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Seawater desalination (RO) as a wind powered industrial process — Technical and economical specifics

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ABSTRACT

Already today wind power offers low and long-term stable costs of energy and therefore is able to compete with large scale conventional power generation. Using wind power directly for energy intensive industrial processes requires an optimized hybrid configuration as well as a balanced load and/or energy management. The technical and economical specifics for wind powered seawater desalination with reverse osmosis as a completely integrated solution are presented and emphasize its capability and potential to be implemented in medium and large scale within the next few years.

Keywords: Seawater desalination; Reverse osmosis; Wind power; Load management; SYNWATER®

1. Introduction

Within seawater desalination in general, the energy consumption of the processes applied at industrial scale has been lowered significantly during the past decades. Especially for the reverse osmosis (RO) process the advantages in membrane technology and energy recovery devices have led to a relatively low specific energy consumption (SEC) at around 2–4 kWh/m^3. Due to its flexibility and lower installation costs the RO process gained a significant market share within the total desalination capacity and will increase it prospectively.

Regarding the expanding desalination market, the total energy consumption of desalination in general and especially for RO (electric energy) will increase. Until today, nearly all of the electric energy used for commercial seawater desalination with reverse osmosis (SWRO) is generated by fossil fuels. Burning fossil fuels for supplying the already and prospective installed desalination capacity causes concerns:

- *Costs*: Depending on the contract between the desalination plant operator and the energy provider as well as on the local circumstances, the costs for energy supply represent a significant share of about 30%–60% of the levelised specific water costs of the RO. This cost share will even increase further due to the increase of fossil fuel costs. Also its high volatility has to be considered.
- *Reliability*: If the fossil energy sources are not available at regional or national level, the reliability of the energy supply could be affected negatively by conflicts.
- *Environment*: Despite direct local effects of electricity generation by fossil fuels, the emission of carbon dioxide is under reasonable suspicion to cause a global warming and thus to endanger the livelihood of mankind.

For desalination at industrial scale, these concerns are avoided or minimised at long-term only by using locally available renewable energies — like wind or solar.

The paper explains briefly, why wind power is a very promising option for powering industrial processes and which further general aspects regarding energy con-

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sumption and the use of storages have to be considered. Within the second part, the basic characteristics of wind powered industrial processes regarding the ratio of the capacity of the wind power plant and the process load are highlighted. The third part illustrates the application of the industrial RO-process to the fluctuating wind power supply. In the last section the application for a wind-powered SWRO with SYNWATER® and its economic specifics are presented.

2. General aspects of wind powered industrial processes (WIP)

2.1. Why wind power?

Using the freely accessible source wind energy offers low and long-term stable power generation costs (Table 1). Furthermore wind power stands for low environmental impact, proven technology and many competing manufacturers around the world.

Considering the steadily increasing grid tariffs, the direct consumption of wind power within a local sub-grid constellation is becoming the most beneficial option for an increasing number of sites.

2.2. Energy intensive industrial processes

The higher the electrical energy demand of the process, the more the substitution of conventional grid power by local wind power might be beneficial. There are in principle two types of energy intensive industrial processes:

Type	1	2
Energy consumption per unit produced (EC):	low	high
Total amount of units produced per period (TA):	high	low

Example – Type 1:
membrane processes – e.g. seawater desalination (RO); EC = 3.5 – 5.5 kWh/t; TA = 500–300,000 t/d, energy share of product costs: 30–60%

Example – Type 2:
electrothermal processes – e.g. aluminium melting; EC = 410 – 690 kWh/t; TA = 1 – 100 t/d, energy share of product costs: 5–20% [1]

Considering both, the total amount of energy needed as well as the energy share of product costs, the energy intensive industrial process Type 1 is especially recommendable for the WIP concept — despite the relatively low EC value.

2.3. Storages

Project or sub-grid integrated storage facilities increase directly the wind energy share used for the process and decrease the energy exchange with the main grid respectively. Since storage facilities require additional investment and cause additional energy losses, its WIP integration is rectified by technical restrictions and/or by adequate benefits because of a reduced energy exchange with the utility grid. There are in principle two options of large-scale/multi-hour storage integration:

Option 1: upstream of the process: storage of electrical energy
Option 2: downstream of the process: storage of products

In order to use strong wind periods, the storage Option 2 can be implemented simply, cost efficiently and in large scale. In contrary to Option 1, the storage of products requires additional process capacities and to some extent additional investment.

The storage Option 2 is especially advantageous, if the additional capacities required can be activated by temporarily exceeding the existing nominal process capacities (overload) — see therefore also section 3.2 and chapter 6.

3. Characteristics of wind powered industrial processes

3.1. Wind power capacity

The general concept and design of a WIP-project mostly depends on the tariff levels for feeding-in wind energy and consuming conventional grid power. The feed-in tariff determines significantly the optimal wind power capacity to be installed at site (Table 2 and Fig. 1).

The most probable option of a medium feed-in tariff level leads to the recommended project category *Wind Powered Process*. This implicates a sufficient wind power capacity installation[1], so that — considering the local wind resources — wind energy generated is similar to the process energy demand within the same period (regularly within one year).

[1] Depending on local wind resources around 3–5 times of the nominal process power, typically.

Table 1
Economic prognosis for a power plant installed in 2009

Power generation	Generation costs (€ct/kWh)	Cost increase (% p.a.)	Volatility
Fossil fueled (> 5 MW)	3–10	3–5	Medium to strong
Wind (> 500 kW)	3–10	<1	Low
Photovoltaic (> 500 kW)	20–30	<1	Low
Solar thermal (> 500 kW)	12–16	<1	Low

Table 2
Feed-in tariff level and belonging project categories

Feed-in tariff level	Capacity ratio	Energy ratio	Ratio E_{WT}/E_{PR}	Project categories
	Wind/process	Wind/process	Wind penetration	
Low	$P_{WT} = P_{PR}$	$E_{WT} < E_{PR}$	Low	Process with wind power support
Medium	$P_{WT} > P_{PR1}$	$E_{WT} \approx E_{PR}$	Medium to high	Wind powered process
High	$P_{WT} >> P_{PR}$	$E_{WT} > E_{PR}$	High	Wind power with coupled process

P_{WT} — nominal power of the wind turbine
E_{WT} — energy generation of the wind turbine
P_{PR} — process power
E_{PR} — energy consumption of the process

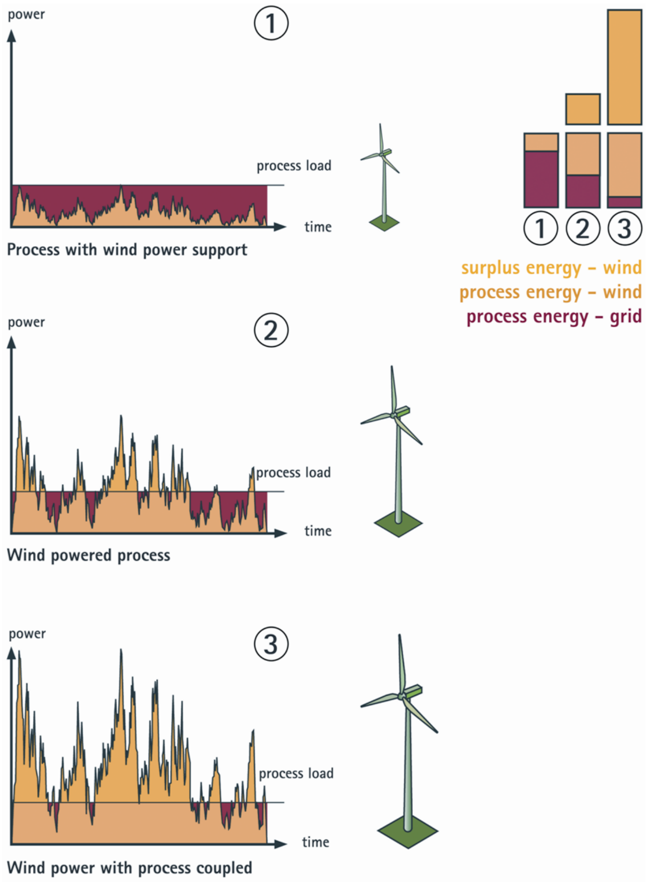

Fig. 1. Possible project categories regarding the ratio of wind power and process load.

The ratio of wind energy directly used for the process to the total process energy demand — the so-called *Wind Penetration* — can be affected significantly not only by the probability distribution of the generated wind power itself, but by a continuous process load adaptation to the current wind power generation (load management), too.

3.2. Process capacity and operation

The further increase of *Wind Penetration* of the *Wind Powered Process* by load management requires the provision or activation of additional process capacities in order to use periods of strong winds. If and to which degree the load management should be realised is determined by a specific cost-benefit analysis. The project specific result is mainly affected by the ratio of the grid tariff level compared to the site-specific wind energy costs and the costs of additional process capacity.

In case of no additional process capacity and no load management, the *Wind Penetration* is only affected by the site-specific wind conditions and will be up to 50% in best cases.

A variable process control that could activate up to 150 % of the nominal process capacity in periods of strong winds would increase the *Wind Penetration* up to around 80% even under moderate wind conditions, ref. Section 6.2.

The bigger the difference between grid tariff and wind energy costs, the more extensive measures could be implemented to increase the *Wind Penetration* further more — up to 100% theoretically.

4. Seawater desalination as industrial process

4.2. Principles of seawater desalination

At industrial scale, thermal as well as membrane processes are used for seawater desalination:

The thermal desalination processes are characterised by the phase change of the seawater in which the product is separated by condensation of the vapour (Fig. 2 left). Well-known applications of thermal desalination at industrial scale are the multistage flash evaporation (MSF), the multieffect distillation (MED) and the mechanical or thermal vapour compression (M/TVC).

The membrane processes operate without phase change. By regulation of the chemical potential across a semi-permeable membrane a partial flow of seawater

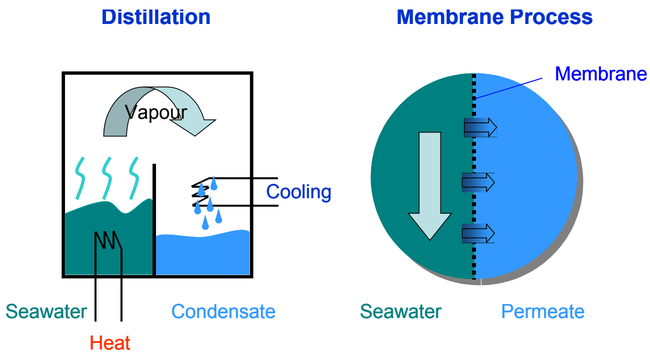

Fig. 2. Schematic representation of applied desalination principles.

is separated as permeate (Fig. 2 right). Within industrial seawater desalination, the reverse osmosis (RO) is increasingly important. For desalination of brackish water with lower salinities the electrodialysis is as well applied.

In consequence of a lower energy consumption per unit of product, lower investment costs, a simple process control and a very flexible plant design, the RO gained a significant market share within the field of small and large-scale desalination plants (> 100,000 m³/d) and will increase it prospectively. Thermal desalination plants are applied predominantly, where appropriate waste heat is available.

Compared to other desalination principles, following characteristics make the RO more reasonable for a wind powered desalination process compared to other desalination principles [1–4].

a) a broad load range — to avoid an excessive modularity of the total desalination capacity and the resulting frequent activation- and deactivation sequences,
b) a low and uniform energy consumption per unit of product within the total load range,
c) a high process dynamic — to adjust the power of the desalination plant to the fluctuating wind power quickly.

5. Reverse osmosis as wind powered process

5.1. Principle of RO process for seawater desalination

The RO is applied as cross-flow filtration. The pressurised seawater — feed flow — flows along the semi-permeable membrane. If the feed pressure exceeds the osmotic pressure of the seawater a fraction of water diffuses through the membrane and is collected as permeate flow (Fig. 3).

The retentate flow is depressurised by the downstream energy recovery device. The recovered energy is transferred as hydrostatic pressure directly to an equal fraction of the feed flow or indirectly by boosting the high-pressure pump.

The power of the high-pressure pump could be adjusted continuously within a broad range of feed pressure and flow — in order to adjust the permeate production to varying water demand and feed conditions or — relevant for WIP — to the fluctuating wind power generation.

5.2. Variable operation of RO process

Since the RO is applied for seawater desalination, the concept of powering the RO with the abundant wind energy potential is introduced and developed further.

Within the RO-community there exists no concluding assessment if the thin-film composite membrane material reacts on long-lasting variable process parameters with a performance deterioration. To date industrial RO plants are operated with constant process parameters. The membrane suppliers recommend the uninterrupted operation at nominal capacity in order to maximise utilisation of the costly membranes.

To reach a verifiable assessment, comparative long-term tests have been carried out by the authors team with variable and a constant operated membrane, respectively [5,6]. The performance deterioration due to compaction and reversible fouling — mainly affecting the RO performance under constant operation — was investigated comparatively. For the variable operation, periodically altered process parameters were set in a way that at the beginning of the test run both membranes had the same feed power.

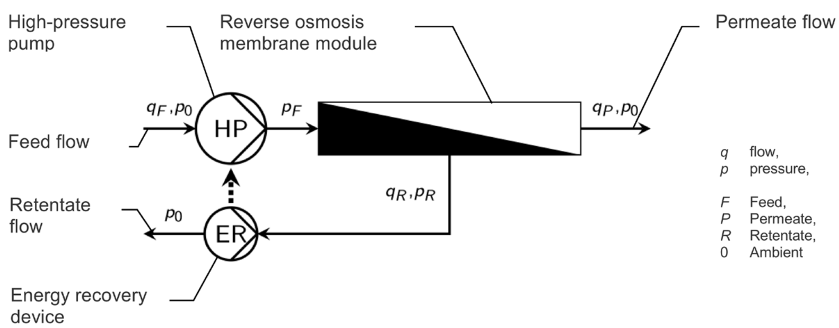

Fig. 3. Schematic representation of a seawater reverse osmosis process.

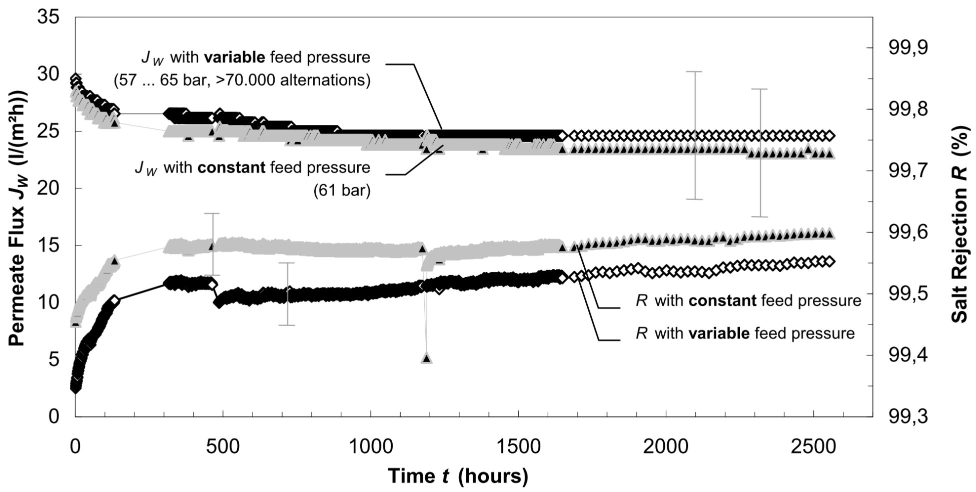

Fig. 4. Permeate flux and salt rejection of SWRO membranes SW30-2540 at variable and constant feed pressure. With feed concentration of 36.4 g/l total salinity at 25°C.

Altogether, in none of the five test runs a performance deterioration of the variable operated membrane compared to the constant operated membrane could be observed (Fig. 4).

Due to deactivation periods resulting from periods of insufficient wind power and due to the continuously varying process parameters minor positive effects on the membrane performance are expected (ref. to results of other authors, too [7]).

6. SYNWATER®

6.1. The system

The very flexible SYNWATER® modules together with the integrated load and storage management permit an optimal direct use of the freely accessible and low-cost resource wind as process power.

The surplus production and storage of potable water in strong wind periods and the complementary hybrid power supply (wind/grid) enable a safe and cost efficient water supply even in lull wind periods.

The modular SYNWATER® system can be optimally adapted to individual sites, feed water qualities, water demand and local wind conditions.

The SYNWATER® modules are designed for medium (200–5,000 m³/d) and large (more than 5,000 m³/d) plant capacities and consists of the following components:

- SYNWATER® Pre-processing
- SYNWATER® Kernel system
- SYNWATER® Post-processing
- SYNWATER® Load management (LM)
- SYNWATER® Wind power

Site-specific components:

- SYNWATER® Pre- and post-processing are in general designed for variable operation in general. The individual design is site-dependent.

System-specific components

- SYNWATER® Kernel system consists of variable driven UF/RO membrane combinations and is designed site-independent.
- The high-grade pre-treatment and the special supervision procedure for the RO membrane characteristics allows a temporary increased production for the optimal use of strong wind periods.

6.2. The load management

The system integrated load management SYNWATER® LM contains different function levels:

- basic functionality:
  - Continuous adaptation of the process capacity to the current wind power and therefore an optimal direct use of the profitable and long-term stable resource wind as process power;
  - Special control and monitoring tools to supervise the temporary overproduction in strong wind periods (Fig. 5 – right side between 100 and 150%).
- extended functionality
  - Consideration of flexible tariff and demand scenarios for water and energy;
  - SYNWATER® LM is designed for an optimal system integration into the flexible and intelligent networks of the 21st century (smart grids).

6.3. Economic aspects

As indicated in section 3.2 the application of the load management depends strongly on the level of grid tariffs. Beside that, several techno-economic parameters will also affect the most economic configuration and op-

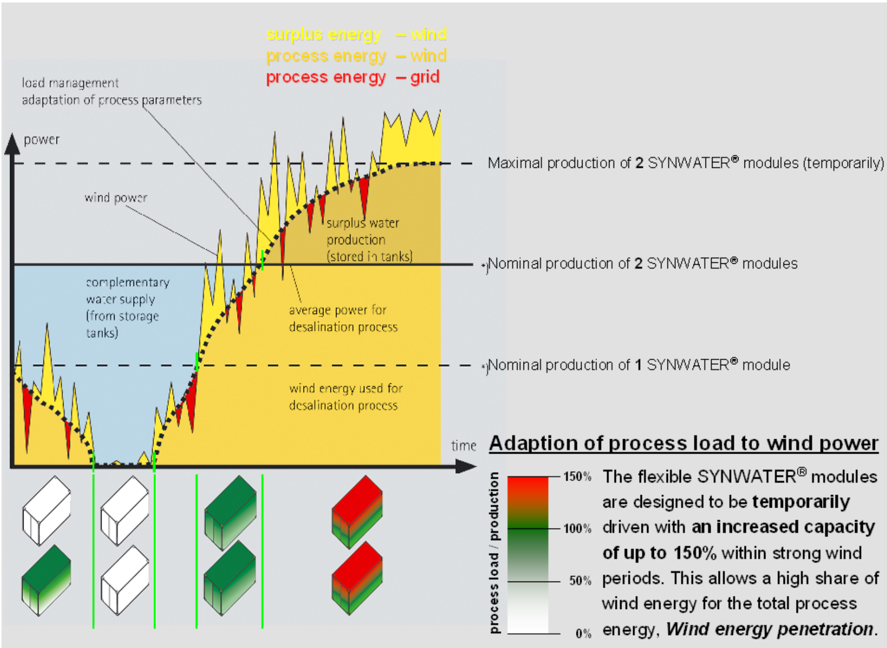

Fig. 5. Principle of SYNWATER® load management.

Table 3
Basic assumptions for SYNWATER® (Project category: Wind Powered Process), no CDM effects considered

Project		Wind turbine		Desalination	
Project time	20 years	Investment cost	1.250–1.450 €/kW	Investment cost	800–1100 €/(m³/d)
Interest rate	5–8 %	O&M cost	0.010–0.014 €/kWh	O&M cost	0.25–0.35 €/m³
Annuity factor	0.0802–0.1019	Feed-in tariff	0.04–0.07 €/kWh	SEC	3.5 – 5.5 kWh/m³
		Capacity factor	25–35 %		

eration of the process load. For broad range of possible SYNWATER® projects, the techno-economic parameters are represented by the following assumptions (Table 3).

Fig. 6 presents three application fields, where — in relation to the average grid tariff at site over 20 years (!) — the respective application realizes the lowest water production costs.

For a grid tariff level up to 5 €ct/kWh in general (with an extended range in extreme cases) the conventional grid-connected desalination could be the most economical solution [Fig. 6 (blue)].

Within the prevailing level of medium grid tariffs, ranging from 5 to 12 €ct/kWh (with an extended range in extreme cases), SYNWATER®-technology with standard capacities provide desalination at lowest water production costs [Fig. 6 (pink)].

For grid tariffs higher than 12 €ct/kWh (with an extended range in extreme cases) it is recommendable to extend the SYNWATER® capacity above the nominal water demand resp. nominal process capacity [Fig. 6 (orange)].

6.4. Status quo

Since 2010 the SYNWATER®-technology is offered by SYNLIFT Systems GmbH. Currently the preparations for implementing the first system module SYNWATER®200 is taking place (Fig. 7).

References

[1] J. Käufler, Wind powered electrothermal processes, Heat Processing, 7(3) (2009) 211–214.
[2] V.J. Subiela, J.A. Cartá J. and González, The SDAWES project: lessons learnt from an innovative project. Desalination, 168 (2004) 39–47.
[3] J.A. Cartá, J. González and V.J. Subiela, Operational analysis of an innovative wind powered reverse osmosis system installed in the Canary Islands, Solar Energy, 75 (2003) 153–168.
[4] D. Zejli, R. Benchrifa, A. Bennouna and K. Zazi, Economic analysis of wind-powered desalination in the south of Morocco. Desalination, 165 (2004) 219–230.
[5] R. Pohl, Entwicklung und Auslegung windbetriebener Membranprozesse, Institut für Energetik und Umwelt gGmbH, Reg. Nr. Inno-Watt 051260, Sachbericht, 2008.

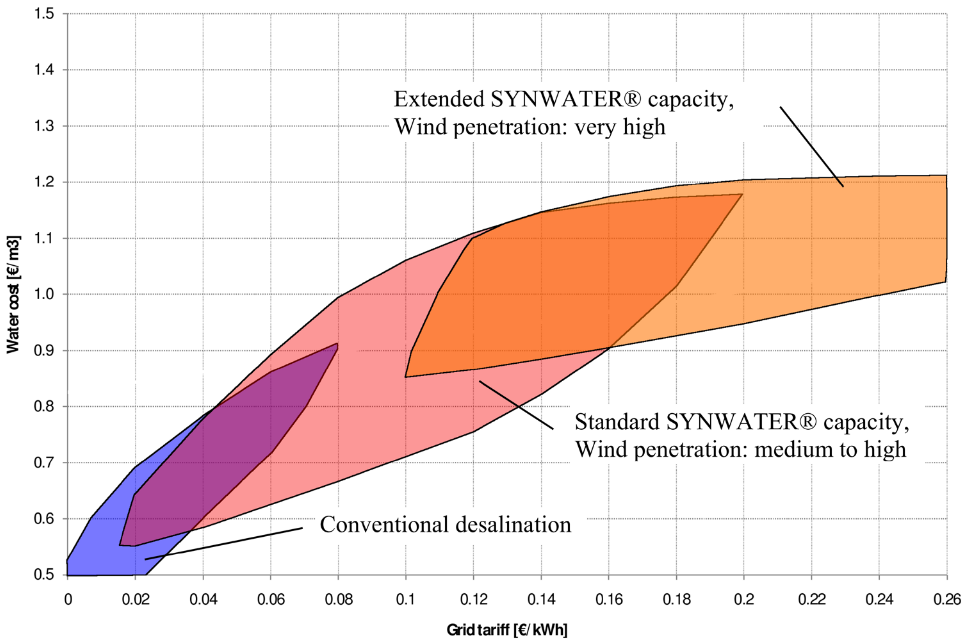

Fig. 6. Fields of application depending on the grid tariff.

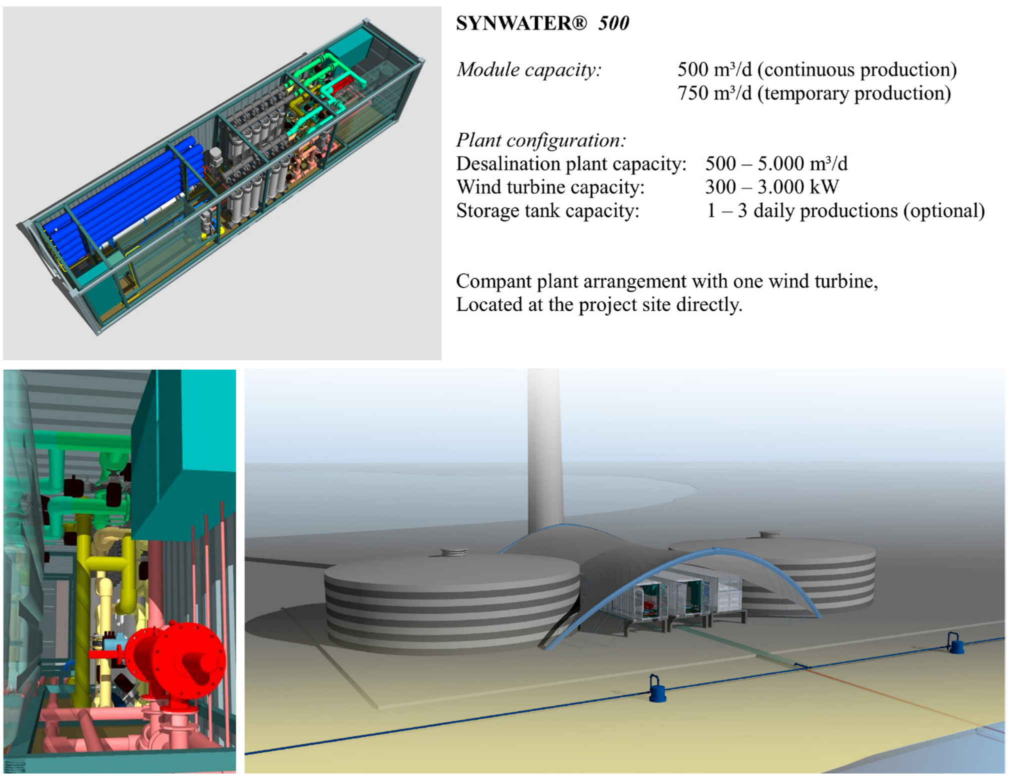

Fig. 7. Containerized SYNWATER® 500 module for a 3×500 m³/d project configuration with storage tanks.

[6] R. Pohl, M. Kaltschmitt and R. Holländer, Investigation of different operational strategies for the variable operation of a simple reverse osmosis unit. Desalination, 249 (,2009) 1280–1287.

[7] V.J. Subiela, J. . de la Fuente, G. Piernavieja and B. Peñate, Canary Islands Institute of Technology (ITC) experiences in desalination with renewable energies (1996–2008).Desal. Wat.Treat., 7 (2009) 220–235.