High TBT (85°C) MED Technology Development

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Doosan Water R&D Center Dammam, KSA
INTRODUCTION TO DOOSAN WATER

BUSINESS GROUPS

WATER BUSINESS IN DOOSAN

HT MED TECHNOLOGY DEVELOPMENT

INTRODUCTION

PREVIOUS STUDY IN KOREA

JOINT DEMONSTRATION IN KSA

CONCLUDING REMARKS
At Doosan Heavy Industries & Construction, our vision is to be a global leader in power and water, and we are committed to helping our clients meet tomorrow’s challenges and opportunities.

- **Global Leader in power and water**
- **Front Runner in industrial plants**
- **Boost in global business competencies**
- **Renewable Energy for our future**

- **Revenue**: US$18.1 billion
- **Employees**: 8,200

(2014 figures / Locally hired employees excluded)

**NUCLEAR**

**EPC**

**WATER**

**POWER**

**CASTING & FORGING**

- Doosan Skoda Power
- Doosan Lentjes
- Doosan Babcock
- Doosan IMGB
- Doosan Power System India
- Doosan Enpure
- Doosan Hydro Technology
- Doosan VINA
**DESALINATION TECHNOLOGIES**

**MSF (MULTI-STAGE FLASH)**
- Large-scale unit, one-module fabrication, and hybrid solution

**MED (MULTI-EFFECT DISTILLATION)**
- High TBT MED-TVC

**RO (REVERSE OSMOSIS)**
- World’s largest RO train with application of 16-inch membranes

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**World’s Largest Desalination Plant with Hybrid Config. (MSF + RO)**
- **Capacity**: 228MIGD (1,036,488m³/day)
- **Location**: Ras Al Khair, Saudi Arabia
- **Client**: Saline Water Conversion Corporation (SWCC)
- **Evaporator Unit Capacity**: 20MIGD (90,920m³/day)
- **Configuration**: 20 MIGD x 8 units
- **Performance Ratio**: 9.5
- **Dimensions(m)**: W118.8 x L24.3 x H11.4

**World’s Largest Multi-Effect Distillation (MED) Distiller**
- **Location**: Yanbu, Saudi Arabia
- **Client**: SWCC
- **Distiller Unit Capacity**: 15MIGD (68,190m³/day)
- **Configuration**: 15 MIGD x 1 unit
- **Gain Output Ratio**: 9.7
- **Delivery**: 18 months

**Largest Desalination Plant in South America**
- **Capacity**: 47.5MIGD (215,935m³/day)
- **Pretreatment**: Pressurized DMF
- **Configuration**: 5.3MIGD x 9 trains
- **Feed water TDS**: 39,300 mg/L
- **Product water TDS**: < 700 mg/L
- **Client**: Minera Escondida (BHP Billiton)
- **Currently delivering the project for the world’s largest copper mining operation**

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[Largest Desalination Plant in South America](#)

[Largest Desalination Plant with Hybrid Config. (MSF + RO)](#)

[World’s Largest Multi-Effect Distillation (MED) Distiller](#)
OPERATION & MAINTENANCE

Know-how
Based on commissioning experience with over 20 plants

Flexibility
Offered through a unified channel (EPC + O&M)

Efficiency
Provided through ICT* solutions

O&M Optimization

[Shuwaikh RO] Kuwait
Kuwait’s First SWRO Desalination Plant
- Capacity: 30MIGD (136,380m³/day)
- Pretreatment: DAF+UF
- TDS: 45,000 mg/L
- O&M Period: 3 years (’11.10~’14.10)
- Client: Ministry of Electricity & Water
- Challenging conditions including frequent red tides events and high TDS

[World’s Largest Desalination Plant (Hybrid (MSF+RO))]
- Capacity: 228MIGD (1,036,488m³/day)
- Pretreatment: DAF+DMF+Cartridge filters
- TDS: 45,000 mg/L
- O&M Period: 6 years (’13.12~’19.4)
- Client: SWCC
- Simultaneous service for both thermal (MSF) and SWRO plants

[Ras Al Khair Ph.1] Saudi Arabia
Korea’s First Large-scale Desalination Plant
- Capacity: 10MIGD (45,460m³/day)
- Pretreatment: DABF+UF/DABF+DMF+C.F.
- TDS: 34,500 mg/L
- O&M Period: 20 years (’14.7~’34.6)
- Client: Busan Metropolitan City
- Service for the world’s largest capacity RO train (8MIGD) with 16-inch membranes

[Busan Gijang RO] Korea
Kuwait’s First SWRO Desalination Plant
- Capacity: 30MIGD (136,380m³/day)
- Pretreatment: DAF+UF
- TDS: 45,000 mg/L
- O&M Period: 3 years (’11.10~’14.10)
- Client: Ministry of Electricity & Water
- Challenging conditions including frequent red tides events and high TDS

**O&M Optimization**

* Information & Communication Technology
MORE THAN 20 LARGE-SCALE DESALINATION PLANT REFERENCES IN MENA AREA

References & Records

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<th>Project Name</th>
<th>Capacity (MIGD)</th>
<th>Type</th>
<th>Country</th>
<th>Construction Period</th>
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<td>RO</td>
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<td>Kuwait</td>
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Total of 33 Projects : 1,626 MIGD*
For daily use by 24.7 million people**

* 7 million ton/day
** 300 liter/person

1 MIGD (Million Imperial Gallon per Day) = 4,546 m³/day water production
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INTRO… Desalination Technology

Current Technologies

Future Technologies

High Reliability & Energy Efficiency

High [Reliability]

[Energy Efficiency]

Low

High
Seawater condition in **Gulf area is much worse than any other region.**

- **Spain**
  - TDS: less 40,000 ppm
  - Turbidity: less 2 NTU
  - Red Tide: None

- **Mediterranean**
  - TDS: less 41,000 ppm
  - Turbidity: less 2 NTU
  - Red Tide: None

- **Gulf Area**
  - TDS: over 45,000 ppm
  - Turbidity: 5~12 NTU
  - Red Tide: Occasionally
  - TSS: 20~30 PPM

- **Singapore**
  - TDS: less 35,000 ppm
  - Turbidity: less 2 NTU
  - Red Tide: Rare

- **Chile**
  - TDS: less 38,000 ppm
  - Turbidity: 3~6 NTU
  - Red Tide: Rare

- **Gulf Sea**
  - TDS: HIGH
  - Turbidity: 7~12 NTU (PEAK 50)
  - TSS: 20~30PPM (PEAK 80PPM)
  - Temp. : 15~35℃

- **Red Sea**
  - TDS: RELATIVE LOW
  - Turbidity: 1~2.5 NTU
  - TSS: 1~2.5 PPM
  - Temp. : 25~35℃

RAS LAFFAN
### Difficulties for SWRO in Gulf Area

<table>
<thead>
<tr>
<th>Gulf Area</th>
<th>Difficulty</th>
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<tr>
<td><strong>Salinity</strong> (TDS, ppm)</td>
<td>• Highest salinity in the world (45,000ppm)</td>
</tr>
<tr>
<td></td>
<td>• Recovery ratio to be decreased</td>
</tr>
<tr>
<td></td>
<td>• Shorten life time of membrane</td>
</tr>
<tr>
<td><strong>Turbidity</strong> (NTU)</td>
<td>• 5~12 NTU</td>
</tr>
<tr>
<td></td>
<td>• Peak 50 NTU</td>
</tr>
<tr>
<td></td>
<td>• Conservative pretreatment design to be required (2~3 stage)</td>
</tr>
<tr>
<td><strong>TSS</strong> (Total suspended Solid, ppm)</td>
<td>• 20~30 ppm</td>
</tr>
<tr>
<td></td>
<td>• Peak 80 ppm</td>
</tr>
<tr>
<td></td>
<td>• Conservative pretreatment design to be required (&lt; 5ppm)</td>
</tr>
<tr>
<td><strong>Red Tide</strong></td>
<td>• Occasionally</td>
</tr>
<tr>
<td></td>
<td>• Reliability to be decreased sharply</td>
</tr>
<tr>
<td></td>
<td>• DAF is essential system</td>
</tr>
<tr>
<td></td>
<td>• Beach well can be required</td>
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</tbody>
</table>

- High CAPEX for sufficient pretreatment
- Low recovery ratio
- Low reliability
- High O&M Cost
Multi-Effect Distillation (MED) is an advanced form of thermal desalination now playing a major role in large-scale desalination projects with the higher efficiency.

How It Works

1. Steam passes through the inside of the tubes
2. Seawater is sprayed onto the outside of tube, generating vapor which is moved to next effect to be used as the heat source
3. Vapor condenses inside of the tube and is collected as fresh water
Increasing TBT 65 → 85°C allows 50% increase in MED efficiency (GOR* & PR**).
= ~33% Steam Saving to produce the same amount of water

** Typical MED: 10kg Water from 1kg Steam **

<table>
<thead>
<tr>
<th>Water</th>
<th>65°C</th>
<th>61</th>
<th>57</th>
<th>53</th>
<th>49</th>
<th>45</th>
<th>41°C</th>
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<td>1</td>
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<td>1</td>
<td>1</td>
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<td>10</td>
</tr>
</tbody>
</table>

GOR = 10

** New HT MED: 15kg Water from 1kg Steam **

<table>
<thead>
<tr>
<th>Water</th>
<th>85°C</th>
<th>81</th>
<th>77</th>
<th>73</th>
<th>69</th>
<th>65</th>
<th>61</th>
<th>57</th>
<th>53</th>
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<th>45</th>
<th>41°C</th>
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<td>2</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>15</td>
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</table>

GOR = 15

33% less energy to produce same water

* GOR: Gain Output Ratio = product water [kg] / steam consumption [kg]
** PR: Performance Ratio = product water [kg] x 2,326 [kJ/kg] / energy input by steam [kJ]
Energy cost is a huge portion in desalting seawater. Saving steam consumption in HT-MED reduces the water production cost of MED.
© High Performance (PR 10 → 15+) MED
- Breakthrough in MED EFFICIENCY (by 50+%)
  - Steam & Seawater Saving 30+%
PREVIOUS STUDY: 24 ton/day Pilot

[2008-2009] 24 ton/day Pilot in Korea - precise experiments for different conditions:
TBT 85°C is targeted after 29 experiments for 75~95°C

☑ 29 experiments
☐ Feed TDS up to 64,000ppm
☐ (MENA tube bundle bottom)
☐ Temperature: 75~95°C
☐ Feed flow: 700~1,100 kg/hr
☐ New chemicals tested

→ TBT 85°C achievable!!
0.1MIGD High Temperature MED-TVC with Brine-Recirculation

- Top Brine Temperature: 85°C
- Bottom Brine Temperature: 67°C
- Sea water intake: 30~40 (ton/hr), 20°C, 27,000~32,000 ppm
- Total feed water supply: 60~70 (ton/hr), 65°C, 45,000~53,000 ppm
- Distillate production: 17 t/h = 0.1 MIGD (410 t/d)

PREVIOUS STUDY: 410 ton/day Pilot Demonstration

[2010~2012] Demonstration of TBT 85°C MED-TVC with industrial-size pilot (410 ton/day) in Korea

• TVC performance test
• Feed optimization test
• Anti-scalant dosage rate test
• Long term operational demonstration
At the end of each experimental case, tubes were sampled and shipped to A/S Supplier for further analysis.

**Sampling Tubes**
- 1st Effect: #1~5, 7
- 2nd Effect: #1~3, 5
- 5th Effect: #1~3, 5

- A/S Supplier: Scale Analysis with AAS, SEM, XRD
As a result of chemical composition analysis, it was shown that soft scale was dominant in the scale deposition as an amorphous species.

- **SEM**
  - Coupon surface totally covered with a thin scale layer

- **XRD**
  - Indicates that scale is only based on amorphous species

**SOFT SCALE**

- **AAS (Tube)**
  - scale detected in Effect #1
  - very low scale detected in Effect #2
  - very low scale detected in Effect #5
JOINT DEMONSTRATION WITH SWCC-DTRI

Signing Ceremony for HT MED Collaboration Project

- Date: 7th Feb, 2016
- Collaboration Period: 3 years (2016 ~ 2018)
- Collaboration Target:
  - Demonstration of High Temperature (TBT 85°C) MED-TVC at Gulf Water condition with DTRI(SWCC)

< Signing Ceremony >
JOINT DEMONSTRATION WITH SWCC-DTRI

- **DTRI MED Pilot**

  - Location: DTRI in Jubail
  - Capacity: 1.3 ton/hr
  - Type: Brine Recirculation MED-TVC
  - No. of Effect: 4
  - Tube Material: Titanium
  - No. of Pass: 2
  - Feed Type: Tray + Perforated plate

- **Operating Condition of 5 Months Scale Test**

  - Top Brine Temperature: 85°C
  - Bottom Brine Temperature: 78°C
  - Total feed water supply: 35 ton/hr, 60,000~63,000 ppm
  - Distillate production: 1 ton/hr
JOINT DEMONSTRATION with SWCC-DTRI

**MED Pilot Schematic Diagram**

- **Steam from boiler**
- **Feed Seawater**
- **Cooling water**
- **Seawater**
- **Brine blowdown**
- **Distillate**

Diagram showing the flow of water and steam through various components labeled E1, E2, E3, and E4, with connections to TVC, distillate condenser, and other relevant points.
Shutdown due to electricity supply issue

Stable Operation

OPERATION DATA : TEMPERATURE PROFILE

Temperature [°C]

Time [hr]

Temperature [°C]

Time [hr]

TBT  Feed  Make-up seawater

Steam  Vapor in E1  Vapor in E2  Vapor in E3  Vapor in E4

Shutdown due to electricity supply issue
FOULING FACTOR ANALYSIS: HTC* & FF** PROFILE

Stable Operation

Normalized HTC

E1  E2  E3  E4

Normalized FF

E1  E2  E3  E4

Design Value: 1.0

*HTC, Heat transfer coefficient
**FF, Fouling factor
FOULING FACTOR ANALYSIS: HTC* & FF** PROFILE

FF value is expected to be less than the design value after 1 year

- Expected Trend of Overall Fouling Factor Increase

- Breakthrough point: 18,858hrs (2.15yrs)

\[ Y = 5.3 \times 10^{-9} \times X \]
After 5-month test, very thin film layer was entirely formed on the tube, which expected to be soft scale

• Before 5-month Scale Test

• After 5-month Scale Test
VISUAL INSPECTION RESULT

Very thin film layer was easily removed after water flushing and scale composition was confirmed as mostly CaCO3 (Soft Scale) by chemical analysis.

- Before 5-month Scale Test
- After 5-month Scale Test
- Cleaning with water

- Chemical composition analysis
  - CaCO3 is a dominant part of scale.
Comparing to conventional MED-TVC (PR 11.5), High TBT MED-TVC plant (PR 18.3) has significant improvement in HTC and reduction in OPEX

- Steam consumption reduction: Over 30%
- LCOW* reduction: 6.4%

- Based on Fuel Cost of 24 USD/bbl
Based on technical and experimental studies (2008~2012), high TBT (85°C) MED-TVC is a competitive technology.
- PR is increased from 9-11 to 13.5-15.8 kg distillate/2,326kJ
- 33% Less Steam Consumption

SWCC-Doosan Joint Demonstration (5 months) verified the High TBT (85°C) MED-TVC technology under Jubail seawater condition (2016~2017).
- HTC & FF monitoring: Consistent HTC and FF trend show high TBT (85°C) MED-TVC operation can be achieved.
- Visual inspection: Only thin film soft scale appeared on the tube surface, which can be easily removed by water flushing
- Chemical analysis: Ongoing to verify scale composition

Based on demonstration test, it is proved that HT MED-TVC is technologically viable in Gulf Area.
Building Your Tomorrow Today