Thermal Processes for Water Desalination

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Outline

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Introduction

- Notwithstanding improvements in water management, **non-conventional resources are necessary** to meet current and future freshwater demand.
- **Seawater**, present in abundance, constitutes reliable sustainable source of freshwater.
- Today, **many countries strongly depend on desalinated water**.
- **Many countries turn to desalination** to develop and diversify water supply options.
- **Desalination has also become economically more competitive**.
- **Established desalination markets** in the Middle East and North African (MENA) and Mediterranean regions are expected to **expand**.
- **New markets** such as China, India and Latin America are expected to **develop**.
- Despite rise of membrane-dominated markets, e.g., in the Mediterranean regions, **evaporative (thermal) desalination technology continues to be adopted on a large scale**, e.g., in the Gulf and in the Red Sea.
Growth of Desalination Market

Data source: IDA Desalination Yearbook 2011-2012

* data 2011: for some months only
GWI DesalData predicts that total contracted capacity will reach 119.2 million m³/d by the end of 2016.
Total Worldwide Capacity by Feedwater Category

- Seawater: 58.85%
- Brackish water: 21.24%
- River water: 8.54%
- Wastewater: 5.42%
- Pure water: 5.05%
- Brine: 0.2%

Installed capacity: 66.4 mio. m³/d

Data source: IDA Desalination Yearbook 2011-2012
“Conventional wisdom in the industry says that thermal desalination is in terminal decline. However, data from the Inventory shows that the thermal market has continued to grow. Despite the rise of membrane-dominated markets such as Algeria, Spain and Australia, thermal technology continues to be adopted on a large scale.”

Source: IDA Desalination Yearbook 2011-2012

Data source: IDA Desalination Yearbook 2010-2011
Capacity by Region

Top 10 countries by total installed thermal capacity since 1945

United States of America
Saudi Arabia
Spain
China
United Arab Emirates
Algeria
Japan
Korea (South)
Australia
India

Top 10 countries by total installed membrane capacity since 1945

Data source: IDA Desalination Yearbook 2011-2012
Seawater Desalination Processes - Overview

Main seawater desalination processes

Thermal processes
- MSF
  Multi-stage flash evaporation
- MED
  Multiple-effect distillation
- MED-TVC
  Multiple-effect distillation with thermal vapour compression
- MVC
  Evaporation with mechanical vapour compression

Membrane processes
- RO
  Reverse osmosis
Multi-Stage Flash (MSF) Once-Through Distiller

原理：闪蒸蒸发

Inlet 1st stage: 112 °C
Outlet 1st stage: 108 °C

Inlet 2nd stage: 104 °C
Outlet 2nd stage: 100 °C

Inlet 3rd stage: 100 °C
Outlet 3rd stage: 96 °C

ΔT = Pressure / bar

Saturation curve
Multi-Stage Flash (MSF) Recycle Distiller

Of the two MSF process configurations, the recycle distiller is exclusively employed:

- **Distillate production:** 5,000 – 80,000 m³/day
- **Number of stages:** mostly 16 – 22
- **Top brine temperature:** 90 – 120°C, mostly 100 – 112°C
- **Concentration factor:** CF = 1.3 – 1.5
- **Specific heat consumption:** 70 – 110 kWh_{th}/t; nowadays, large distillers: 65 - 70 kWh_{th}/t
- **Specific electric energy consumption:** 3.5 – 5 kWh_{el}/t
- **Salinity of distillate:** < 10 ppm
MSF Stage Layout

Cross flow of brine inside tubes and flashing brine

- Condenser tube bundle
- Vent extraction (non-condensable gases + vapour)
- Condenser tube bundle (here: circular tube bundle)
- Distillate tray
- Vapour + non-condensable gases + liquid droplets
- Flashing brine

- Wire mesh mist eliminator (demister)
- Splash plate
- Interstage brine transfer device, e.g. orifice and weir
Example: MSF Recycle Distiller

MSF plant: JEBEL ALI L Phase II, Dubai, UAE, 4 MSF units, 62500 m³/d per unit, commissioned 2008

Source: Fisia Italimpianti S.P.A.
Multiple-Effect Distillation (MED)

- Distillate production: 100 – 15,000 m³/day
- Number of effects: ...4 – 12...
- Top brine temperature: 55 - 70°C
- Concentration factor: CF = 1.3 – 1.5
- Spec. heat consumption: 60 – 220 kWh/th/t
- Spec. electric energy consumption: 1.5 – 2.5 kWh/el/t
- Salinity of distillate: < 10 ppm
MED Stage Layout

Source: Charles Desportes, ENTROPIE, VEOLIA Water Systems
DME Seminar “Fouling und Scaling in der Meerwasserentsalzung“, 2005
Example: Small MED plant

Source: K. Wangnick, DME Seminar “Introduction to Seawater Desalination“, 2006
MED with Thermal Vapour Compression

- **Distillate production:** up to 40,000 m³/day
- **Number of effects:** ...3 – 6...
- **Top brine temperature:** 55 - 70°C
- **Concentration factor:** $\text{CF} = 1.3 – 1.5$
- **Spec. heat consumption:** 60 – 160 kWh\textsubscript{th}/t
- **Spec. electric energy consumption:** 1.5 – 2.5 kWh\textsubscript{el}/t
- **Salinity of distillate:** < 10 ppm
Example: MED-TVC Plant (1)

MED-TVC plant,
2 x 5000 m³/d,
Saudi Arabia

Source: Aquatech International Corporation, USA
Example: MED-TVC Plant (2)

MED-TVC desalination plant, 2 x 36368 m³/d, Layyah Power Station, Sharjah, UAE

Source: SIDEM, VEOLIA Water Systems, France
- Distillate production: 10 – 3000 m³/day
- Number of effects: 1 - 3, mostly 1
- Top brine temperature: up to 70°C
- Concentration factor: CF = 1.3 – 1.7
- Spec. electric energy consumption: 8 – 16 kWhₑ/t
- Salinity of distillate: < 10 ppm
MVC Distiller Layout

1 - compressor
2 - spraying nozzles
3 - feed water
4 - evaporator tube bundle
5 - evaporator shell
6 - vapour suction channel
7 - distillate pump
8 - switch cabinet
9 - measuring instrument
10 - chemical dosing station
11 - plate heat exchanger

Source: K. Wangnick, DME Seminar “Introduction to Seawater Desalination“, 2006
Example: MVC Distiller

500 m³/d, 1 stage

Source: K. Wangnick, DME Seminar “Introduction to Seawater Desalination“, 2006
Example: MVC Distillers

Source: Entropie, Veolia Water, France

2 x 216 m³/day, 1 stage, Egypt
Scale Formation in Thermal Desalination Plants

- Seawater = multi-component electrolyte solution
- Co-precipitation of inorganic salts, e.g., CaCO$_3$, Mg(OH)$_2$, CaSO$_4$
- Scale formation on heat transfer surfaces is major problem in thermal desalination plants
  - hinders heat transfer process
  - increases specific energy consumption
  - reduces production capacity
- Over-sizing heat transfer surface area, scale prevention methods, cleaning methods, production losses
- MED, MED-TVC, MVC: scale on outside of tubes → no mechanical cleaning by sponge balls possible

→ Capital, operating and maintenance costs
→ Essential to achieve effective scale control
Further Development of Anti-Scalants

$t_{EV} = 70{^\circ}C$, $t_{CO} = 90{^\circ}C$, $S = 45$ g/kg, $\Gamma = 0.1$ kg/(s m), $\tau = 50$ h

Source: H. Glade et al., University of Bremen and BASF
Material Selection in Thermal Desalination Plants

- Highly corrosion-resistant metals are used: titanium, copper-nickel alloys, aluminium brass, stainless steel
- Metal prices have increased dramatically since 2003, e.g.
  - Cu: 2…10…8 USD/kg
  - Ni: 8…54…18 USD/kg
- Long lead times for tubes and plates (10 months and more)
- Additionally, corrosion and scale formation problems

Application and further development of thermal desalination plants impaired

Source: The London Metal Exchange Ltd.
**Development of Evaporators with Polymeric Materials**

- **Challenges:**
  - low mechanical strength
  - low wettability
  - low thermal conductivity

- Compensating low thermal conductivity of polymers by
  - using **polymer films** with low wall thicknesses in falling film evaporators
  - using **polymer-composite tubes with metallic or ceramic particles** in horizontal tube falling film evaporators

Source: TU Kaiserslautern, Germany

Source: University of Bremen, Germany
Coupling of thermal desalination plants with renewable energy sources, especially solar energy, gaining increasing importance

Source: DLR

solar field  power plant + multiple-effect distillation plant
Often small plant capacities: about 50 m³/day or less
Medium or even large capacities are possible when coupled with concentrating solar power (CSP) plants

Source: German Aerospace Center

Source: University of Bremen and German Aerospace Center
New Desalination Processes: Membrane Distillation (1)

Source: Fraunhofer ISE, Freiburg, Germany
New Desalination Processes: Membrane Distillation (2)

Solar driven membrane distillation pilot plant

Source: Fraunhofer ISE, Freiburg, Germany
Future Trends in Thermal Desalination (1)

- Development of **larger single unit capacities**
  - MSF: at present 80,000 m$^3$/day $\rightarrow$ bidding 95,000 m$^3$/day - …
  - MED: at present 40,000 m$^3$/day $\rightarrow$ contracted: 68,000 m$^3$/day

Source: SIDEM, France

15 MIGD MED-TVC unit
LP Steam @ 3 bar abs
GOR 9.5

Source: Aquatech International Corporation, USA
Future Trends in Thermal Desalination (2)

- Increase in top brine temperature
- Improvements in scale control by suitable polymeric anti-scalants, lower dosing rates
- Improved and cost-effective materials (e.g. polymers for MED), smaller wall thicknesses, surface coatings
- New evaporator design
- Further development of hybrid plants: nanofiltration + thermal plants + RO plants
- Improved integration of thermal desalination (power plants, industrial production plants, waste heat utilisation)
- Use of renewable energies (solar, wind)
- Reducing environmental impact
Conclusions and Outlook

- Though being established processes, MSF and MED systems still possess optimization potential in various aspects.
- Main areas for future improvements in MSF and MED systems are:
  - scale control, increase in top brine temperature
  - material selection
  - use of renewable energies
  - optimized integration with power plants, hybrid systems
  - new processes for small, decentralized plants
- The top brine temperatures of MSF and MED distillers are expected to rise as soon as improvements in scale control allow this.
- Unit capacities will keep growing in the near future.
- Improvements will lead to reduction of energy consumption, more efficient chemicals, increase in plant availability and reliability and, thus, to a further reduction of costs.