ADVANCES IN DESALINATION AND WATER TREATMENT

Abstract

Over the past few decades, several kinds of seawater desalination techniques have been invented to boost the availability of water in arid regions of the nation. Many nations cannot afford this method as a clean water source due to the limitations of high desalination costs. But the steadily rising use of saltwater desalination has shown that it is a practical water resource independent of changes in precipitation. Desalination is a process that uses a variety of separation techniques and some kind of energy. Among the most important and widely used processes, RO (Reverse osmosis) and MSF (Multi-stage flash) distillation are both economically viable. Because they are the most efficient ways to extract significant quantities of fresh water for commercial use from seawater, the MSF and RO desalination processes are given a lot of attention in this chapter.

Keywords: Saltwater, Advance water treatment, Reverse osmosis, Solar powered desalination system.

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I. INTRODUCTION

Natural freshwater resources are in inadequate supply in many nations throughout the world. Future population growth, higher living standards, more industrial and agricultural activity, along with increased living standards, will all result in a greater need for fresh water. Freshwater supplies from rivers and the ground are currently scarce and are being rapidly and alarmingly reduced in many regions. The world's largest water reserve is found in the oceans. 97% of the water on earth is in ocean and the remaining 2% is appeared in the form of ice in polar ice caps and glaciers, whereas only around 0.5% water supply is available as fresh water (Parfit and Graves, 1993). The earth's surface is covered in enormous fresh water reserves, but a large portion of these is too underground to be commercially accessible.

In addition, seawater is unsafe for use in agriculture, industry, and human consumption. Desalination has become a key supplier of fresh water by eliminating salt from the nearly infinite supply of sea water. Several nations today get all of their fresh water demands met by desalination technologies. Especially in the Middle East, where it is employed in Saudi Arabia, Kuwait and the United Arab Emirates, desalination is a vital and reliable source of fresh water (Alawadhi, 2002). Desalination's acceptance in the Middle East is also probably going to increase. It is estimated that desalination provides fresh water to about 75 million people worldwide. According to the IDA Desalting Inventory 2004 Report (Inventory, 2004), by the end of 2002, there were 17,348 brackish and seawater desalination units installed and under contract globally, spread among 10,350 desalination services, with a total capability of 37.75 million m3/day of clean water. The top five desalination-capable nations in the world are Saudi Arabia (17.4%), the United States (16.2%), the United Arab Emirates (14.7%), Spain (6.4%), and Kuwait (5.8%) (Inventory, 2004). Desalination plant capacity is currently 40 million m3/day, with a 12% annual growth rate over the last five years (Intelligence, 2006).

II. TECHNICAL DEVELOPMENT IN DESALINATION

1. **Multi-stage flash (MSF) distillation:** The MSF plant design has been improved throughout the last three decades. The important areas of success for optimization include equipment design and configuration, thermodynamic design, material selection, structural factors, and production and distribution methods (Morris, 1993). The data below shows how the desalination process has evolved over the last three decades.

   Around 1960, the larger-scale desalination process first began to take shape. The MSF idea, combined with parallel technological advancement, came at a time when requirements for water in dry areas like the Middle East was rising. Desalination plants now have a larger market because of this. Although research in the lab and on prototypes was done to test proposed designs, marketplace demand was so great that plants with a capacity of up to 4500 m^3/day had been constructed. But these plants mostly performed as intended.

   In the early 1960s, equilibration as a concept was not thoroughly understood. This manifested as a widening difference in the vapor pressure of the related brine at low temperatures. In prototype tests, this behaviour wasn't seen to the same extent. The scale of the unit that the technology has attained at the Shuweiat project in the United Arab Emirates is 75,850 m^3/day (Sommariva and Venkatesh, 2002). Comparing a large-scale unit to a small-scale unit, the former offers significant economies of scale that lower expenses.

According to one study, a unit size can be increased to something like 136,260 m^3/day (Hanbury, 1993). By avoiding boiling, the multi-stage flash concept lessened an impact of scalability on heat transmission surfaces, but some scale formation still happened. According to Morris (1993) and El-Saie (1993), chemical additives have been devised to manage & alter the scale that had evolved. It prevented long-term efficient operation and remained a barrier to heat transfer. Scale removal by acid treatment was expensive and expensively risky for corrosion. Long-term operation was only made possible by the addition of online ball cleaning in MSF systems. Later thermal additives associated with ball cleaning systems allowed operation at temperatures as high as 115 degrees Celsius, effectively eliminating the necessity for acid as an additive (Morris, 1993). Carbon steel (CS) was largely recommended for the outer and internals shell in MSF plants built prior to 1980. The thickness of the carbon steel alloy used in the building of the evaporator had to be raised to account for corrosion because the CS metal destroys in the presence of saltwater. The weight and size of the units increased as a result.

After 1980, improved materials including duplex stainless steel and stainless steel (SS) were used to build new plants. The MSF facilities' operational experience helped to improve understanding of the numerous corrosion issues that can arise during the evaporation process. The use of SS resulted in thinner metal being utilized in the evaporator's various parts, which in turn led to a decrease in mass and overall size of the unit (Sommariva and Venkatesh, 2002). The use of titanium tubes in the ejection condensation chamber increased the heat and mass transfer ability of the ejector system (Sommariva and Venkatesh, 2002), which successfully regulated the flow of harmful gases inside the evaporation chamber (Khawaji and Wie, 2001). Carbon steel, stainless steel, copper-nickel alloys, aluminum alloys, titanium, and FRP are all appropriate materials for MSF plants, depending on their application (Hodgkiess, 1993; Khawaji *et al*., 2008; Muddassir, 1996; Ghalaini, 2002).

2. **Multiple-effect distillation:** A key large-scale thermal process that has the potential to significantly lower water costs is multi-effect distillation. In comparison to the normal 4 kW h/m^3 power consumption of multi-stage flash, the particular power consumption for multi-effect distillation is less than 1.8 kW h/m^3. Compared to multi-stage flash, which essentially caps the gained output ratio (GOR) at 10, multi-effect distillation has the capacity to produce a significantly better gained output ratio GOR of over 15 kg in output / kg of steam. Low temperature MED units are getting bigger. In Sharjah, United Arab Emirates, two setups with a 22,700 m^3/day capacity were being built. By reducing scaling and corrosion rates to manageable levels, the low temperature multi-effect distillation units with top brine temperature (TBT) up to 70 ^oC have solved the primary issues with conventional high temperature distillation facilities. The plan used several innovative ideas to significantly reduce the plant's capital cost.

3. **Reverse osmosis:** The RO process has undergone significant advancements over the past two decades, which are shown in the sharp decline in capital and operating expenses. The majority of the advancements have been made by upgrading the membranes themselves.

   In the 1970s, RO started to challenge MSF. Early research focused on creating a functional membrane, primarily for brackish water followed by saltwater. Companies that specialize in manufacturing membranes took on the development effort. The size of the RO plant has gradually increased to 9084 - 13,626 m^3/day (Al-Mudaiheem, 2002), but it is still considerably below the 56,775 - 68,130 m^3/day and 75,700 m^3/day MSF unit sizes reported by Borsani and Ghiazza in 2002. The largest seawater RO plant in the world has 32 10,192 m^3/day and a design capacity of 326,144 m^3/day. Around two thirds of the world's desalination water is produced in the Middle Eastern countries, where the current RO plant recovery rate is around 35%. According to recent reports (Kurihara et al., 2001), the Pacific Ocean water has a substantially greater recovery rate i.e., 60%. Without energy recovery, the RO plant uses about 6 to 8 kW/m^3 of energy. According to Moch and Moch (2002), setting up an energy recovery system significantly lowers energy consumption to 4-5 kW h/m^3. According to Rovel (2002), the unit usage of electricity can be as low as 2 kW h/m^3. The remarkable accomplishment is made possible by an energy recovery device's ingenuity. The pretreatment region presents the biggest challenge for RO plants in the Middle East and abroad (Rovel, 2002; Khedr, 2000; Hamida, 1996). The traditional filtration techniques are insufficient. Numerous plants have experienced issues as a result of the turbidity, increased biological activity and periodical organic blooms. The membrane must be chemically cleaned frequently to prevent biofouling, which results in productivity loss. With good results, the recently invented nanofiltration (NF) membrane pretreatment was successfully implemented in a pilot plant and then in an operational plant (Hamed *et al*., 2005; Hassan *et al*., 1998; Hassan *et al*., 1999). By eliminating turbidity and germs, the procedure avoided membrane fouling, and the operational plant saw a 40% boost in output (Hassan et al., 2002). One option to reduce the cost of producing water is to use a combination of methods that combines multiple desalination processes (Al-Sofi *et al*., 1992; Al-Mutaz *et al*., 1989; Awerbuch *et al*., 1989).

4. **Other processes:** Higher temperature MED desalination provides a greater efficiency ratio, whereas lower-temperature MED plant operation requires greater energy expenses. The operation at a higher temperature can result in scale formation. Operating a lower temperature MED with a vapor compressor could be one answer to this issue, which would lower the cost of producing water. At lower temperatures, this kind of hybrid plant can greatly improve the performance ratio. On the basis of this theory, small plants have been constructed and unit sizes have grown. A mechanical VCD plant's compressor, which has movable components and a size restriction, is one of its drawbacks. Steam jet ejectors, also known as thermo-compressors, can be used in place of a mechanical compressor because the pressure rises at lower temperatures are comparatively low.

   As a result, the number of impacts and capacity of VCD units will increase. Due to extensive research and development (R&D) work (Hanafi, 1991;

Hamed *et al*., 1993; El-Nashar, 1993) and the widespread interest in solar energy usage, there has been advancement in the field of solar evaporation over the last thirty years. These interests are currently increased by concern for ecological sustainability. Even with rising fuel cost and stricter pollution standards, the present competitiveness in the power sector is relatively slight. This is owing to the high cost of installation of a solar-powered desalination system, despite the fact that the energy for evaporation is free. However, it is anticipated that cost effectiveness will increase as R&D efforts to improve technology.

III. RESEARCH AND DEVELOPMENT IN DESALINATION OF SEAWATER

1. **Thermal desalination:** These require an enormous amount of energy. Some of the subjects to take into account are listed below:

   - Creation of substitute energy sources.
   - Scaling and fouling mitigation and control.
   - Alternative building materials.
   - Process design simplification.
   - Modifications to component design.
   - Control mechanisms to reduce wasteful utilization of products.

2. **Membrane desalination:** Processes for membrane desalination have significantly improved recently, and they are now cost-competitive at some locations. Some of the subjects to take into account for process improvement include the following:

   - Modern membranes.
   - Design of a membrane module and process.
   - The recovery of energy in reverse osmosis processes.
   - Primary treatment procedures and fouling control.
   - The foundations of scaling and fouling.
   - Design of process and supporting equipment.

3. **Alternative desalination technologies:** The following are some examples of areas where research and development is being considered:

   - Fresh desalination ideas and feasibility research.
   - The use of unconventional energy sources in desalination operations.
   - Fresh ideas for the design of procedures used in reported non-traditional desalination methods.
   - Creation of fresh design ideas for technology used in processes.
   - Systems for measurement and control.
   - Scale control, cleaning, and monitoring systems.

4. **Energy integration:** All desalination techniques use considerably more energy than is necessary, even at the thermodynamic minimum. The main source of expense for running a desalination plant is energy. The desalination and solar power must be economically and effectively linked, which involves the development of innovative technology.

5. **Environmental aspects:** The entire desalination procedure needs to be green. Some of the crucial study topics include the following categories:

- Enhancements to effluent disposal and/or effluent reduction techniques used in desalination.
- Analysis of the effluents from desalination plants.
- Techniques for evaluating the effects of desalination plant effluents on the environment.
- Environmental impact assessment procedures for desalination plant effluents.

All methods of desalination, whether in operation or being developed, must be taken into account when determining their environmental effects.

IV. FUTURE PROSPECTS

The cost of producing water has significantly decreased as a result of the substantial advancements that have occurred in seawater desalination techniques over the past 20 years. This has increased the industry's acceptance and growth globally, especially in dry areas of the globe. However, many nations cannot to spend on this kind of technology as a supply of fresh water because desalination costs are still very high. Therefore, it is essential to prioritize and reenergize R&D in technological advancements that will eventually result in a marked decrease in the cost of producing desalinated water. The ultimate goal of seawater desalination is to offer conveniently accessible, affordable fresh water. Continued research and development efforts are anticipated to be performed in a number of areas linked to saltwater desalination procedures, including the ones listed below (Al-Azzaz et al., 2002):

- Efficient systems for producing both power and desalinated water.
- Use of nuclear and solar energy.
- Techniques for thermal distillation at higher temperatures.
- Electricity, steam, and water are combined, improved, and hybridized.
- Proper material selection for building and the creation of less expensive materials.
- RO membrane development and improvement.
- Scale and rust prevention and management.
- Growth of large-scale seawater desalination facilities.
- Desalination control and intelligent systems.
- Seawater hardness separation is improved by magnetism.

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