Energy use in water purification as criterion for selecting drinking water treatment technologies

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Abstract

Quality of produced water is usually the criterion for selecting between different desalination technologies for turning seawater into drinking water. However, contemporary trend in drinking water treatment sees a convergence between different technologies for the same water quality. Hence, how do different desalination technologies differentiate amongst each other? Awareness of climate change impact as well as price of produced water, energy use per unit of treated water is an oft-used criterion for assessing the effectiveness and efficiency of different desalination technologies. Specifically, comparing multi-effect flash evaporation and reverse osmosis, the latter enjoys a significant energy use advantage given the lack of the need for converting water into the vapor phase as in multi-effect flash evaporation. Thus, energy used in producing drinking water is significantly higher in multi-effect flash evaporation compared to the high pressure process of reverse osmosis. From the operation perspective, reverse osmosis also benefits from its ability to scale linearly in increasing water production capacity through addition of extra membrane modules, which is not the case for multi-effect flash evaporation where a new distillation column is required for significant increase in production capacity. Collectively, with the same quality of water produced by different desalination technologies, comparison between different technologies increasingly relies on the energy use per unit of produced water. Using this criterion, reverse osmosis membrane desalination has a significant advantage relative to multi-effect flash evaporation in energy cost, which translates to a lower price of produced water.

Keywords: reverse osmosis, desalination, multi-effect flash evaporation, energy cost, water quality, latent heat of vaporisation, membrane modules, scale-up, production capacity, pressure requirement

Subject areas: aquatic and marine chemistry, ecohydrology, ecosystem science, environmental impacts, food, water and energy nexus,

Water scarcity is a looming threat for many cities around the world due to the effect of climate change in altering rainfall patterns. Specifically, the situation may be even worse for many coastal cities lacking freshwater drinking resources; thus, making previously untenable options such as seawater desalination a policy option for alleviating anticipated shortages in drinking water supply in view of population expansion. However, given the highly energy intensive nature of seawater desalination, how should cities around the world choose between competing technologies. With the need to reduce carbon emissions in view of climate change mitigation goals such as those stated in the Paris Agreement, and given the close links between energy expenditure

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and price of water, energy utilized for producing each litre of drinking water becomes a relevant criterion for assessing the relative merits of competing technologies for purifying water from seawater.

One option for desalinating seawater is multi-effect flash evaporation that utilizes repeated boiling of water at different sections of the distillation column for producing clean drinking water. Known to be energy intensive, the technique is a mature technology that does not scale linearly with production capacity. Specifically, multi-effect flash evaporation plants are built for specified production capacity. Attempts at increasing the water production capacity would require building an additional distillation column. Hence, multi-effect flash evaporation faces challenges with limited capacity for future expansion, as well as a high energy cost due to the large latent heat of vaporisation of water in turning liquid water to steam during desalination. Although the produced water is pure, the high energy cost of multi-effect flash evaporation meant that the technique is only suitable for cities with cheap sources of fossil fuel or solar energy.

On the other hand, a relatively new desalination technique relies on reverse osmosis membranes for purifying seawater into drinking water. Specifically, utilizing non-porous membrane which are hydrophilic, water molecules could "dissolve" into the membrane and migrate to the other side of the membrane where clean drinking water is produced. Lack of pores in the membrane meant that ions and other contaminants are rejected in the feed water; thus, making the produced water potable for drinking with very low concentration of ions and other contaminants.

While the process requires the use of pressure on the feed water side to force water through the non-porous membrane, the energy used in transferring water across the membrane is relatively low compared to multi-effect flash evaporation since there is no change of phase for water. Thus, energy use for reverse osmosis membrane desalination is likely to be lower than that for multi-effect flash evaporation for each litre of water produced. Additionally, the reverse osmosis process scale linearly in production capacity as additional membrane modules could be easily added for increasing water production capacity. Thus, scale-up of membrane-based desalination process is much easier compared to multi-effect flash evaporation.

One point of contention for using reverse osmosis membrane desalination process is the high energy cost of the high pressure applied for producing pure water. To this end, operating the reverse osmosis process at a lower pressure would potentially yield cost savings in energy expenditure as well as reducing damage to membrane. Specifically, given that energy usage scale nonlinearly with applied pressure, attempts to increase water production capacity and rate through increase in applied pressure would not be preferable compared to achieving the same production capacity through reducing the applied pressure but with more membrane modules. In this way, the

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same water production capacity could be achieved with a larger total membrane surface area using a lower applied pressure.

Hence, while competing water treatment technologies often come with specific advantages and disadvantages, using the criterion of energy utilized for producing per unit of water would provide a platform for evaluating each technology based on their energy use performance. Specifically, given that multi-effect flash evaporation suffers from the high latent heat of vaporisation of water, it is less competitive compared to reverse osmosis membrane desalination technologies, which are less energy intensive. Thus, the highly scalable membrane based desalination technology is preferable over the more mature multi-effect flash evaporation process in energy cost per unit of water produced. More importantly, process improvements such as reducing the applied pressure would help reduce membrane damage and downtime, while reducing energy wasted given the nonlinear increase in energy expenditure with applied pressure.

Conflicts of interest

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