Summary of Issues | Strategies | Benefits & Costs | Key Uncertainties | Additional Resources

KEY POINT: Achieving high recovery (including zero liquid discharge (ZLD)) is typically cost prohibitive for municipal utilities.

SUMMARY OF ISSUES

- ZLD is a processing option and a subcategory of the more general term of high recovery processing. Due to its only recent consideration in municipal desal it is considered a concentrate management option rather than a processing option. ZLD means no water leaves the plant boundary. From its earliest use at power plant sites ZLD processing included the use of evaporation ponds as a final processing step, as well as processing of the brine to produce mixed solids.

- While original ZLD systems included only thermal evaporative equipment for volume reduction, later systems included a membrane volume reducing step prior to the thermal step, and in some cases the system did not include any thermal step. Inclusion of membrane step decreased system capital costs in nearly all cases.

- High recovery systems can be ZLD systems when no liquid crosses the plant boundary. As with ZLD, high recovery systems can be comprised of either membrane or thermal steps or a combination of the two. Final brine can be processed all the way to mixed solids, discharged to evaporation ponds, or deep well injected. The higher salinity brines are typically incompatible with receiving waters - whether surface water, sewer water, or groundwater.

- High recovery and ZLD systems typically have significant capital costs, high energy consumption, and potential high costs related to final brine or salt disposal. The capital and operating costs of high recovery systems utilizing thermal equipment can sometimes exceed the cost of the desalting facility (NRC 2008).

- Due to these high costs, high recovery (including ZLD) concentrate management approaches are typically not considered for municipal drinking water applications (Mickley 2006, NRC 2008). For high recovery applications to become more viable, improvements are needed that reduce both capital and operating costs.

Brine Concentrators (Vapor Compression Evaporator Systems)

- At present, approximately 75 wastewater brine concentrators are in operation in the U.S. and overseas. Of these, approximately a dozen are being used to concentrate reject
streams from industrial RO plants. The operating experiences of these plants have shown that using brine concentrator evaporators on RO concentrate is a viable application and that the systems are highly reliable.

- The cost of brine concentrator evaporators varies widely depending on the chemistry and volume of the feedwater stream to it (i.e., the concentrate). Feedwater chemistry affects the concentration factor, energy usage, evaporator surface area, construction materials, need for chemical additives, and other design and operating parameters.

- Brine concentrator capital cost per volume treated is typically three or more times higher than seawater RO capital cost (Mickley personal com 2010).

- Brine concentrators typically include titanium evaporator tube bundles and stainless steel construction. The number of units necessary at a given plant depends on the volume of concentrate from the initial desalting process.

- Most brine concentrators are powered by electrically driven vapor compressors that constitute a major portion of the operating cost. Electric power consumption can ranges from about 60 to 100 kilowatt (kW)*hr/1,000 gal of feedwater. In the design of the brine concentrator, the cost of the evaporator surface area can be traded off against the vapor compressor energy cost to optimize total system cost. In most cases, the evaporator surface area is selected to produce a power demand of 80 to 90 kW*hr/1,000 gal of feedwater flow.

- Where brine concentrators are installed in conjunction with RO plants, the added labor required to operate the brine concentrator ranges from 2 to 4 hours per 8-hour shift, depending on the overall quality of facility operation and maintenance. Brine concentrators require laboratory support similar to that of RO plants, where it is advantageous to have operators perform basic lab analyses, such as those for TDS and suspended solids. Maintenance, other than normal instrumentation, controls, and equipment requirements, is usually limited to chemical cleaning of the evaporator tubes, normally once or twice a year (Mickley 2006).

**Crystallizers**

- For RO concentrate disposal, crystallizers would normally be operated following a brine concentrator evaporator to reduce brine concentrator brine to a transportable solid. Crystallizers can be used to concentrate RO reject directly, but their capital cost and energy usage is much higher than for a brine concentrator of equivalent capacity. Crystallizer technology is especially applicable in areas where solar evaporation pond construction cost is high, solar evaporation rates are negative, or deep well disposal is costly, geologically not feasible, or not permitted.
Crystallizer costs also vary widely depending on the chemistry of the feedwater - in this case the concentrate stream from the brine concentrator. When operating on brine concentrator blowdown, crystallizers can be exposed to corrosive environments that often require expensive materials.

Crystallizer capital cost per unit volume treated is generally two or more times higher than brine concentrator capital cost (Mickley personal com. 2010)

Power consumption for vapor compression crystallizers ranges from 200 to 250 kW*hr/1,000 gal of feedwater. Crystallizers are generally more cost effective than spray dryers for feedwater streams above 10 gpm.

When crystallizers are operated in conjunction with a brine concentrator or RO plant, 2 to 4 additional labor-hours per 8-hour shift are normally required if the crystallizer is designed properly and the facility is well organized (Mickley 2006).

Spray Dryers

Spray dryers provide an alternative to crystallizers for concentration of wastewater brines to dryness. Spray dryers are usually operated in conjunction with brine concentrator evaporators. If the RO concentrate stream ranges from 1 to 10 gpm, spray dryers can be cost effective when applied directly to the stream, thus eliminating the brine concentrator evaporator.

Spray dryer costs can be significantly affected by the chemistry of the feedwater—in this case, the blowdown from the brine concentrator. This determines the construction materials that will be required.

Energy usage for spray dryers operated with natural gas or oil as heating fuels averages about 0.70 BTU per gpm of feedwater flow. Operating labor requirements for spray dryers are similar to those for crystallizers, adding about 2 to 4 man-hours per 8-hour shift to an RO facility, provided sound design methods and operating philosophy are applied (Mickley 2006).
Membrane Systems

When a second membrane step is used to reduce the volume of concentrate it may be a brackish water RO (or EDR) or seawater RO depending on feedwater salinity. The capital and operating costs of membrane systems are significantly less than those of thermal evaporative systems just discussed.

Table 1. Comparison of traditional disposal methods to advanced ZLD in Phoenix, AZ (millions $) (Mickley 2005)

<table>
<thead>
<tr>
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<th>Traditional disposal</th>
<th>Advanced ZLD options</th>
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<tbody>
<tr>
<td></td>
<td>Pipeline to Sea of Cortez</td>
<td>Evaporation ponds</td>
</tr>
<tr>
<td>Total capital cost</td>
<td>310</td>
<td>410</td>
</tr>
<tr>
<td>Annual operating costs</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Total annualized costs</td>
<td>24</td>
<td>33</td>
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<tr>
<td>Water lost (mgd)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
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Source: Adapted from Xu et. al. 2009, based on Mickley 2005. The costs were estimated based on $0.05/kWh, sludge disposal at $30/ton; annualized cost at 40 years and 7.125% interest.
Development of beneficial salt reuse options and specific salt separation methods are also important to cost reduction of the overall process (Drioli et al. 2004). Some examples of beneficial reuse of the solid product include extraction of gypsum and sodium chloride by means of selective precipitation, although the economic viability of beneficial reuse of desal byproduct salts depends on finding local markets to avoid high transportation costs (Jordahl 2006).

BENEFITS & COSTS

Benefits

Cost aside, there are several advantages to ZLD (Mickley 2006):

- It may avoid a lengthy and tedious permitting process.
- It may gain quick community acceptance.
- It can be located virtually anywhere.
- It represents a positive extreme in recycling, by efficiently using the water source.

Costs

- In general, thermal evaporation-based processes are characterized with high capital costs and high energy requirements. These costs can sometimes exceed the cost of the desalting facility.
- Once most or all of the liquid is removed from the wastes, landfilling costs can be significant.
- The high costs and high-energy requirements, are a large deterrent to application of this process, particularly for large municipal applications.

KEY UNCERTAINTIES

For ZLD applications to become more viable, improvements are needed that reduce capital costs and/or energy usage.
ADDITIONAL RESOURCES


