# INTEGRATION OF COOLING AND DESALINATION PROCESSES AND POWER GENERATION

Dr. Jürgen Scharfe
Entropie GmbH, Munich (Germany)
info@j-scharfe.de

## INTRODUCTION

The production of chilled water for air conditioning purposes and sea water desalination is usually considered to be process which involves large amount of heat and electricity. In both cases the demand for ever higher efficiency is driven by continuously rising energy prices. Since the capacities of water production facilities are usually fairly large only thermal power plants can provide the heat and power required. The same development is taking place in air conditioning where centralized district cooling plant are more and more replacing local chillers, roof top or window units.

In the past many units have not been optimized in terms of fuel efficiency due to low energy prices in most of the countries where water is produced by desalination which led to a situation where the fuel cost hasn't played a signifiant role in the selection of technologies. However, this is changing rapidly with the rise of energy cost in particular for natural gas as new gas pipelines are currently under construction mainly in the Gulf countries in order to develop a market for gas consumers.

The key into the process of optimization of the combined production of power, water and cooling is a sound understanding of the requirements and limitations of the various processes in order to be able to define the interface conditions between the power and water island. The presentation will however focus on the technologies which are currently seen to be the leading ones in the future. On the thermal side the the MED – multi effect desalination – has become the leading technology after almost 25 years of continuous improvement and competition against the MSF technology. MED has the advantage of being more efficient, having a higher flexibility and very low electrical consumption. On the other hand MED has to compete against membrane processes which have gained ground in a couple of areas.

In this paper various concepts and combinations of cooling and MED with and without internal heat recovery systems will discussed. The comparison will be focused on the overall efficiency of the power island connected to the water island.

The efficiency of the different processes is expressed in terms of specific power consumption including all auxiliaries and adverse effects on the power production process in order to compare the processes correctly. For the water process the efficiency can be expressed as the ratio of :

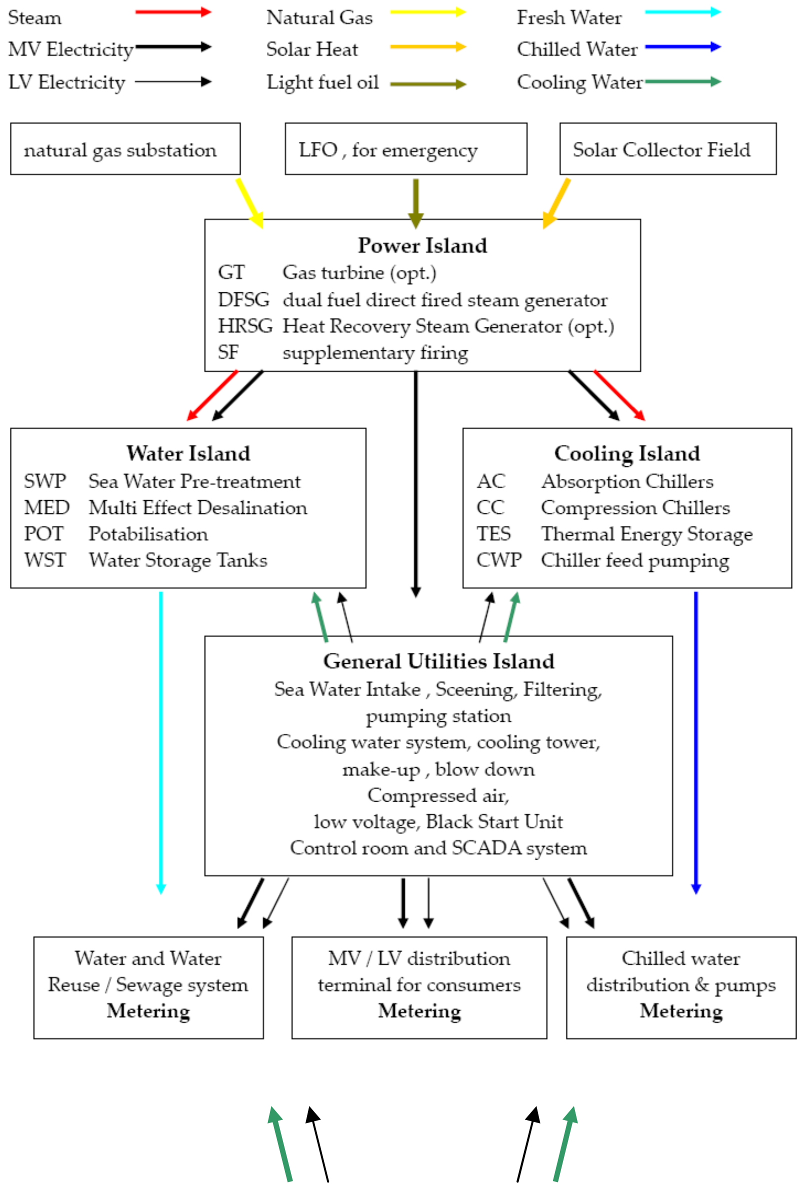
Efficiency = ( power consumption + loss of power production ) / water production

which has to be calculated as a function of the water / power ratio for each specific solution.

The results show a surprisingly small differences between the membrane processes and equally sophisticated MED processes and the same for absorption and compression cooling .

## THE MAIN CONCEPT

The integrated multi-utility-plant is a arranged in a four-island configuration which are inter-connected by a well defined set of interfaces such that responsibilities are clearly defined and overall performance can be guaranteed without ambiguities by the respective contractors.



The details of the interfaces include a large variety of different media between the islands which are usually summarized in a utility matrix which contains all the details of each interface including definitions of quality of each utility

Fuel
— natural gas high pressure ( > 26bar for gas turbines)
— natural gas low pressure
— diesel
— solar energy
Water
— cold, drinking water
— hot for sanitary purposes
— boiler make up water
— closed circuit cooling water ( for critical systems that cannot be cooled with sea water )
Sea Water
— for architectural purposes ( lagoons etc )
— for desalination
— for cooling tower make up
— for cooling purposes ( heat rejection)
— screening debris disposal
Steam
— high pressure
— condensate for desuperheating
— medium pressure
— low pressure
Electricity
— Medium Voltage ( 6 or 10 kV)
— Low Voltage ( 400 V )
— UPS Low Voltage ( 400 V )
— DC 24 V
— UPS DC 24 V
— Earthing
— Black Start facility
Control and measurement System
— data bus
— DCS andmonitoring

— load management system
— control room
Other
— Compressed air for instruments
— Compressed air for filter flushing
Chemicals
— Nitrogen for blanketing
— antiscale
— antifoam
— chlorine

— chlorine scavenger
— anticorrosive for cooling network
— sodium hydroxide
— acid for cleaning
— ammonia
— hydrazine
— lubrication oil for turbines
— .....

## THE INTERFACE PROBLEM AND IMPACT ON OVERALL EFFICIENCY

The biggest problem to overcome in an integrated plant is the issue of interface conditions. Usually the electrical side is quite simple while the thermal side can be a real challenge

On the heat consumer side

| Consumer | Media to provide | temperature supply / return |
|---|---|---|
| space heating | Hot water | 70-100°C / 40-60°C |
| sanitary hot water | Hot water | min. 60°C |
| kitchens and laundries | steam | 4 bar min |
| Air conditioning | cold water | 5-8°C / 12- 18°C |
| Absorption Chillers | hot water | 95 / 75°C depending on cooling water |
| | Or steam | 0.8 to 1.5 bar abs. for single effect |
| | Or steam | 4 - 8 bar for double effect |
| MED desalination | hot water | 80/ 70°C for pure MED |
| | or steam | 0.35 bar abs. for pure MED |

| | | |
|---|---|---|
| vacuum pumps | steam | min. 3-4 bar |
| MED with TVC | steam | min. 3 bar |

The list already looks quite incoherent and one might be inclined to simplify the list by selecting a heat source with sufficiently high temperature and provide the form a single point. However this will drastically reduce the overall efficiency of the systems and may even render it uneconomical.

To illustrate this the impact of various cases has been calculated for both, absorption chillers and MED units, the absorption case is shown below.

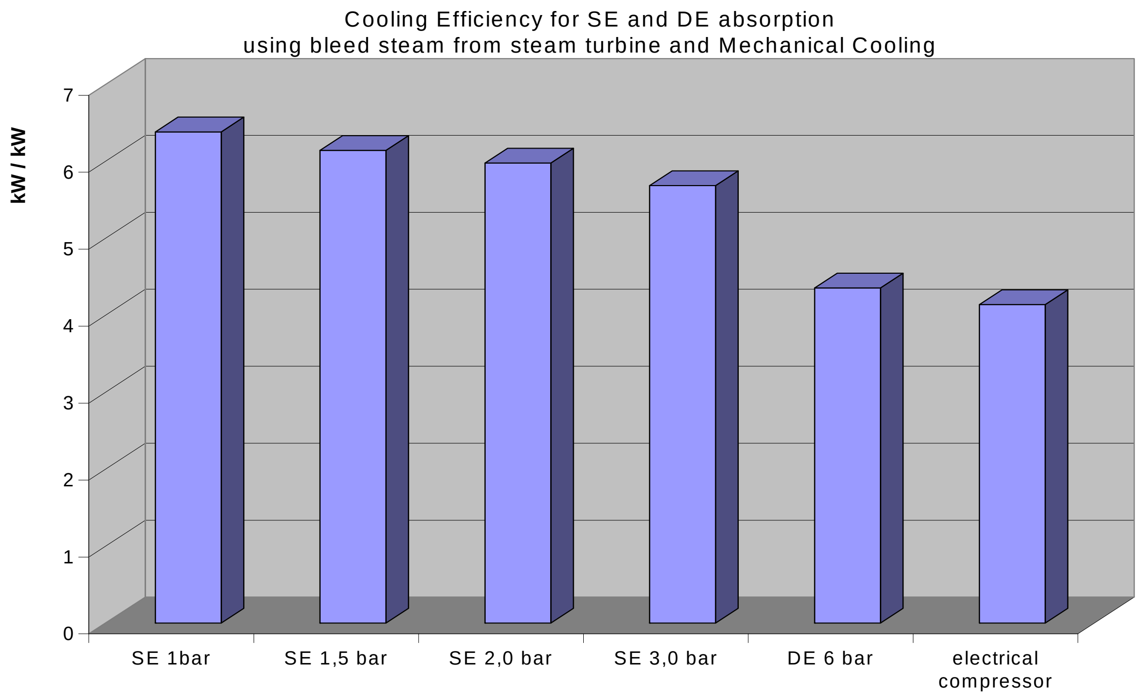



*Figure 1. Cooling efficieny of different systems*

The following diagram shows the cooling efficiency of a steam power cycle combined with absorption chillers or compression chillers. It should be noted that roof-top or window units are not even shown here since their real cooling efficiency is hardly ever above 2 to 2.5 .

The first four columns show the cooling efficiency of a single effect absorption chiller driven with bleed steam at different pressure from a steam turbine for a case in the Middle East ( Emirates ). Interesting to see the impact of steam pressure. The double effect chiller which is usually considered as more "efficient" cannot compete because its higher internal COP cannot compensate the power loss in the steam turbine

The efficiency is defined such that all auxiliary consumers are included as well as the loss of of production in the steam turbine due to bleeding steam.

Cooling Efficiency = cooling capacity / total power invested

It is important to determine the total power invested very carefully :

+ power consumed by chillers ( pumps and compressors )

+ power consumed by cooling water pump for chillers

+ power consumed by cooling tower ( if not directly cooled by sea water )

+ loss of power production in steam turbine due to bleed steam extraction

– reduction of power for cooling water pump for turbine condenser

– reduction of power consumed by cooling tower for turbine

......

Once the major contributors are integrated into a model the simulation can be run under various boundary conditions.

The same exercise can be performed for the desalination systems.

In this case the competing systems are heat driven or pure electricity driven such as Reverse Osmosis or mechanical vapour compression units (MED-MVC) .

Here again, once the power consumption is calculated including auxiliaries and the impact on power production the differences between the two main technologies are by far not as big as one might expect.

The typical efficiency of a 10 stage MED desalination driven by 0.35 bar steam plant is roughly equivalent to 7,5 kWh / m³ including sea water intake etc. while a two stage RO unit is also around 5,5 once the effort for intake and condenser cooling water in the condensing turbine are correctly accounted for.

For a 5000 m³/day unit the annual difference would make up roughly 3,5 GWh or 5% of a total of 63 GWh of exported power to the grid in the selected example.

The problem in combined water and cooling production is that the both processes compete for the heat. The evaluation of the overall efficiency shows that the absorption process is superior to a compression process for cooling, while for the desalination process the question is much less evident although in terms of energy a well designed MED is comparable to an RO unit the impact on the entire plant may be drastic especially for a smaller power plant.

The boundary conditions for both cases are

cooling water 34°C summer / 25°C Winter

condensing turbine stage only for RO-coupled plant

MED coupled unit with back pressure turbine , T sat 85°C winter / 105°C summer

As soon as the available heat is insufficient, the impact may be important if too much heat is used for desalination instead of cooling. The following example shows a case where water production by MED consumes too much heat in the period of low cooling load.

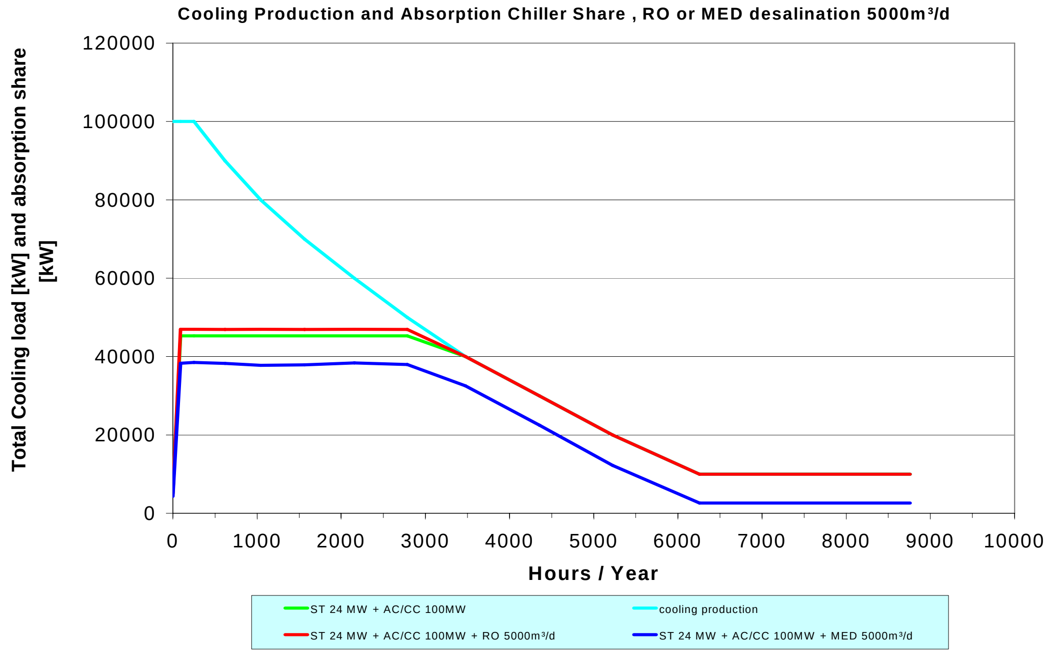


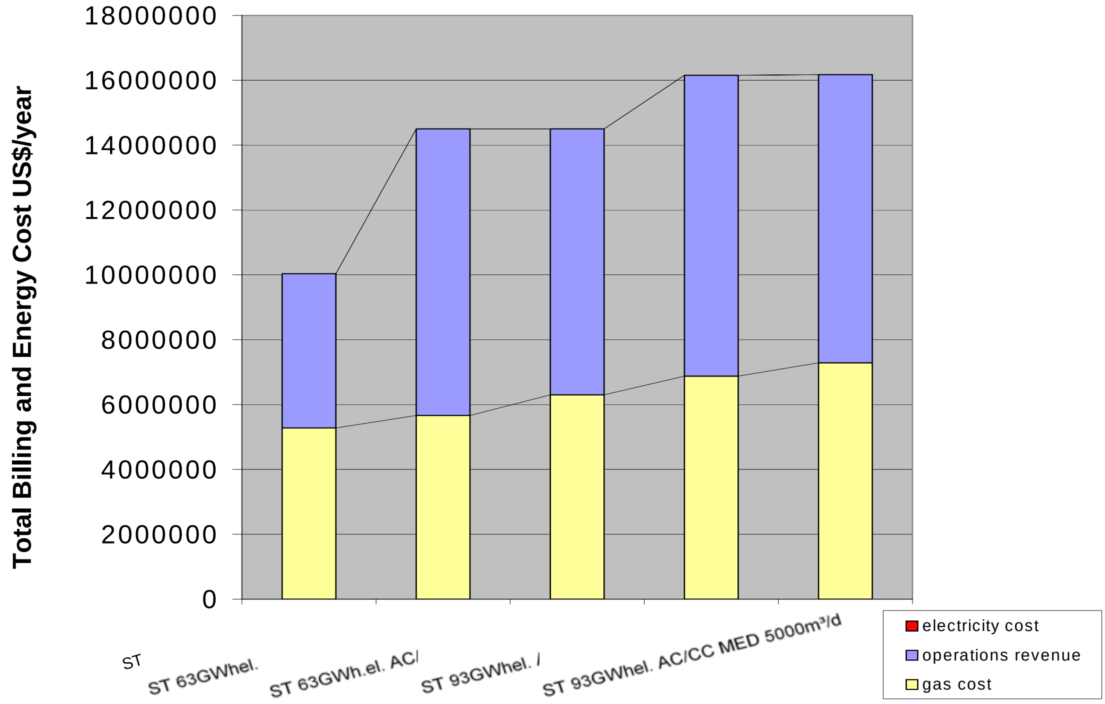

*Figure 2: share of absorption chiller load for MED and RO system scenarios , for reference no desalination - green line*

In the reference case ( green line ) of combined power and cooling plant the absorption chillers usually covers the entire base load up to roughly 45% of the maximum load, if cooling load is higher the compression chillers will take the extra load. Surplus power will be sold to the local grid ( 63 GWh ) in this case. In the reference case the annual profile of power generation is dictated by the cooling load. Under peak cooling load all power generated will be used in the plant for running compressors, while in mid-season and low load the plant is controlled by heat requirements and consequently power will be exported in order to avoid too low load.

The other two cases have then been calculated with a 10 stage MED unit operating at constant load ( 5000m³/day ) or a RO unit , while the power export profile remains identical ( 63 GWh/year ) .

The total impact of desalination shows a larger difference than expected and cannot be explained by the small difference in performance, ( in fact it would be almost invisible in the fig. 2 ) because graphs both desalination systems have nearly the same impact on power production.

In this case however the use of heat for the desalination instead of using it in the absorption chillers has a negative impact on the overall economy.




The five columns show the total income and the gas cost for the boiler for different modes of operation

| | cooling | water | power | gas |
|---|---|---|---|---|
| No. 1: with no water production | 302 GWh | 0 Mm³ | 63 GWh | 441 GWh |
| No. 2: like No.1 + RO 5000 m³/d | 302 GWh | 1.79 Mm³ | 63 GWh | 474 GWh |
| No. 3: like No. 1 + MED 5000m³/d | 302GWh | 1,79Mm³ | 63 GWh | 527 GWh |
| No. 4: No. 2 but more power export | 302 GWh | 1.79 Mm³ | 93 GWh | 575 GWh |
| No. 5. No. 3 but more power export | 302 GWh | 1.79 Mm³ | 93 GWh | 609 GWh |

As a matter of fact the annual cost for raising steam increases when steam is used for MED instead of absorption chillers. The main reasons for this are not immediately obvious but a detail analysis clearly reveals them:

- absorption chillers require higher steam pressure than MED.
  In the selected model a single LP steam back pressure is implemented because this would be a realistic case. All the steam for MED has to be taken from the same point. Since this pressure is much higher than required ( roughly 105°C instead of 73 °C saturation temperature ) the loss of power production is higher than expected for the MED
- efficient absorption chillers have to be replaced by less efficient compression chillers due to limited amount of steam.

The negative impact of the competition on steam is reduced if power export is increased while the difference is 50GWh in the cases 2 and 3 with the difference decreases to 35GWh in the cases 4 and 5 . The difference decreases further if the cold end of the steam turbine is modified to provide back pressure steam for Absorption and MED at appropriate level.

The value of this difference must then be seen in the light of operation and maintenance cost and balanced against investment cost. An exercise which would go beyond the scope of this presentation.

## CONCLUSION

In an integrated power, water and cooling plant the impact of the competing heat and power consumers for water and cooling may have surprising results on the performance of the plant. This is especially true for smaller plants where optimization of the power block cannot always be taken to necessary point because the available equipment does not allow this mechanically – for example back pressure turbines with a low pressure bleed. Especially the desalination process requires attention since the temperature required for desalination is very low and no other heat user can operate at this temperature level.

MED and RO system can be designed to reach almost identical overall efficiency and therefore the impact on power generation practically disappears once aspects like quality of water, operation and maintenance, cleaning and replacement of membranes are accounted for. In many cases the MED turns out to be the most competitive solution especially where sea water quality is difficult.

In a combined cooling water and power plant the competition of the processes for heat may lead to surprising results because the interfaces cannot always be chosen appropriately both all processes and consequently efficiency may drop for reasons which are not immediately evident.

For larger plants steam turbines with split back pressure stages are available which then allows to operate chillers and MED units close to their optimum. The size of plants where this becomes possible is within what is foreseen for the next years as district cooling and water plants in the Middle East. Plant capacities of 200 MW cooling and 10000 m³/day of water production will requires power plants of more than 50 MW electrical power which will a allow to implement sophisticated plants with hybrid schemes for cooling ( AC/CC ) and water production (MED/RO )