Exergy Efficiency Enhancement Of MSF Desalination By Heat Recovery From Hot Distillate Water Stages

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Overview

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1. Study Objective

- Conduct overall exergy efficiency analysis of 3800 m$^3$/h Multi-Stage Flash (MSF) desalination.
- Carry out exergy efficiency analysis for each of MSF desalination stages.
- Allocate the distribution of the exergy destruction through the system.
- Study exergy efficiency enhancement for MSF desalination.
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2. MSF Desalination Process Description.

- Multi-Stage Flash (MSF)
- Multi-Effect (ME)
- Vapour Compression (VC)
- Electrolysis Filtration (EF)
- Reverse Osmosis (RO)

- 75% of the world’s total desalted water in 2003 was produced using the MSF process.
All studies agree that desalination technologies overall exergy efficiency is too low, less than 30 %. MSF is considered the lowest exergy efficiency among the desalination technologies, its exergy efficiency varies between 1.8% - 7.73 %. 

Studies published in desalination exergy are limited due to the lack of the data and complexity of exergy calculation of the seawater stream.
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3. MSF Unit Overall Exergy Analysis.

- Stream total specific exergy \( (e_t) \) consists of:

\[
e_t = e_{ph} + e_{ch} + e_{po} + e_{ke}
\]

\[
≈ \quad e_t = e_{ph} + e_{ch}
\]

- Stream total exergy depends on mass flow rate \( (\dot{m}) \):

\[
E_T = \dot{m} \cdot e_t
\]

- Physical exergy is:

\[
e_{ph} = (h - h_0) - T_0(s - s_0)
\]

- Chemical exergy is:

\[
e_{ch} = \sum_{i=1}^{n} w_s (\mu_i^* - \mu_i^0)
\]
Exergetic Efficiency: defined as ratio of minimum exergy input required (known as minimum separation work) to the total actual exergy input.

\[ \eta_{II} = \frac{W_{min}}{E_{input}} \]

Exergetic Destruction: defined as the difference between the inlet exergy and the outlet exergy for component or system

\[ E_D = E_{inlet} - E_{outlet} \]
The MSF unit studied

- MSF plant parameters:

<table>
<thead>
<tr>
<th>Flow (t/h)</th>
<th>Specific Heat Consumption kWh/m³</th>
<th>Ratio</th>
<th>Concentration</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seawater</td>
<td></td>
<td></td>
<td>10555.00</td>
<td></td>
</tr>
<tr>
<td>Brine</td>
<td>12872.99</td>
<td>152.51</td>
<td>72.47</td>
<td>1.67</td>
</tr>
<tr>
<td>Steam</td>
<td></td>
<td></td>
<td></td>
<td>8.43</td>
</tr>
</tbody>
</table>

- MSF IPSEpro Model:
Exergy Destruction

Exergy Destruction (%)

Evaporator

MSF Components

PP = Pumps
BH = Brine Heater
HRC = Heat Recovery stages
HRJ = Heat Rejection stages
C = Cooling disposal
P = Product disposal
B = Brine disposal
Co = Condensate disposal
Th = Throttling
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- Allocation of the exact exergy destruction through the evaporator generally and heat recovery stages specifically is important, since it is shown to be the main contributor to the exergy destruction.

* Animation Source: http://ga.water.usgs.gov/edu/drinkseawater.html
4. Stage Exergy Efficiency

- Understanding stage construction is important to define the stage exergy efficiency and obtain the required parameters for this calculation.

- Stage Construction:

\[
\eta_{II(\text{stage})} = \frac{(E_{\text{out}} - E_{\text{in}})_{\text{Cooling}} + (E_{\text{in}} - E_{\text{out}})_{\text{Distillate}}}{(E_{\text{in}} - E_{\text{out}})_{\text{Brine}}}
\]
The lowest exergy destruction occurs in the first stage and then increases gradually in the heat recovery and sharply in the heat rejection stages:
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- Exergy efficiency where there is net gained exergy crossing the system boundary is (Bejan, 1996):

\[ \eta_{II} = \frac{W_{net} + E_{useful}}{E_{In}} \]

- Recovering heat from the stage hot distillate water \( E_{useful} \) will enhance the unit exergy efficiency.
- Recovering heat from hot distillate water up to stage 8 increased exergy efficiency of the unit from 5.82 % to maximum 14.47 %:
Technically extraction of the hot distillate water is possible because most MSF plants have lines which are used to dump the distillate to the brine chamber in case of high distillate Total Dissolved Salts (TDS) during unit start up.
Discussion

- The recovery of the hot distillate water up to stage 8 provides optimal exergy efficiency of this MSF unit. The Factors affecting the optimal hot distillate water extraction stage are plant load, seawater temperature and operational requirements of the end user.

- The parameters of the hot distillate at this stage are suitable to power other thermal processes such as Multi-Effect Desalination (MED) or absorption chillers based on the Lindal chart.
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Analysis:

- **Overall exergy efficiency** of this MSF unit is only 5.82% which offers potential for improvement.

- **Most of the exergy destruction** occurs in the MSF evaporator, specifically in the heat recovery stages (54.54%).

- **Stage exergy efficiency** is the highest at the first stage and declines to the last stage.
Enhancement:

- Recovering waste heat from the hot distillate water could enhance the MSF exergy efficiency from 5.82% to 14.47%.
- The operational parameters up to the optimal stage for hot distillate extraction are suitable for powering other thermal processes such as absorption chiller or MED.
Thank You!

Questions ???