Proceedings of the 10th Brazilian Congress of Thermal Sciences and Engineering -- ENCIT 2004
Braz. Soc. of Mechanical Sciences and Engineering -- ABCM, Rio de Janeiro, Brazil, Nov. 29 -- Dec. 03, 2004

Paper CIT04-0043

OPPORTUNITIES OF INTEGRATING DESALINATION TO COGENERATION FOR BRAZILIAN CONDITIONS

Eduardo Manfredini Ferreira
Universidade Estadual Paulista
Av. Dr. Ariberto Pereira da Cunha, 333 CEP: 12516-410 – Guaratinguetá, S.P., Brasil.
mfeduardo@uol.com.br

José Antônio Perrella Balestieri
Universidade Estadual Paulista
Av. Dr. Ariberto Pereira da Cunha, 333 CEP: 12516-410 – Guaratinguetá, S.P., Brasil.
perrella@feg.unesp.br

Abstract. One of the human problems in this century refers to the availability of potable water, necessary to the populations' survival; the world population is continually increasing and natural resources are proportionally decreasing, and the development of potable water production techniques demands intensive efforts. Electric power requirement is also necessary to the development of nations. Desalination processes are widely used in countries with low offer of potable water. Technologies nowadays in use are multi-stage-flash distillation (MSF), multi-effect distillation (MED) and reverse osmosis (RO) process. In MSF and MED processes, the main technique is distillation. Reverse osmosis technique relies on the osmotic principle, in which a solvent passes through a membrane. Since the middle of 1950, these desalting techniques are widely used mainly in Middle East countries, where water shortage is almost absolute. Although uncommonly conceived, discussing the implementation of desalination processes in association to cogeneration systems for Brazil is a necessary task for the long-term planning. In this way, this paper proposes to review the successful experiences presented in the literature as a way of establishing how electric power and fresh water production can be produced from seawater desalting processes in an optimized way. Another objective pursued in this paper is awakening more attention to this matter, that deserves discussing the skill staff formation and the know-how of such technologies in the strategic planning to the water resource management, specially because these investments require a considerable time for human resources development and the knowledge of the most adequate technology to be implemented for the integration of desalting and cogeneration units.
Keywords. desalination – cogeneration – natural resources planning

1. INTRODUCTION

Water is a natural resource of first necessity for the existence of any form of life such as we knows it. Human being needs the water consumption to live, not being used just for this; sanitation and personal hygiene are other uses. But another use that suggests high dependence human is of the electric energy generation, by use in hydroelectric plants or through its use for steam attainment in thermal plants.

Beyond the existing problems in many places with respect to the water scarcity, the reality of supplying systems in some country regions and other parts of the world face several difficulties. At certain moments its availability is not enough, so it doesn't attend the population set; at another moment it is inefficient, for allowing losses through leaks, lack of maintenance and the bad use by the users, with flagrant wastes. According to Graça (2004), Brazilian water wastes, relatively to the water produced in the country, reach 46%, that it is equivalent to 5,8 billion of m^3 per year. In Europe, this index is around 10% and, in Cingapura, 6%.

Relatively to the electric energy consumption, waste is about of 15% of the consumed value, equivalent to the Angra 2 production. Several research reports that about 0,8% of the available water in the world is in the form of fresh water (including treatment and sewer stations reuse water), about 2,2% are in glaciers and around 97% is formed of salty water; Brazil would withhold 12% of the fresh water of the world, according to UNIAGUA (2003). Because of this, it can be seen as exceptional fact, in a first moment, a study that deals with evaluating the conditions for the desalination technologies use in Brazil, that still counts, comparatively to other countries, with a good position in terms of hydric resources, especially when in cogeneration thermoelectric systems association, which are not part of the Brazilian energy sector. In terms of the energy planning and the natural resources, however, it is glimpsed the needed to start studies directed to the question of the drinking waters availability in the near future, as well as the possibilities of trust of its production and of the generation of electric energy, in time to enable human resources to attend future demands of this order, besides establishing the preliminary conditions to medium and long term decisions that will be necessary.

This article presents the methods of desalination of seawater world-wide used – multistage flash distillation (MSF), multi-effect distillation (MED) and reverse osmosis (RO) – in association to the cogeneration schemes, which will be useful to generate the required energy by the desalination processes and, perhaps, the generation of electric energy for commercialization. The application of the cogeneration/desalination integration in Brazil is also argued due to the necessities relatively to the drinking water and electricity increasing demands, and the problem of modeling must contemplate the possible alternatives in an exempt and scientific way; of this form, the integration proposal must be faced as a possible alternative, fitting technician, logistic and economic studies to establish the conditions for its implementation.

2. COGENERATION APPLIED TO DESALINATION

Cogeneration is based on the exploitation of multiple energy forms from a same primary energy; in general, a cogeneration system make available energy in electrical/mechanical or thermal form (steam, water and/or hot and/or cooled air), and the economic attractiveness about enterprises of this order will depend on the analysis of the structure of the involved costs in the production of such products. When in association with desalination systems, the involved products are, in the majority of cases, electric energy and water with degree of acceptable potability relatively to certain standards, being steam and/or cooling equally desirable products.

The potability of the water is defined from standards established for regulating agencies; in the Brazilian case, the demandable characteristics and the maximum mineral contents allowed in its composition must be in accordance to Decree MS 518 12-00, published in 25/03/2004. For Balestieri (2002), a unit of process that demands energy in the form of thermal (symbolized for S in Fig. 1) and electromechanical (symbolized for E in the same figure) must be guided through specific characteristics of its operation, the project of the cogeneration system associated to it, which will have to be projected to produce, in all or in part, thermal energy (symbolized for S') and electromechanical energy (symbolized for E').

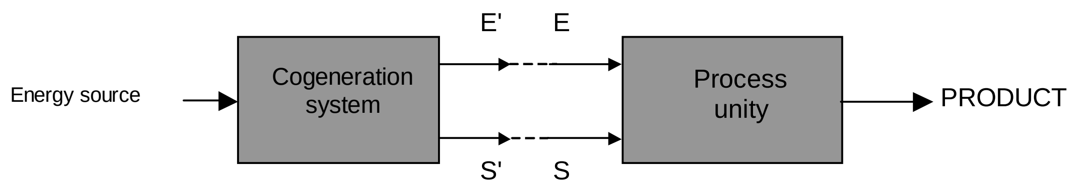

Figure 1- Structure between cogeneration system and process unity

The harmonization between the parcels E and E’, as well as S and S’, depends on the strategies that are conceived for the cogeneration system design. Thus, a project with thermal parity is that one in which it is imposed that the parcels S and S' are equal, implicating that the production and the consumption of thermal energy must be equal, and to the other parcel of generated energy (E') to be bigger, equal or lesser that its consumption E; in this case the electric energy purchasing or selling hypothesis must be analyzed. Equal analysis must be proceeding when the parity is electric.

Cogeneration systems association with desalination processes is based on the necessity that these last ones presents with respect to the necessity of thermal and/or electric energy, in function of the considered technologies of desalination. The variability analysis of loads of the process unit must take in account daily and seasonal aspects of the energy, as well as characteristics of loads fluctuation, batch or continuous processing, market influences, among others.

The decision concerning the configuration to be used, as well as the analysis of the dispatch and coordination of the cogeneration system operation associated with a desalination process, involves certain complexity, as shown in Barclay (1988). For example, a combined unit that presents low ratio in electricity/water produced rate, even with low efficiency, will must be operated to satisfy the water demand; depending on the chosen technology, in the case of the winter electricity demand is reduced, it could have a significant reduction of low available cost steam for the drinking waters production.

A cogeneration system can accommodate diverse consolidated technologies, as well as, in hypothesis, to consider new technologies that are under development. The energy sources for the cogeneration system can be derived from fossils fuels (as natural gas or combustible oil) or renewed (as *in natura* or gasified vegetal biomass). In this way, technologies that have been used in cogeneration–desalination systems, according Azoury (2001) and El-Nashar (2001), are:

- Steam cycle, with conventional boilers and backpressure turbines (CCONV + TVCP);
- Steam cycle, with conventional boilers and condensation and extraction turbines (CCONV + TVCD-E);
- Gas cycle, with gas turbines and heat recovery steam generators (TG + CREC);
- Combined cycles, composed by gas turbines, heat recovery boilers and backpressure turbines (CC/TVCP);
- Combined cycles, composed by gas turbines, heat recovery boilers and condensation and extraction turbines (CC/TVCD-E).

3. DESALINATION PROCESSES

The desalination processes, such as the cogeneration systems, present recognized technologies that are being employed in countries where the water scarcity is great, maybe total; there are desalination processes that still are, at the moment, in diverse stages of development, occupying the bound knowledge. The main processes of desalination currently used are:

- Multi-effect distillation (MED)
- Multistage flash distillation of steam (MSF);
- Reverse osmosis (RO).

According to Van der Bruggen and Vandecasteele (2002), MED process was one of the pioneers in this area, being the oldest one. Multiple effects distillation is based on the transportation of condensing steam heat for the seawater in a series of stages or effects. In the first effect, the preheated water condenses primary steam. This steam passes to a second stage in a fewer pressure and temperature, and the condensed steam returns to the boiler. Distillers can be horizontal or vertical. MED plant problems are associated to corrosion and scaling by the presence of $CaSO_4$. Advantages of its use are associated to the raised water production rate compared to its steam consumption.

The MSF is based on a series of chambers where steam is generated by the feeding water. The steam is condensed by the exchange of heat in a series of closed pipes where seawater is preheated. Collecting trays are used to collect the condensed and the resultant brine is re-circulated to increase the water recovery. Main advantage is its reliability. Inorganic compounds precipitation can occur and its reduction is made through acid or antiscalling as well as biocides to decrease the bacteria risk. The produced water presents about 50 ppm of total dissolved salts (TDS). The main disadvantage of the MSF is its performance rate, approximately 11, resulting in a high-energy consumption that reveals, sometimes, to be economically feasible, as showed by Van Der Bruggen and Vandecasteele (2002).

Although reverse osmosis is known and applied 50 years ago, only in the 1980s it becomes competitive in comparison to the distillation techniques. It is a separation process for membrane in which seawater passes through a membrane by means of an external pressure superior than the osmotic pressure. Pure water produced is named permeate, and the concentrate fraction is named concentrated or brine. The majority of the membranes are polymeric, consisting of a separation thin layer and support layers. Even with a high pumping cost, the produced water cost by RO is half of that MSF and MED, with about 0.50-0.70 USS/m^3, with a good permeate quality. The disadvantage of the reverse osmosis consists in the membrane sensitivity relative to its scaling and the damage by oxidized compounds, being necessary a pre-treatment to guarantee a stable module performance, as cited for Van Der Bruggen and Vandecasteele (2002).

Other processes that are still in development, or present reduced practical use at this moment, are:

- Electro-Dialysis (ED) and reverse electro-dialysis (EDR), which are only feasible for brackish waters or with low salt concentration;
- Steam Compression (VC), used for small installations.
- Solar desalination, which still is considered not economically viable because of its low conversion.

It can be perceived, moreover, that even so the authors defend their methods as the most efficient and of lesser costs, it must be taken into account that some environment impacts are consequent to the desalination process, which must be considered in a comparative analysis, according Morton, Callister and Wade (1996); the comparison of desalination processes must taken in account investment costs, specific energy consumption and the consequent environment impacts relative to their use.

Applegate (1984) presents energy specific consumption values zones for drinking waters production: while electrodialysis points out in the range of 1.6 to 2.6 kWh/m^3, reverse osmosis varies from 1.6 to 2.1 kWh/m^3 for brackish water and from 9.2 to 10.6 kWh/m^3 for seawater, the ultrafiltration consumes from 0.5 to 20 kWh/m^3, depending on the use, and systems with distillation consumes 43,3 kWh/m^3 of produced water, second Maldonado (1991). Applegate (1984) still explain several membrane separation processes, as well as the kind of the membranes, RO devices, pretreatment, and application, economics and the future of the many types of membrane processes, as reverse osmosis, electrodialysis and ultrafiltration.

Maldonado (1991) presents a study that completes Applegate's data, so micro and nanofiltration, dialysis, pervaporation and gas permeation are also studied. It still presents international and national perspectives. Semiat (2000) presents comparative costs, shown in Tab. 1, for the different desalination techniques described in his study, valued in publications or proposals available at that time. Just general cases are treated. The differences of produced water cost are visible in comparison to distillation methods, mainly the steam flash, steam compression and reverse osmosis methods. The cost range depends mainly on the installation size; presented values are representative of the application of the technologies in installations in countries with great constraints of drinking waters availability.

Table 1 – Desalination cost comparison

	MSF	**MED**	**VC**	**RO**
Installation costs (US$/$m^3$/day)	1200–1500	900–1000	950–1000	700–900
Product costs (US$/$m^3$)	1.10–1.25	0.75–0.85	0.87–0.95	0.68–0.92

Several research reports established costs for associated cogeneration desalination systems, and values of the order of 0.47 USS/m^3 for units MED and 0.86 USS/m^3 for associated 120 MW cogeneration MSF units, or 0.64 and 1.01 USS/m^3, respectively, for association with cogeneration system of 30 MW, according Safi and Korchani (1999) are described in the literature. It is needed to emphasize that such values had been based on traditional economic methods, and not in the exergoeconomic analysis, and describes another countries reality.

A preliminary study of water costs for Brazilian public services discloses values close to that ones presented in literature for different desalination technologies. Tab. 2 presents values for the state service and an autonomous service of water and sewer of São Paulo State. It must be detached that values presented for Tab. 1 refers to the costs of drinking water production and the values described in Tab. 2 correspond to the practiced actual values, having therefore to be affected for taxes and tributes. A distribution of costs as shown by Semiat (2000) is presented in percentage form in Fig. 2, for which the main osmosis unit costs are related to electric power consumption. Poulikkas (2001) applies another systematic of costs for desalination reverse osmosis, which is given in Tab. 3. Carvalho (2000) demonstrates, that reverse osmosis was, for the 1991 data, the methodology more used in worldwide level, as showed comparatively to the other methods in Fig. 3. For the energy consumption point of view, the reverse osmosis presents the lowest consumption, as shown in Fig. 4.

Table 2 – Costs comparison for the state and autonomy service of water and sewer in São Paulo State

	SAAEG		**SABESP**	
m^3/month	**Industrial**	**Residential**	**Industrial**	**Residential**
0 a 10	3.94 US$/month	1.73 US$/month	6.88 US$/month	3.43 US$/month
11 a 20	0.68 US$/m^3	0.33 US$/m^3	0.81 US$/m^3	0.48 US$/m^3
21 a 50	1.26 US$/m^3	0.56 US$/m^3	1.32 US$/m^3	0.73 US$/m^3
More than 50	1.94 US$/m^3	0.92 US$/m^3	1.55 US$/m^3	0.87 US$/m^3

Note: (a) conversion factor: 1US$= 2.80 R$ (b) relative values to the price charged by the water offer (c) SAAEG: Autonomy Service of water and sewer of Guaratinguetá (d) SABESP: Basic Sanitation Company of State of São Paulo (2004)

Sources: <http://www.saaeg.com.br/tarifas.htm> and <http://www2.sabesp.com.br/agencia/informe–se/tarifas.pdf >, access in 16/04/2004

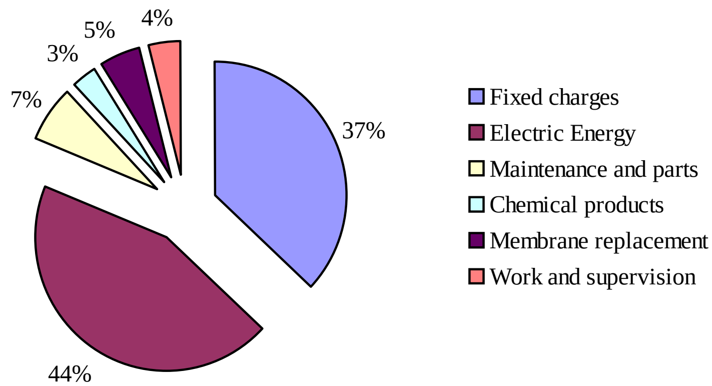

Figure 2 – Seawater reverse osmosis typical costs

Table 3 – Typical range of desalted water production cost

Components	Contribution, %
Capital recuperation cost	30 – 50
Energetic cost	30 – 50
Operation and maintenance	15 – 30

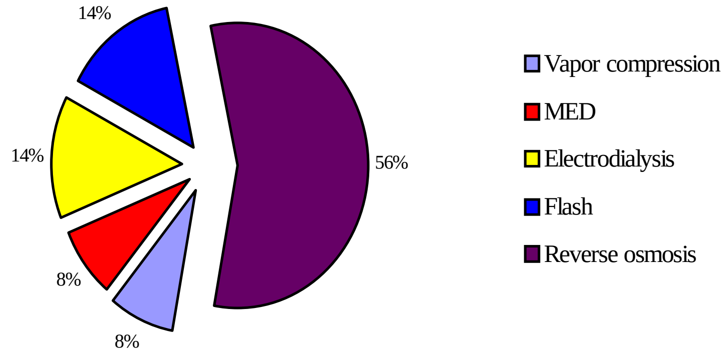

Figure 3 – Comparative use of desalination methods

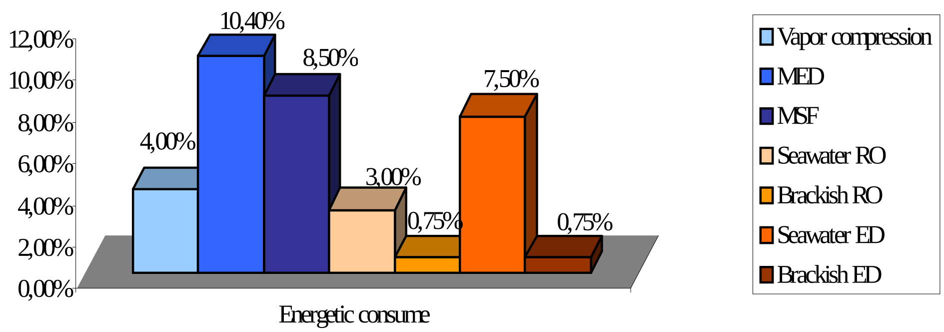

Figure 4 – Energetic consume (kg oil/m^3 of purified water)

A hillside that has been explored for some research groups is the association of the solar energy with desalination processes. Distinct values for the water production for squared meter of solar panel it is shown in literature; Van der Bruggen and Vandecasteele (2002) describe 3.0 l/m^2. For Semiat (2000), the analysis considers that 250 m^2 of solar collectors to the production of 1 m^3 of fresh water is needed. In this way, Carvalho (2000) assures that the use of photovoltaic panels for desalination is just feasible in regions in which there is not electric energy supply and with a drinking water consumption less than 12 m^3/day.

Although MSF, MED and RO are nowadays the most conventional techniques used, they can present a higher efficiency when connected in hybrid desalination processes, in which they can be combined to compose RO-MSF, RO-MED, RO-VC or some other combinations. As the trend to the use of MSF units is decreasing, installations MSF-RO must be considered promising alternatives.

In special conditions, literature registers that reverse osmosis process can become the recommended choice, mainly when increases in the fuel costs for installations MSF and MED are observed. With a hybrid system running, which can include RO/MSF or RO/MED processes, as cited in Van der Bruggen and Vandecasteele (2002) and Altmann (1997), respectively, these could become economically feasible, although they are not still commonly operated.

Other hybrid systems can be visualized, as that one considered for Uche, Serra and Valero (2001), in which it is considered an integrated unit of seawater management, brackish water and water reuse for human consumption and agricultural, in which a combined cycle of gas turbine/steam turbine associated with RO and MED installations.

4. REVIEW OF THE INTERNATIONAL EXPERIENCE

MSF desalination technology is used more than 50 years in Arab countries in result of its strong restrictions of drinking waters availability, as described by El-Nashar (2001); countries like Bahrain, Oman, Qatar, Saudi Arabia, United Emirates Arab and Kuwait pertain a region of severe lack of renewed water resources, and in this last country more than 95% of the drinking water is produced from desalination, as described for Azoury (2001). This author shows for 2001 data the desalination capacities of these Gulf countries and the percentages of use of each desalination process in each one, as summarized in Tab. 4.

Tab. 4 – Desalination capacities and percentages in the Gulf

Country	**Total desalination capacity (10^6m^3/y)**	**MSF (%)**	**MED (%)**	**VC (%)**	**RO (%)**	**ED (%)**
Bahrain	113	52.02	0.00	1.46	41.73	4.50
Kuwait	562	95.47	0.68	0.00	3.39	0.33
Oman	70	84.06	2.18	0.00	11.73	0.00
Qatar	207	94.43	0.64	3.26	0.00	0.00
Saudi Arabia	1917	65.66	0.31	1.21	30.97	1.85
U.A.E.	790	89.80	0.38	2.97	6.49	0.24

A study considered for Uche, Serra and Valero (2001) demonstrates an alternative to the Spanish Hydrological Plan, that initially foresaw the transference of the river Elbro course, which is based on processes of combined desalination cogeneration systems to eliminate the fresh water scarcity in littoral areas, that occurs due to the extreme increase of the tourism associated with an intense agriculture in half-barren regions. The authors consider the use of desalination by RO-MED hybrid process in association to a combined cycle cogeneration system. The investment costs in the cogeneration system to meet electric demand are analyzed, as well as desalinated water investment costs are investigated as a function of the installation size. Another analysis done by these authors consisted of seawater and brackish water desalination by reverse osmosis for drinking water production, integrated to a unit of residual water treatment, which supplies water irrigation, as showed by Fig. 5.

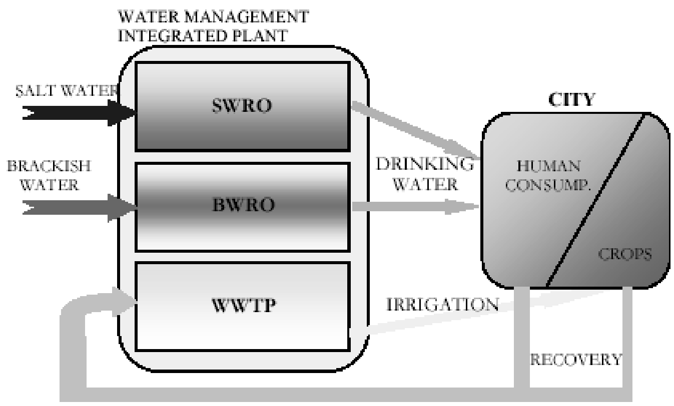

Figure 5 – Scheme of the water demand management

Although the hybrid unit depends on its size and on electricity and fuel prices, they offer more attractive returns regarding the alternative of the transference process of the river Elbro. This model can be an interesting alternative to be thought for the Brazilian northeast region, in which water scarcity is a problem in the major part of that States.

Al-Mutaz (1996) presents a comparative analysis between MSF and RO units in a historical and worldwide context, but the study is focused for the internal regions of Saudi Arabia, showing the arrangements of configurations under operation, the cities where they are located, the installed capacity, some aspects of chemical treatment eventually realized by describing these techniques; also, an economic comparison among MSF units and a graphical representation of a unit in which reverse osmosis presents better total capital cost is presented. The author also lists some differences between RO and MSF, as described in the Tab. 5

Table 5 – Technical differences between RO and MSF

	Comparisons	
Technical characteristics	**MSF to RO**	**RO to MSF**
Seawater intake	Twice	----
Energy consumption	Three times	----
Volume and area required	Large	----
Foundation	Heavy because the weight	----
Thermal energy consumption	----	----
Pumping energy	----	25 %

The focus of the main studies involving desalination systems, with or without integrated cogeneration, are in function of the production cost for cubic meter of produced drinking waters and/or the unit total cost in function of the installation capacity with a fastest possible payback. To get trustworthy results in these analyses, there are several factors that must be taken into account, as the process efficiency, the choice of the thermal cycle and the individual capacity of the machines, the type of used fuel, the types and options of pre- and post-treatment, amongst others, and for this, different methodological approaches are used.

Mathematical optimization models and thermoeconomic models are the ones most recommended for this analyzing the feasibility of desalination processes. Poulikkas (2001) uses an optimization algorithm for the calculation of the drinking water unitary cost. Such algorithm is applied to some configurations of reverse osmosis. As an optimization algorithm, its objective is to find a solution that leads to the minimum global installation cost, that corresponds to the investment annualized cost sum of the energetic cost, operational and maintenance specific cost, membrane replacement costs and of the cost of the used chemical products in the operation of the system. The author also presents typical ranges of desalinated water production cost of the main components, such as in Tab. 6.

Table 6 – Typical range of desalinated water production cost

Component	**Contribution, %**
Capital recovery cost	30 – 50
Energy cost	30 – 50
O & M (labor, spares, membranes, chemicals, etc…)	15 – 30

Hajeeh et. al. (2003) develops an optimization model in a dual purpose unit with desalination, based on distillation, which presents an objective function subjected to the constraints regarding energy generation, load, water supply, among others. This optimization problem is a mixed-integer nonlinear minimization problem in large scale.

Helal et. al. (2003) analyzes RO-MSF hybrid units for the determination of an optimum project. The paper is divided in 3 parts, having been the first come back toward the study of the modeling and the algorithms. Studied cases are presented as:

a. a MSF unit with brine recycle.
b. a RO unit of seawater.
c. Seven hybrid MSF-RO units, with variations in the disposal of equipment and flows.

Authors present the mass and enthalpy balance of the related project sections, as well as the formulation of pertinent heat transference of each section. The formulation is made initially for the cases (a) and (b) and, later, adjusted specifically for the cases of the item (c).

In another paper, Helal et al. (2004) elaborate the discussion and results of their analysis showing that the adoption of RO units is highly recommended and specially if coupled to an MSF installation it can reduce the water costs in up to 24%. The third part of his study treats the results by means of sensitivity analyses with variations in the component costs and in operational conditions, but it was not published and it is not available for consultations on-line.

5. TECHNOLOGIES INTEGRATION OPPORTUNITIES

The integration of desalination and cogeneration technologies is particularly important considering that cogeneration systems may supply the necessary energy for operating desalination units, either by means of the steam production in the units of distillation or by electricity for water pumping to overcome the osmotic pressure of the reverse system. The associated drinking water production to the generation of electric energy can warranty the attractiveness of this enterprise.

The association of different fuels, multiple cogeneration systems configurations and associated to different desalination technologies allows a sufficiently diverse arrangement universe that extends the possibilities of alternative solutions with adequate costs and environmental advantages for the combined generation of electricity and drinking water. In this way, the availability of superstructures or project modules, as proposed in Balestieri and Correia (1997) and Silva et al. (2002), would be very useful for the components selection of the installation in the conceptual phase of design optimization modeling. Fig. 6 illustrates a superstructure proposal for the three systems chaining.

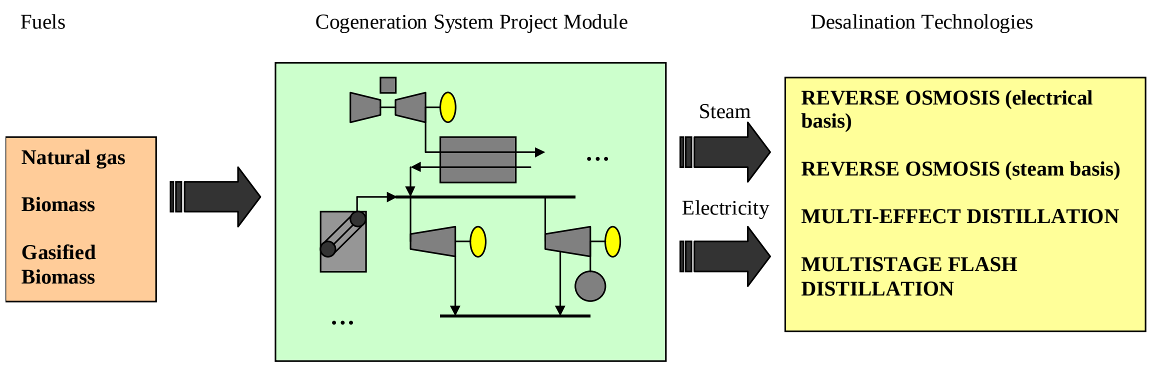

Figure 6 – Superstructure for the association cogeneration and desalination technologies

There are many studies presented in the literature related to the desalination/cogeneration field, with differentiated level of details, whose objectives are the electric and drinking water production and, mainly, reduction in the produced water cost. As the cogeneration system produce two or more products, one suitable partition of costs can make possible achievements that dedicate to offer electricity and drinking water at reasonable prices.

The existence of more than one form of available energy as product of a cogeneration system allows to their costs to be balanced in accordance to the conveniences of the market; thus, electric energy and drinking water prices in an associated desalination/cogeneration system will have to be situated in a contract range, as seen in Fig. 7, in which they will oscillate aiming to attend the requirements of demand increases for one or another form of energy in function of the market conditions.

According to Verbruggen (1983), assuming known the marginal costs to the electric and thermal energies production, a straight line of negative angular coefficient can be gotten if two points, A and B, have been chosen, corresponding respectively to the purely electric marginal costs (CC_A/E) and purely thermal (CC_B/Q), allowing in that way an infinity number of alternatives of costs partition for the combined generation. Some authors consider that the allocation costs rule for combined generated energies must be arbitrary; there is, however, a trend in terms of the use of exergoeconomic models for the costs partition.

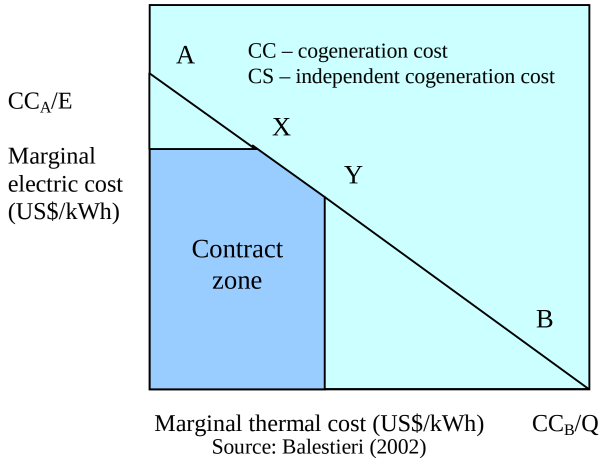

Figure 7 – Electrical and thermal marginal costs plane

The operational strategy of integrated desalination/cogeneration systems must take in account the seasonal characteristics of the siting facility, that impose in summer periods powerful demands for drinking water and electricity (associated to the use of conditional air systems for compression mechanics). As described by Barclay (1988), "*in combined water and electricity systems, unit commitment theory is more complex than in electricity only systems. For example, a station with a relatively low electricity/water ratio inevitably has a low efficiency, but must be operated because the water demand must be satisfied. Moreover, the use of exergy theory is essential in order to characterize the thermal performance of the plant and to separate the water and electricity costs.*"

Coastal cities are particularly affected by problems of water and electricity supply in the summer periods, when the tourist presence raises from 3 to 4 times the number of inhabitants of certain localities; however, in three-quarter of the year, the attendance of the same demands is enough. For these situations, the operational strategy must consider the possibility of using a set of components electrically driven (when this form of energy surpasses the demand) and/or a set of steam driven systems (in the remainder moments), such as described by Altman (1997).

The cogeneration concept considered by Altman (1997) considers the association of electric (ROE) and steam driven (ROS) reverse osmosis systems, whose prime movers are steam turbines; this type of installation provides good flexibility relatively to the demand of drinking water and energy, and in the economic analysis presented in the same reference reveals a reduction in the range of 15–20% in the of production water costs for ROE when compared with MSF units with cogeneration. The possibilities of bottling and drinking water commercialization generated by desalination processes must be considered in the months that follows to the high demands, as well as the transportation and selling of electricity for the concessionaire, as alternatives to achieve the economic feasibility of this enterprise.

6. CONCLUSIONS

The decision concerning the use of cogeneration systems in Brazil was contained, on the part of the entrepreneurs, up to the time that an extreme situation, "the 2001 blackout", evidenced the serious structural problems that the Brazilian electrical system was displayed during many years. In the current conjuncture, the productive sector uses electricity offers on the part of the concessionaires, but grows the company's number that occupies to analyze the economic viability of this nature.

Up to the moment, the question of the water supply follows similar way, with the favorable distinction that the moment of occurrence of the crisis of water supply for absolute lack of this natural resources is yet far from now, and can be foreseen in a space of time of one or two decades. The concepts of strategical planning of long term suggest that, if anticipated in 10 to 15 years, the alternatives for the pinch in the offer and demand of the future scenarios can be established and the problem can be overcome; therefore, it is important to contemplate just now the integration of desalination and cogeneration systems processes in its economic and technical aspects.

Strategic analysis and simulations will reveal the best alternatives for Brazilian conditions; however, it can be seen that configurations that include the reverse osmosis system (RO) in its structure and distillation/reverse osmosis hybrid unit (MSF-RO), mainly in the units older than are adjusting to the new technologies, must be considered as the preliminary schemes. Moreover, the levels of practiced costs in the international market for the established technologies of desalination reveal that there are opportunities to be considered, and it is important the analyze the feasibility of the integration of desalination cogeneration systems processes according to the national standards.

For the analysis of integration between desalination processes and cogeneration systems, the use of an optimization model in a superstructure for the optimization of arrangement selection between components is recommendable, aiming to maximize the net benefit of the investment, taking environmental limits as constraints for the decision process. The use of exergoeconomic modeling has been considered in literature as the most recommendable for the evaluation of the suitable partition of costs between the desalinated water and electricity in cogeneration central and must be considered in the sequence of this work.

7. REFERENCES

Al-Mutaz, I. S., 1996, “A comparative study of RO and MSF desalination plants”, Desalination Vol. 106, pp. 99–106.

Altmann, T., 1997, “A new power and water cogeneration concept with the application of reverse osmosis desalination”, Desalination Vol. 114, pp. 139–144.

Applegate, L.E., 1984, "Membrane separation processes", Chemical Engineering, Vol. 91, No. 12, pp. 64–89, 1984.

Azoury, P.H. Power and desalination in the Arabian Gulf region: an overview. Proc. Instn. Mechanical Engineers, Vol. 215, Part A, p. 405-419, 2001.

Balestieri, J.A.P., 2002, “Cogeração – geração combinada de eletricidade e calor”, Editora da UFSC, Florianópolis, Santa Catarina, 279 p.

Balestieri, J.A.P., Correia, P.B., 1997, "Multiobjective linear model for pre-feasibility designs of cogeneration systems", Energy, Vol .22, No.5, pp.537 - 548.

Barclay, F.J. Co–generation in arid and cool climates: a new unified perspective using exergy analysis. Journal of Power and Energy Proceedings of the Institution of Mechanical Engineers Vol. 202, No. A2, pp. 129–139, 1988.

Carvalho, Paulo, 2000, “Água potável via energia solar” Ciência Hoje, Vol. 27, No. 158, pp. 72–74.

El-Nashar, A.M., 2001 “Cogeneration for power and desalination - state of the art review”, Desalination, Vol. 134, pp. 7-28.

Graça, Antônio, 04/2004, “País do desperdício”, Revista Update, Câmara Americana de Comércio, disponível em http://www.amcham.com.br/revista/revista2004-03-15a/materia2004-03-22a/pagina2004-03-22b

Hajeeh, M, Mohammad, O., Behbahani, W., Dashti, B., 2003, “A mathematical model for a dual-purpose power and desalination plant”, Desalination Vol. 159, pp. 61–68.

Helal, A.M., El-Nashar, A.M., Al-Katheeri, E., Al-Malek, S., 2003, “Optimal design of hybrid RO-MSF desalination plants. Part I: modeling and algorithms”, Desalination Vol. 154, pp. 43–66.

Helal, A.M., El-Nashar, A.M., Al-Katheeri, E., Al-Malek, S., 2004, “Optimal design of hybrid RO-MSF desalination plants. Part II: results and discussions”, Desalination Vol. 160, pp. 13–27.

Maldonado, J., 05/1991, “Membranas e processos de separação”, Instituto nacional de tecnologia.

Morton, A.J., Callister, I. K., Wade, N. M., 1996, “Environmental impacts of seawater distillation and reverse osmosis processes”, Desalination, Vol. 108, pp. 1-10.

Poulikkas, A., 2001, “Optimization algorithm for reverse osmosis desalination economics”, Desalination Vol. 133, pp. 75–81.

Safi, M.J., Korchani, A., 1999, “Cogeneration applied to water desalination: simulation of different technologies.” Desalination, Vol. 125, pp. 223–229.

Semiat, Raphael, 2000, “Desalination: present and future”, International Water Resources Association; Water International, Vol. 25, No. 1, pp. 54–65.

Silva, A.M., Holanda, M.R, Balestieri, J.A.P., Magalhães Filho, P., 2002, "Simuladores para análise de projetos de sistemas de cogeração", Brazilian Congress of Engineering and Thermal Sciences, Proceedings (in CD–ROM), 7 pp.

Uche, J., Serra, L., Valero, A., 2001, “Hybrid desalting systems for avoiding water shortage in Spain”, Desalination Vol. 138, pp. 329–334;

UNIAGUA. Água no planeta. Available in <www.uniagua.org.br> Access in 10/09/2003.

Van der Bruggen, Bart, Vandecasteele, Carlo, 2002, “Distillation vs membrane filtration: overview process evolutions in seawater desalination”, Desalination Vol. 143, pp. 207–218;

Verbruggen, A., 1983, “Cogeneration- allocation of joint costs”, Energy Policy, Vol. 11, No.2, pp. 171-176.