the plant running under D.U.C. control mode at constant load, the Optimization control mode has been inserted, so that the controlled set points on the regulators are automatically switched to the optimized ones, and a sufficient time has been waited to allow the plant to reach steady state conditions.
Afterwards, an evaluation of the produced water unit cost (US$/m^3) has been carried out with the plant running under Optimization control mode, and the two results have been compared.

The comparisons for each of these cases, <u>with real data collected on the plant during the system test period</u>, are shown in Fig. 5, Fig. 6 and Fig. 7.

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DESALINATION UNIT # 3
OPTIMIZATION SYSTEM FUNCTIONAL TEST

CALCULATION SHEET AT **84 TBT** **SW** **25**

PLANT CONTROL:			**D.U.C.**	**O P T**
Readings				
Date:			25/4/97	26/4/97
Starting time:			11:00	20:00
Distillate flow rate				
Average distillate production (volumetric)	q'	m3/h	1,400	1,480
Brine recycle flow rate				
Average brine flow (volumetric)	Wr'	m3/h	16,118	16,462
Average bottom brine temperature	Tb	°C	31.9	32.4
Brine tds	salr	g/l	50.8	51.1
Density of brine	ρr	kg/m3	1,032.5	1,032.6
Average brine flow (mass)	Wr	t/h	16,642	16,998
Steam cost for unit water				
Average top brine temperature	TBT	°C	84.00	85.93
Average brine to B.H. temperature	TiBH	°C	78.06	79.93
Average brine specific heat	cpr	KJ/Kg°C	3.94	3.94
Brine heater heat load Q = Wr*cpr*(TBT-TiBH)	Q	GJ/h	389.8	402.2
Steam unit cost	Cv	US$/GJ	1.11	1.11
Steam cost for unit water $\Phi1 = Cv*Q/q'$	Φ1	US$/m3	**0.309**	**0.302**
Antiscale cost for unit water				
Antiscale solution flow	Was'	l/h	14.25	14.40
Antiscale solution concentration	conc	Kg/l	0.20	0.20
Antiscale unit cost	Cas	US$/Kg	1.42	1.42
Antiscale cost for unit water $\Phi2 = Cas*Was*conc/q'$	Φ2	US$/m3	**0.003**	**0.003**
Electrical cost for unit water				
Total pumps power consumption	ΣPi	KW	8510.6	8629.5
Electrical energy unit cost	Cel	US$/KWh	0.03	0.03
Electrical cost for unit water $\Phi3 = Cel*\Sigma Pi/q'$	Φ3	US$/m3	**0.186**	**0.178**
Total cost for unit water $\Phi = \Phi1+\Phi2+\Phi3$	Φ	US$/m3	**0.495**	**0.480**

Fig. 5: Comparison at Minimum Load

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DESALINATION UNIT # 6
OPTIMIZATION SYSTEM FUNCTIONAL TEST

CALCULATION SHEET AT 100 TBT SW 25

PLANT CONTROL:				**D.U.C.**	**O P T**
Readings					
Date:				21/4/97	22/4/97
Starting time:				13:00	12:00
Distillate flow rate					
Average distillate production (volumetric)		q'	m3/h	2,025	2,030
Brine recycle flow rate					
Average brine flow (volumetric)		Wr'	m3/h	19,170	18,820
Average bottom brine temperature		Tb	°C	33.0	32.8
Brine tds		salr	g/l	58.3	52.8
Density of brine		ρr	kg/m3	1,037.7	1,033.7
Average brine flow (mass)		Wr	t/h	19,893	19,454
Steam cost for unit water					
Average top brine temperature		TBT	°C	99.32	99.53
Average brine to B.H. temperature		TiBH	°C	92.98	93.48
Average brine specific heat		cpr	KJ/Kg°C	3.92	3.94
Brine heater heat load	Q = Wr*cpr*(TBT-TiBH)	Q	GJ/h	494.3	464.0
Steam unit cost		Cv	US$/GJ	1.11	1.11
Steam cost for unit water	Φ1 = Cv*Q/q'	Φ1	US$/m3	**0.271**	**0.253**
Antiscale cost for unit water					
Antiscale solution flow		Was'	l/h	48.00	39.00
Antiscale solution concentration		conc	Kg/l	0.20	0.20
Antiscale unit cost		Cas	US$/Kg	1.42	1.42
Antiscale cost for unit water	Φ2 = Cas*Was*conc/q'	Φ2	US$/m3	**0.007**	**0.006**
Electrical cost for unit water					
Total pumps power consumption		ΣPi	KW	8455.8	8451.4
Electrical energy unit cost		Cel	US$/KWh	0.03	0.03
Electrical cost for unit water	Φ3 = Cel*ΣPi/q'	Φ3	US$/m3	**0.128**	**0.127**
Total cost for unit water	Φ =Φ1+Φ2+Φ3	Φ	US$/m3	**0.406**	**0.386**

Fig. 6: Comparison at Nominal Load

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DESALINATION UNIT # 2
OPTIMIZATION SYSTEM FUNCTIONAL TEST

CALCULATION SHEET AT 112 TBT SW 25

PLANT CONTROL:			**D.U.C.**	**O P T**
Readings				
Date:			23/4/97	24/4/97
Starting time:			13:00	12:00
Distillate flow rate				
Average distillate production (volumetric)	q'	m3/h	2,408	2,403
Brine recycle flow rate				
Average brine flow (volumetric)	Wr'	m3/h	19,960	19,555
Average bottom brine temperature	Tb	°C	34.0	33.4
Brine tds	salr	g/l	51.3	53.5
Density of brine	ρr	kg/m3	1,032.1	1,034.0
Average brine flow (mass)	Wr	t/h	20,601	20,219
Steam cost for unit water				
Average top brine temperature	TBT	°C	107.20	108.24
Average brine to B.H. temperature	TiBH	°C	99.50	100.44
Average brine specific heat	cpr	KJ/Kg°C	3.95	3.94
Brine heater heat load Q = Wr*cpr*(TBT-TiBH)	Q	GJ/h	627.1	622.1
Steam unit cost	Cv	US$/GJ	1.11	1.11
Steam cost for unit water $\Phi1 = Cv*Q/q'$	Φ1	US$/m3	**0.289**	**0.288**
Antiscale cost for unit water				
Antiscale solution flow	Was'	l/h	94.25	67.75
Antiscale solution concentration	conc	Kg/l	0.20	0.20
Antiscale unit cost	Cas	US$/Kg	1.42	1.42
Antiscale cost for unit water $\Phi2 = Cas*Was*conc/q'$	Φ2	US$/m3	**0.011**	**0.008**
Electrical cost for unit water				
Total pumps power consumption	ΣPi	KW	8864.5	8989.5
Electrical energy unit cost	Cel	US$/KWh	0.03	0.03
Electrical cost for unit water $\Phi3 = Cel*\Sigma Pi/q'$	Φ3	US$/m3	**0.113**	**0.114**
Total cost for unit water $\Phi = \Phi1+\Phi2+\Phi3$	Φ	US$/m3	**0.413**	**0.410**

Fig. 7: Comparison at Maximum Load

Conclusions

By a comparison of the outputs relevant to the plant operation with and without optimization, it can be seen that in any case the use of the package yielded a decrease in the specific cost of the produced distillate, as far as the set points influenced costs are concerned. Prior to draw some quantitative conclusions about the actual saving of money for a plant like Al Taweelah B, it is worth mentioning that the achievable relative saving of money <u>is not the same</u> when the plant is operated at minimum, nominal or maximum load. As it can be seen, an higher margin of improvement is possible at nominal load, with respect to minimum and especially to maximum load, as expected. This is due to the fact that at minimum load there is no margin of improvement as far as the antiscale cost is concerned, since at very low top brine temperatures the antiscale dosing rate does not depend on the temperature any more, while at maximum load there is a very short margin on every set point, being the plant already operated at its limit conditions.
At last, we would like to show how even apparently negligible reductions in the cost of the distillate can result in <u>considerable savings</u> when we refer to a plant with a size like Al Taweelah B. In Table 2 a quantitative analysis of the possible saving is reported.

		Min. load	**Nom. load**	**Max. load**
Cost without DROPS	US$/m^3	0.495	0.406	0.413
Cost with DROPS	US$/m^3	0.480	0.386	0.410
Cost difference	US$/m^3	0.015	0.02	0.003
Unit production	m^3/day	33640	47730	57740
Availability	-	.9	.9	.9
Annual saving 1 unit	US$/year	165761	313586	56903
Number of units	-	6	6	6
Total Annual Saving	**US$/year**	**$994,566**	**$1,881,516**	**$341,418**

Tab. 2 - Annual saving forecast for Al Taweelah B plant

It's worth mentioning, in the end, that a system of this kind is applied to a plant for the first time in the field of desalination. As shown in the paper, the preliminary results look quite satisfactory, giving hope for such a system to be adopted in the future on a larger scale.

Nomenclature

C pump	condensate pump	[-]
D.U.C.	Distiller Unit Coordinator	[-]
BD pump	brine blow down pump	[-]
F	sea water to reject flow	[t/h]
Mu	sea water make up flow	[t/h]
O P T	Optimization system	[-]
R	brine recycle flow	[t/h]
R pump	brine recycle pump	[-]
SW pump	sea water to reject pump	[-]
swt	sea water to reject temperature	[°C]
tbt	top brine temperature	[°C]

References

1 Leitner, G.F., *Water Desalination, What are Today's Costs?* The International Desalination & Water Reuse Quarterly Vol. 2 - 1, 1992 39-43

2 Ghiazza, E., F. Giovani, *A general tool for a better use of design or verification of mathematical models.* Desalination 105, 1996 51-56

3 Ghiazza, E., B. Fumagalli, *Mathematical modeling and expert systems integration for optimum control strategy of MSF desalination plants.* Desalination 92, 1993 281-293