High-Recovery Desalination and Water Treatment

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Abstract:

Is "Desalination" the Hoover Dam of the next 100 years? There are many water supply challenges facing government, municipal, commercial and industrial industries throughout the United States and around the world. As conventional water supplies are being depleted and alternative water supplies are being developed, we must ensure that the processes we use to treat the waters creating a water supply that lasts well into the future without a legacy of environmental challenges...

Alternative water supplies being considered include low quality surface water, irrigation runoff, brackish groundwater, municipal and industrial wastewater, and seawater. These water sources can be low quality and substantially more expensive to treat than conventional water sources. However, as conventional sources are depleted, and as demand for water continues to increase, the quality of these waters can be improved through treatment processes; and when the cost of treating the alternative source drops below that of the currently available source, opportunity is created.

The production of high-quality water often requires implementation of desalination technologies, which utilize energy in the form of pressure, heat, or electricity to remove salt from water. The main challenges with desalination technologies include high energy consumption and production of a high salinity waste stream. Solutions to economic and environmental challenges may be found in new technologies and combinations of new technologies with conventional ones.

Thermal processes (i.e., distillation processes) have been used for desalination since the 1960s and are still prevalent in areas that have cheap energy sources or available waste heat. Although there have been advancements in thermal technologies, including multistage distillation and multistage flash distillation, thermal process are still more expensive than reverse osmosis (RO) membrane technology. RO desalination technology, which was incubated at universities that were support by funding from the U.S. Government, became mainstream technology used in many industries requiring high quality and low salinity water. The first commercial RO desalination project in 1971 was to produce less than a few thousand gallons per day for Texas Instruments. Today, projects requiring well over 100 million gallons per day (MGD) (378.5 megaliters per day (MLD) are being implemented and others over 1 billion gallons per day (3.785 billion liters per day) are being considered.

There have been many advancements in the field of desalination since its inception. These include improvements in fundamental materials, manufacturing techniques, packaging techniques and mechanical energy recovery techniques. In most cases, the objective has been to improve operational aspects of the desalination technology to achieve maximum water recoveries at the lowest energies possible, while minimizing high salinity waste flows. Improvements in the technology have also resulted in reduced temperatures, operating pressures and electrical parameters to near theoretical levels for applications in many different water supplies. Other advancements include treatment chemicals that allow for additional water recovery by extending the saturation limits of salts in solution.

Ideally, the salt and dissolved constituents remaining after the water is separated from the source water, are highly concentrated or in solid form. Achieving high water recovery minimizes the high salinity waste stream that must be discharged. With an increasingly stringent regulatory environment, many areas of the US will not even allow discharge of these streams to wastewater treatment facilities.

The technologies being developed to take advantage of the opportunity costs that are available with the increasing cost of water associated with limited supplies vary in their approach to minimize or eliminate brine streams while minimizing energy requirements. They include controlled-scaling RO, closed-circuit desalination, forward osmosis, electrodialysis metathesis, membrane distillation, capacitive deionization, and brine-bulb technologies. Some of these technologies result from more incremental improvements to existing technologies while others represent entirely new concepts.

This paper will discuss these technologies and technology applications. It will define the opportunities and opportunity costs to show the major drivers in the market that are attracting investors and inventors alike into the field of salt separation technologies.

Hoover Dam: a water supply solution example for the Next Generation:

In the 1920s and 1930s when the United States was going through "The Great Depression", the U.S. government saw the opportunity to get the economy moving again by building the Hoover Dam and other major infrastructure projects along the Colorado River. At the time, the U.S. government could foresee the need for more water supply in the major urban and agricultural areas developing from Colorado through California. Taming the Colorado River would provide ample supply of water into the foreseeable future. The foreseeable future at that time was hard to define and the implications of the project hard to predict. Yet the Hoover Dam was built and provided a water supply solution that allowed the region to grow exponentially and provided significant contribution to the economy and security of the region as a whole.

The Hoover Dam project at its core is a regional water supply solution that provides a stable and sustainable source of fresh water within and beyond the contributing watershed. Although it has brought challenges of cross-state and cross-border supply issues, the Hoover Dam and other dams on the Colorado River are great examples of managed water supply solutions. The project also provides a managed water quality that assures a lower total dissolved solids (TDS) water to the region, which provides an overall water quality benefit to the region in comparison to other brackish sources that are being used throughout the lower Colorado River states. Although the system of dams has been criticized for its environmental impact on the Colorado River, the power supplied, water storage provided and social/recreational and economic benefit have been significant. However, in recent years, the storage and drought mitigation capacity is being tested as demand for water is continuing to increase and water availability from the drought-stricken region proves that there is not as much water available as was originally predicted.

The challenges we are facing today require future leaders, planners and researchers to look to the next 100 years and assess opportunities and risks of water supply solutions. Desalination technologies, when looked at in this context, are potentially the Hoover Dam of this generation and future generations. These technologies provide access to the next available water supplies including brackish groundwater, wastewater and seawater. These are water sources not typically considered for supply because cheaper and more abundant sources were available. Desalination technologies allow for immediate access to sources of water in aquifers and the ocean and wastewater which are all drought-proof sources. Water supply solutions of this generation must have the ability to defend against drought and unpredictable weather. One of the most important considerations when looking at long term water supply solutions that use lower quality water sources is the solution must be able to remove constituents and contaminants to levels that make the water quality commensurate with the proposed uses. One key aspect of desalination technology is that it provides the ability to target the desired water quality.

Desalination technology, not unlike the Hoover Dam, has challenges that affect the environment including higher energy consumption which translates into greenhouse gas emissions. Secondly, the technology creates a residual brine or concentrate waste stream that can have an impact on the environment if not managed properly.

A Brief History of Desalination

Distant history back to the 1960s is where the desalination technology of today was conceived. During that time Lyndon Johnson supported Israel in development of desalination through the Office of Saline Water. The Israeli's, at that time, invested effort in technology using freezing in a vacuum. The technology was not commercialized and did not receive any widespread acceptance. However, from the research and development efforts, there were two technologies developed including Multistage Flash Distillation (MSF) and Multieffect Distillation (MED) technology. These technologies are still in use in desalination projects around the world.

During the same period that Israel was developing desalination technology, the U.S. Government was supporting the development of reverse osmosis(RO). At the time, Dr. Sidney Loeb at UCLA had developed a semipermeable cellulose acetate RO membrane that was capable of removing salt from water. The challenge that Dr. Loeb faced was commercializing the technology. The U.S. Government saw immediate opportunity for the technology and hired General Atomic to develop a commercial product using RO membranes. In 1966, ROGA, a division of General Atomic hired Richard G. Sudak to manage and develop the technology for commercial applications. ROGA developed the first commercial applications and sold the first RO system to Texas Instruments in 1971. Since that time, both thermal and RO desalination technologies have seen wide spread application and improvements that allow them to be utilized through today and into the future.

Desalination Technologies Today

Since that time, desalination technology has been utilized in many fields to obtain specific water quality. For example, in the oil refining industry, membranes are used to generate 2000 pound boiler feed water which requires very low hardness and silica. In the field of microchip manufacturing, RO membranes are used to generate 18 megohm water for specialized washing. In the municipal water field, membranes are used for treating wastewater to meet drinking water standards for applications in indirect and soon to be direct potable water supply.

Advancements in the technologies include optimization and improvements in fundamental materials, manufacturing techniques, packaging and mechanical energy recovery. Improvements in the technology have reduced the temperatures, operating pressures and electrical energy requirements to near theoretical levels for applications in many different water supplies. Other progress includes maximizing water recovery by adding antiscalant chemicals to allow additional water recovery by extending the saturation limits of salts in the concentrate waste stream.

The most significant advancement in the RO technology has been improvements in the membrane material. The industry moved away from cellulose acetate membranes in the early 1990s to a polyamide composite membrane. The polyamide membrane reduced energy requirements from 300-400 psi for brackish water applications to near theoretical osmotic pressures between 100-200 psi. The main disadvantage of the latest membrane material is that it is not oxidant tolerant and therefore they are more susceptible to fouling during operation.

RO Membrane manufacturing changed to automated processes starting in early 2000. Prior to that, membranes were manufactured by hand gluing and rolling of the membranes. The disadvantage of hand rolling was the challenges of quality control and a loss in membrane area. By moving to automated rolling and manufacturing, the membrane area increased by over 10 percent in a module. In addition, the automated rolling also allowed for packaging changes from 8 inch diameter membrane elements to 16 inch and 18 inch diameter membrane elements.

The major advancements for the MSF and MED technologies have been in materials improvements to address corrosion and heat transfer. A wide range of materials are available that can resist corrosion and are more economical. In addition, since the technologies work with vacuum they have addressed challenges with operation with the aid of better sealing technology. The improvements have reduced the energy consumption of the technology.

Energy recovery devices and approaches to energy optimization in desalination have provided significant opportunity. In recent years, there have been more energy recovery devices introduced into the market including high efficiency pressure exchange devices that use ceramic materials that are corrosion resistant. The energy consumption for seawater desalination utilizing RO with energy recovery has reduced from 11 to 14 kW-hr per 1000 gallons(kgal) to 8-11 kW-hr/kgal. In the MSF and MED technology, the energy consumption associated with process improvements and materials has reduced from 15 kW-hr/kgal to 13 kW-hr/kgal.

The Desalination Frontier: Zero Liquid Discharge

The objective of desalination technology is to maximize water recovery while minimizing the high salinity waste stream at the lowest possible energy. There are many challenges in trying to achieve this objective including:

Challenge 1: the amount of salt and the type of salt in the water is directly proportional to how much water can be recovered. As a salt solution is concentrated by removal of water, the solution will approach saturation where liquid salt will start to crystalize and become a solid. The crystal formation can form a scale on the equipment and can ultimately damage the RO membranes or the equipment. The difficulty in predicting when crystal formation and scaling will occur is compounded when there are significant numbers of different types of salts in solution and each one has a different saturation level. Controlling the scaling and precipitation becomes a major treatment challenge where hours are spent analyzing the water quality and understanding the treatment technology and if and where scaling could occur.

Challenge 2: the higher the salinity, the more energy that is required to remove the salt from solution. For seawater at around 35,000 mg/L of salinity in the water, the theoretical pressure required to overcome the osmotic pressure and reverse the flow of water through the membrane from the higher saline side to the clean or fresh water side of the membrane is approximately 700 psi. For sewage in a normal wastewater plant, the pressure required to overcome osmotic pressure is approximately 20-30 psi.

Challenge 3: the high salinity waste flow remaining must be handled as part of the overall treatment process. Treating the residual flow with high levels of salt is a challenge as there are not many practical places to discharge the waste stream. Historically, the most likely discharge locations have been back to the ocean for seawater desalination plants on the coast, into streams and lakes where there are higher volumes of fresh water to dilute the flow in inland areas, into sewers for eventual treatment in sewage treatment plants, and in some locations like Florida there is the possibility of injecting the waste flow back into the ground through injection wells. In the right environments such as the arid regions of the country, there are opportunities for evaporation and enhanced evaporation. Unfortunately with most of the options, the remaining water in the high salinity waste stream is not available as a potential water source.

Unfortunately, limited locations and the physical inability to discharge flows has made desalination a challenge. However, with the ever increasing cost of water where supplies are limited, there are opportunities. For example, current and projected cost of importing and treating surface water in San Diego, California are projected to be $1,926 per acre foot($6.13/kgal) by 2021. The cost of desalinating seawater is currently between $1500 and $3000 per acre foot($4.60 and $9.20/kgal) depending on location and project specific considerations along the California Coast. The cost of seawater is increasing as well due to environmental, permitting and other concerns. However, treating sewage to drinking water is much lower at less than $1,000 per acre foot ($3.06/kgal) and treating groundwater in the Riverside area is around $625 per acre foot ($1.90/kgal). Because the cost of water is rising so rapidly, there is opportunity for desalination technology development to allow for production of water at a lower cost than the projected cost of importing or treating seawater in areas such as southern California. In the desalination industry, there are companies like GE and venture capitalists that are exploring the market and investing to capitalize on the opportunity.

Investment in the research of new and improved technologies for recovering water from impaired and impacted water sources has lead to many different approaches to treating the water. Some technologies that are showing promise and are gaining experience are discussed herein:

Controlled Scaling RO(CSRO) is a technology that allows a third or fourth stage of RO to treat the concentrate from a primary RO system. This technology operates the final stage of the RO system beyond the theoretical saturation and allows for scaling to start but ultimately uses cleaning chemicals to remove scale from the membranes to restore performance. The system is operated beyond saturation for some constituents such as calcium carbonate, calcium sulfate and silica and potentially others. The CSRO is operated in a forward and reversing operation to control scaling and membrane life. The system is cleaned on a frequent basis with various cleaners, acids and bases to keep the membranes operating. This type of system is used at Water Replenishment District of Southern California.

Desalitech[tm] – This technology uses Closed Circuit Desalination or batch desalination which is a concept whereby the high salinity waste stream is recirculated through the RO unit, allowing for recoveries on a batch basis as high as 97%. This technology uses conventional RO equipment operated in a different configuration. At the end of a batch the high salinity waste stream discharged and fresh water is filled into the feed tank and recirculated again. The system operates on low TDS water conditions that are typical for inland desalination and wastewater desalination projects. The technology has some limitations in comparison to straight RO such as varying water quality from the beginning of each batch to the end of each batch.

Forward Osmosis – This technology uses a high salinity stream as a draw solution to pull water from a lower salinity feed water. The feed water can be from a number of sources such as wastewater effluent, high salinity waste streams from desalination systems, brackish well water or other high salinity sources as long as the salinity of the feed is much lower than the draw solution. The difference in salinity between the feed and draw solution provides the energy to move the water across the membrane. The draw solution in some cases is a special solution that can be separated from the water. Alternatively, this technology could be used in seawater application that would use ocean water to draw fresh water from a brackish water source and diluting the seawater to reduce salinity. This allows for a reduction in feed pressure and energy required to desalinate the ocean water. This approach could ultimately provide a viable way to treat seawater using wastewater as a source of pure water that improves the economics and provides environmental benefit.

Brine Bulb Technology – This technology uses AC current across a brine stream to generate heat for evaporation under a vacuum condition. This technology combines various technologies to improve efficiency of the water recovery in a batch process. The technology has shown that it combines electrocoagulation and vapor removal as the main drivers that separate the salt from solution. The benefit of the system is that it allows for further recovery of the water.

Altela Rain SM – Dewvaporation was developed at Arizona State University and is a specific process of humidification-dehumidification desalination, which uses air as a carrier-gas to evaporate water from saline feeds and form pure condensate at constant atmospheric pressure. The heat needed for evaporation is supplied by the heat released by dew condensation on opposite sides of a heat transfer wall. Since external heat is needed to establish a temperature difference across the wall, and since the temperature of the external heat is versatile, the external heat source can be from waste heat, such as solar collectors or fuel combustion. The unit is constructed out of thin water wettable plastics and is operated at atmospheric pressure. The technology is currently sold in the oil field but could have applications in concentrate treatment.

There are other desalination technologies on the cutting edge including capacitive deionization, and membrane distillation. Other companies such as GE are investing in their Aquasel desalination technology, high efficiency RO(HERO), and electrodialysis metathesis. These technologies are all promising and are being tested and applied in various applications.

Solutions for Future Generations:

The Hoover Dam solved many water supply issues for future generations. At the time it provided a water source and energy supply source with immense size and volume that allowed for unfettered growth in the western United States. At the time it provided a huge economic boost to the economy with all of the jobs it provided. It continues to provide an economic boost with the jobs, tourism, energy and water storage. The dam and reservoir it created in Lake Mead are providing a water quality balance to the region. There are tributaries that provide salt into the Colorado River. The stored water allows for a dampening of the salinity impact on the lower Colorado users. At the time the dam and lake were created, they provided a drought proof water supply. Today the limits of the water supply have been reached and the Lake is being impacted by climate change and extended drought conditions in the region.

In today's ever changing water landscape, leaders in the water industry need to consider the next generations and what solutions today will solve water supply and water quality challenges long into the future. Desalination coupled with high recovery technologies are the tools that will be used to solve these challenges. These tools provide access to the next available water supplies and to water supplies once considered impossible to utilize. They provide a water quality solution to ensure safe and reliable water supplies. They also provide access to drought proof water supplies such as wastewater effluent and irrigation drainage flows and secures the region against the effects of climate change and extended drought. The technology provides economic and social benefits for communities as it requires educated, trained and skilled labor. Lastly, the technology can provide a stable solution within the cost boundaries of the ever increasing cost of local supplies.

Desalination technologies, not unlike the Hoover Dam, are capable of solving water supply challenges. High recovery applications are now being investigated heavily and will likely provide a path toward successful implementation of large scale desalination in arid and inland regions with limited ability to discharge the concentrate streams. This is an exciting time in the industry to look forward and at the same time consider the past risks and rewards of visionary thinking.