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DESALINATION AND WATER-REUSE: DEMAND FOR HYDRO-ENVIRONMENT ENGINEERING AND RESEARCH

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With more than half of the world's population living close to the ocean, and having around 70% of the world's mega cities on their shores, seawater desalination is an attractive option for coastal water supply systems. And the trend is clear for the 21st century: worldwide water consumption is growing, driven by an increasing population combined with increasing industrial and agricultural production.

In arid zones and other water-scarce areas, this consumptive demand must indeed largely be met through desalination plants using a variety of technological processes, e.g. thermal distillation processes, such as multi-stage-flash or multi-effect-distillation plants (MSF, MED, Fig. 1 left), or membrane processes such as reverse osmosis plants (RO, Fig. 1 right). In 2005, the total world installed capacity for seawater desalination was about 27.8 Mill. m^3/d of which about 75% was situated in the Middle East and North Africa (MENA) regions. Some states completely depend on desalinated water, such as Kuwait, others to more than 50% of their domestic use, where other drinking water sources are close to depletion. To avert the real threat to resource sustainability and to satisfy the immediate need to increase the production and supply of potable water, desalination is a key focus for governments across the region, generating massive investment and creating demand for global expertise plus the latest advanced systems and technologies. In the period up to 2015, the countries of the MENA region are expected to spend US$24 billion in desalination costs (www.middleeastelectricity.com). Also

Hadera (Israel), world's largest RO desalination plant (275,000 m^3/d, source: IDE Technologies) noteworthy are the increasing plant sizes for these large scale industrial size installations, such as the Al-Jubail (Saudi Arabia) MSF plant with 1.54 Mill. m^3/d capacity.

But also outside the MENA region desalination is a growing market (12% yearly growth of installed capacity over the last five years (GWI, 2007)), where new desalination hot-spots in Australia, Southeast-Asia, Spain and California are emerging. Those developments are usually accompanied with water purification technologies, such as water-reuse (see Fig. 2). For example, the Spanish government informed that production has doubled in the last five years and predicts that it will double again in another five years (Technology Review, 2006). The US Bureau of Reclamation (2003) also states: “By 2020, desalination and water purification technologies will contribute significantly to ensuring a safe, sustainable, affordable, and adequate water supply for the United States”.

Desalination and Water Security

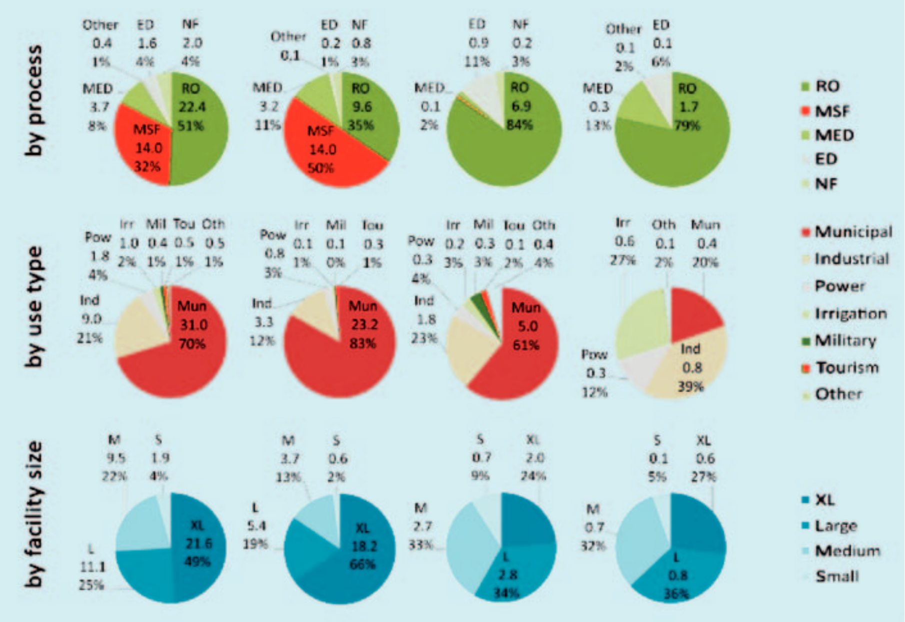
Despite great achievements in reducing the overall energy consumption, desalination plants remain an energy-intensive process. Since most of the energy is taken from fossil sources, the CO_2-emission from desalination plants is an important environmental problem. Another major concern is related to coastal water quality problems caused by brine discharges. The brine (or concentrate) is the waste stream produced by desalination plants and is usually discharged into the sea. The brine flow rates are large, generally up to 40 % (RO) and up to 90 % (thermal, including cooling water) of the intake flow rate, thus either almost as large or even considerably larger than the required drinking water flow rate. The brine is characterized by its high concentration of substances taken out of marine waters (i.e. salt). Furthermore, and often more critical, the brine contains additives and corrosion products, requiring post-treatment or outfall systems (www.brinedis.net.ms).

Unfortunately, major desalination and water-reuse projects, as well as other large water projects in coastal regions, such as marine outfall systems and wastewater treatment schemes are experiencing considerable delays in commissioning. For example, objections in Australia and the USA regarding environmental impacts have already become key issues for project permits, often considerably influencing plant commissioning and design (e.g. Huntington Beach, or Carlsbad, www.carlsbad-desal.com), and thus overall project costs. Henry Salas, formerly of the Pan American Health Organization (PAHO) showed in his keynote at the International Symposium on Outfall Systems (www.outfalls.info.ms) in Mar del Plata, Argentina that many coastal wastewater projects in Latin America did not yet conclude the outfall system. More than 10 large-scale projects (each more than 1 million population served) were mentioned where almost completely raw sewage has been continuously discharged at the shoreline for more than 10 years due to these delays. Such problems of water projects seem to be mainly related to political and administrative problems, but often also to poor understanding of those systems.

There is often a misconception that treatment results in a ‘pure’ and ‘clean’ effluent which can be discharged directly on the beaches. Or back to desalination, that the sun "simply" can evaporate seawater to produce freshwater, and, at the end that one "only" needs to reduce the consumption and individual use of water. On one hand, this can lead to overly expensive wastewater systems, as has been shown in a second keynote given on the same symposium by Burton H. Jones from the University of Southern California, USA, about Huntington Beach. He described intensive field studies, showing that the political decision to upgrade the treatment plant for the existing outfall did not solve the water quality problems because the existing problems are not related to the outfall. Around 1 billion dollars were spent that could have been invested much more productively. On the other hand some of the technical solutions do not reach the consumer. For example, almost identical technologies are used for desalting seawater, and purifying wastewater (water reuse). However, water supply companies have difficulties in selling potable re-

Fig. 1: Left: Thermal distillation plant. Right: 4 membrane pressure vessels of a reverse osmosis plant (Courtesy: Sabine Lattemann)

Fig. 2: Global desalination capacity (in Mm^3/d and %) by source water type (top row), by process and source water type (2nd row), by use type and source water type (3rd row) and by plant size and source water type (last row). Abbreviations: reverse osmosis (RO), multi-stage flash distillation (MSF), multi-effect distillation (MED), nanofiltration (NF), electrodialysis (ED), XL>50,000m^3/d, L>10,000m^3/d, M>1,000m^3/d (www.brinedis.net.ms). (Courtesy: Sabine Lattemann)



used water compared to selling desalinated water. Thus, technological solutions oversee the potential and necessity for a more holistic approach. The trend is clear again, and should not be about competing systems but blended systems, but to what cost for society and environment, and to what share?

Discussing and solving this controversy is one of the key objectives of Water Security with concepts looking on holistic water and energy budgets and subsequent labeling of products and services using footprint calculations (www.waterfootprint.org). These water budgets describe not only conventional hydrological balances in a watershed, but include the balance (i.e. the transport) of embedded water used to grow food or produce products. For example a kilogram of steak embeds about 15,000 litres, the total amount needed to feed the cow and run all the processes that make the steak. Numerous agricultural production sites however are located in water-scarce regions with strongly growing capacities of desalination and water-reuse, such as Spain and Israel. So besides the hydrological water-cycles, there is a considerable water transport through goods and services, which is usually not a closed cycle, but a one-way transport to often water rich regions.

Changes will require a higher level of information and public participation on the individual level. Water security concepts proposed herefore product labeling systems similar to those on electrical devices (e.g. refrigerators), and the calculation of water footprints, allowing not only to change source demand and characteristics, but also to improve acceptance, and understanding of technologies and practices. However, it is not only about optimizing individual technologies, but on integrated approaches. And it is not about green image campaigns, but on well based facts and technologies, and this might be an opportunity for IAHR. Historically, desalination technologies have mainly been related to mechanical engineering developments, whereas treatment technologies where related to the civil/sanitary engineering domain. Currently they become more interdisciplinary, but often still underutilizing the hydro-environmental components. The growing number of joint committees within IAHR and IWA (IAHR/IWA Joint Committee on Marine Outfall Systems (www.outfalls.net.ms), IAHR/IWA Joint Committee on Urban Drainage (www.jcud.org/), IAHR/IWA/IAHS Committee on Hydroinformatics (http://hydroinformatics-community.org/)) reflects that development, and represents a large part of the applied engineering activities within IAHR.

Fig. 3: Seawater Desalination intake system at Barcelona (Spain). Several horizontal subseabed drills with filtration region shown in light blue provide large flows of high quality seawater due to the pre-filtration within the seabed (Courtesy: Neodren system).

Challenges and Impact mitigation

Recent research projects set the base for such approaches and provided comprehensive background information on energy and discharge characteristics of desalination plants, and other coastal water projects in a larger context (e.g. www.brinedis.net.ms). The energy demand of desalination or water-reuse depends on the chosen process (distillation or membranes), and required pre-treatment, and efficiency of those components. Modern seawater RO plants can achieve specific energy demands of <2.5 kWh/m^3 and a total energy demand of <3.5 kWh/m^3 at 50% recovery. Distillation plants require approximately 250-330 MJ of thermal energy and 1.5 - 3.5 kWh/m^3 of electrical energy, thus in total more energy than RO plants. This explains the increasing capacity of RO plant recently overtaking thermal desalination capacities.

In comparison, Pearce (2009) mentions a total energy consumption of 1.7 kWh/m^3 for potable reuse, and 0.8 kWh/m^3 for water reuse (irrigation), and 0.5 kWh/m^3 for tertiary wastewater treatment plants. Conventional surface water treatment and groundwater pumping account for only 0.3 kWh/m^3. However, in locations where the water requires a transport over large distances, seawater desalination might turn out the more energy-efficient option, as in the Perth metropolitan area in Australia. The plant with its capacity of 144,000 m^3/d accounts for about 0.7% of the peak electricity demand in the region, and provides 17% of the city's water. A more holistic view shows also that 30% of electrity is consumed by air conditioning in summer (Crisp, 2008) meaning that 3-4h air-conditioning in a private home is equivalent to the production of 1m^3 of desalted drinking water, which will last for 3-6 days on average. This calls for water security concepts.

The increasing competitiveness of desalination can be related to considerable improvements in hydraulics, such as energy recovery devices or outfall systems, and membrane optimization, causing desalination water costs to decrease from 1.6 US$/m^3 in 1995 down to currently 0.6 US$/m^3, thus already on competing levels with traditional water supply options. Membrane plants are operated at very high pressures (around 60 bar), where the product water leaves the process at around 1 bar, whereas the concentrate still is highly pressurized. The energy recovery devices are transferring concentrate pressure directly to the feed stream applying turbochargers, pelton turbines, work exchangers, pressure exchangers, recovering up to 95% of the concentrate energy into the feed stream. Booster pumps compensate for remaining pressure losses. Unfortunately, the optimization of energy recovery is almost at the limit, but further developments are required to reduce for example pressure losses within the membranes. Those are not only associated to specific geometries, but to biofouling and clogging, thus specifically hydro-environmental processes on a microfluidic scale, and unsteady conditions (including almost hourly backwashing procedures). This applies not only for the desalination membranes, but for all pre-treatment membranes, where nowadays ultra and nanofiltration systems are applied to compensate the usually highly varying intake water quality.

> **The increasing competitiveness of desalination can be related to considerable improvements in hydraulics**

Latter leads to a second large research field related to improvements on intake, and related physical pre-treatment systems, such as grids and settling tanks. For open intakes there are major concerns related to fish impingement (species stuck at the intake facility), and entrainment (species taken through the process, where they will not survive), causing strong hydraulic limitations on such structures (requiring intake velocities less than 0.1m/s) resulting in very large intake structures. There is a huge demand on studies related to fish behavior close to such structures, as well as on fish handling system or jelly-fish diversion to avoid clogging. There are also further options available, such as subsurface intakes (Fig. 3) which however strongly depend on soil characteristics.

On the other end of these plans, the discharge side, however, strong turbulent mixing is required to reduce the density differences, and to avoid the establishment of strong and highly concentrated density currents influencing the benthic communities. More field and lab studies are required to study these phenomena, where very thin (less than a meter thick) density currents develop, which are influenced by the coastal bathymetry and roughness, as well as by the coastal currents. This requires new developments for measuring, and monitoring in marine waters, as well as for related modeling issues.

And further advantages can be taken out of traditional hydraulic research by combining existing long lasting hydraulic research activities with the needs in desalination, such as providing the pressure for the membranes through renewable hydraulic energies (wave, tidal, coastal currents), which even might act similar to the previously mentioned energy recovery devices.

Thus, coupling between energy systems, treatment and purification systems, and hydro-enviromental systems will definitely be required for future projects. Existing projects are already affected by that trend. For example the Changi outfall in Singapore was designed for receiving 100% of the wastewater after treatment. Intensive water reclamation for water supply reduced the flow considerably, which changes effluent characteristics and quantity. A similar example is Orange County, California, were worlds largest reclamation plant has been built, now injecting the reclaimed water into the ground (http://articles.latimes.com/2008/jan/02/local/me-reclaim2). This also reduced the flow to the existing outfall, and increased its salinity, thus changing mixing characteristics and hydraulic performance.

Muscat (Oman), Al Ghubrah power generation and seawater desalination plant (biggest in Oman, capacity: 191,000 m³/d, courtesy: HMR Consultants)

Last but not least, there is the challenge to improve public involvement and the interactions between planners, designers, politicians, administrators, and the public. Conventional planning, bidding, and contracting schemes are quite deficient in that regard, and can result in significant (financial) damages to some projects. In addition, water regulations were changing significantly within the last decade (e.g. the European Water Framework Directive). And for desalination and water-reuse several initiatives are running to define new standards (e.g. California, http://www.sccwrp.org/ResearchAreas/contaminants/MeasurementFateAndBioavailability/BrineDischargePanel.aspx, and http://www.waterboards.ca.gov/water_issues/programs/ocean/desalination/ with the participation of IAHR member and committee chair Philip Roberts).

This shows that we “have the skills and technologies to develop effective solutions to many of the problems that surround global water security” (cited from the foreword of Royal Academy of Engineering, UK, 2010), however, “in isolation these technologies and skills are not enough. It is incumbent on engineers to articulate the issues surrounding water security to those outside of their usual sphere. Engineers must engage with policy makers, economists, financiers, farmers, industry and development agencies in order to build the public-political consensus needed to approach the problem of global water security.”

IAHR setup a Task Force (https://sites.google.com/site/globalwatersecurity/), to cover that gap in current developments and putting the research into practice. The big growth in desalination and reuse, and the concepts of water security represent a perfect opportunity for hydro-environmental engineering and research and where IAHR has much to offer.

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