Trends in Desalination Technology

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1.0 Introduction

The modern era in desalination technology may be considered to have developed over the past 50 years. Prior to the mid fifties desalination was only undertaken commercially on a relatively small scale and it was entirely distillation based. The technology had developed largely from marine evaporators producing boiler feedwater on steam ships. The simple multiple effect, submerged tube technology employed reached its zenith in the mid fifties with the installation of 1 Migd (million imperial gallons per day) plants consisting of many interconnected vessels and relatively high capital costs.

Two events around this time changed the course of desalination development: firstly the introduction of the multistage flash distillation process (MSF) which significantly reduced the capital costs of large plants, and, secondly, the advent of government backed R & D programmes in desalination technology (particularly the OSW programme in the US) that led to the development of reverse osmosis as a commercially viable desalination process.

As far as seawater desalination is concerned, the subsequent fifty years has seen a refinement of the MSF distillation technology in terms of materials, unit sizes and scale prevention techniques. It has also seen the development reverse osmosis membranes capable of desalinating seawater in a single pass, considerable improvements in membrane durabilities and stabilities, very significant reductions in sea water reverse osmosis (SWRO) energy requirements, and a steady improvement in fouling prevention techniques.

Development in brackish water desalination over this period has seen the elimination of distillation technology, the continued use of electrodialysis for some dilute water applications, but reverse osmosis has emerged as the dominant process in this sector - again RO membrane development, reductions in energy consumptions and improved pretreatments playing key roles.

2.0 Seawater Desalination.

2.1 Multistage Flash Distillation.

Early MSF distillers tended to be built in unit sizes of 1.0 Migd or less, had painted mild steel shells, were of the long-tube or the cross-tube configuration, were either acid dosed or had to operate at low top brine temperatures (< 90°C) with polyphosphate antiscalants. Over the past fifty years following trends can be discerned in MSF technology:-

a. The MSF unit sizes employed have steadily increased by an order of magnitude from 1.0 Migd to 10 to 13 Migd. This has both introduced economies of scale and has improved the efficiencies of the process.

b. The cross-tube design has become dominant.

c. There has been a trend towards using high grade materials of construction which has led to a significant reduction in corrosion problems, to reductions in the optimum number of stages to be used, and, probably of most significance, has greatly increased the potential life-span of the distillers.

d. The development of high temperature scale prevention additives together with the use of sponge-ball on line cleaning systems has greatly improved the reliability of the distiller performances and the load factors achievable.

e. The major remaining problem with MSF technology is that of vapour-side corrosion of the condenser tubes leading to tube failures in older plants (after 15 to 20 years service).

In summary, MSF distillation has become a mature technology giving reliable operation for seawater desalination and expected plant lifetimes of more than 30 years. To be economic it has to be operated on a large scale using the waste heat from power generation stations. For this reason MSF plants are usually planned and installed as an integral part of a power generation station.

It has two major advantages versus seawater reverse osmosis (SWRO):-

a. In common with all distillation processes it produces a high purity product (typically < 30 ppm TDS).

b. It is capable of desalinating warm high concentration seawaters effectively and reliably (e.g. Arabian Gulf waters)

In situations where energy is expensive and/or where new power generation capacity is not necessary or affordable (i.e. for stand alone desalination), MSF is not usually the optimum technology. Here either SWRO, or thermocompression multiple effect distillation (particularly for high salinity seawaters), is more likely to be the optimum technology.

2.2 Thermocompression Multiple Effect Distillation

Thermocompression driven multiple effect distillation has been used for small scale seawater desalination for the past thirty years or so. Its energy efficiency in terms of steam consumption is comparable with that of MSF (although higher quality (pressure) steam is required). The steam is usually supplied by a package boiler in the stand alone situation. For small to medium capacities thermocompression units provide a smaller capital cost and a smaller electrical power requirement that MSF, while retaining the ability to produce a pure distillate product water. Over the past 10 to 15 years, the installed unit sizes for these thermocompression plants have gradually been creeping up - unit sizes of 1 to 2 Migd are now fairly common for stand alone plant. In this range its principal competitor is SWRO.

2.3 Seawater Reverse Osmosis (SWRO)

Membranes

Reverse osmosis was first demonstrated as a possible desalination process in the mid fifties. Reid (financed by the OSW) showed that cellulose acetate could reject 98% of the salt in seawater. But the fluxes were not commercial. In the late fifties asymmetric cellulose acetate membranes were developed by Leob and Sourirajan, allowing higher, commercial, fluxes. The rejections of these early membranes were not sufficient to desalinate seawater in a single pass - for seawater desalination a two stage process had to be used. However, steady progress in membrane materials and technology over the sixties and early seventies lead to the development of artificial polymer membranes (principally polyamides) which gave performances capable of single pass seawater desalination. These appeared in two forms: firstly as hollow fine fibres giving very large surface areas and utilising relatively low fluxes, and, secondly in the form of thin film composite membranes employed, principally, in the spiral wound configuration. Additionally cellulose triacetate membranes were developed and used in the hollow fine fibre format. The salt rejections were, and still are, such that if either a high concentration seawater is used as feed or a relatively pure product water is required, a two stage desalination process is still sometimes necessary.

Membrane performances tend to deteriorate with time due to a combination of irreversible fouling and polymer degradation. Membrane lives have improved but are still relatively short (typically 5 years, although some are used for much longer, but at lower rates of production and/or with deteriorated product qualities).

Pretreatment

Since RO membranes act as very fine filters they are particularly susceptible to fouling. Fouling occurs in several forms:-

Scaling - due to the precipitation of inorganic salts reaching their saturation concentrations,
Plugging - due to the accumulation of suspended solids on the membrane surface,
Biofouling - due to the growth of biofilms (bacterial) on the membranes surfaces.

In many cases actual fouling films consist of a mixture of these foulant types. To control or prevent these fouling phenomena, reverse osmosis feed waters have to be pretreated. Such pretreatment tends to consist of a number of components such as filtration, acidification, antiscalant dosing and sterilisation (often by chlorination). Chlorine is particularly damaging to most of the artificial polymer membranes (polyamides etc.) and so has to be removed before the water contacts the membranes. Good pretreatment is critical to the successful operation of any RO plant.

In some locations, where seawater beach wells can be used, the pretreatment can be safely minimised (the beach well carrying out the filtration) and a much more economical installation be achieved.

Membrane filtration is at present being developed as a pretreatment for SWRO and holds out the prospect of considerably simplifying the necessary pretreatment processes.

Energy consumptions
In the early days the typical energy consumptions of SWRO were in the range from 10 to 20 kWh/m3. However with the development of better membranes allowing higher recoveries and the introduction and improvement of energy recovery devices to recover the energy in the high pressure brine reject streams, energy consumptions have fallen dramatically (towards the theoretical minimum ~ 1.5 kWh\m3). Values of 3 to 4 kWh\m3 are now achievable.

These low energy consumptions make SWRO particularly attractive compared with MSF distillation where the pumping energy requirements are of the same order of magnitude let alone the much larger thermal energy requirements for the distillation process. (But remember that the product quality and reliability considerations still tend to favour the distillation process).

Seawater reverse osmosis often provides the optimum seawater desalination solution particularly in situations where no waste heat is available, the fuel costs are relatively high and the seawater feed is clean and not too saline.

2.4 Hybrid Seawater Desalination Plants.

There is considerable interest presently in the possibility of constructing hybrid seawater plants where a power generation cycle provides waste heat to distillers and power to both the distillers and to a SWRO plant. Considerable savings are possible in terms of shared facilities and the products of the two processes can be blended (mitigating the relatively high TDS of the SWRO product water).

3.0 Brackish Water Desalination.

Two processes compete for brackish water desalination: reverse osmosis (BWRO) and electrodialysis (ED). Reverse osmosis has by far the larger share of the market and is capable of economically desalinating brackish waters of any salinity (up to seawater strengths). RO also provides a barrier to organic organisms and suspended particles which electrodialysis does not. ED is however most competitive when one wishes to halve the salinity of a slightly water (e.g. a reduction from ~1,000 ppm to 500 ppm TDS).

3.1 Electrodialysis

In the electrodialysis process, the salt ions are conducted out of the product water through ion-permeable membranes by passage of an electrical current across a membrane stack. In its most modern form, the electrodialysis reversal process (EDR), the current polarity (direction) is reversed at regular intervals - this significantly reduces membrane fouling and saves on feed water pretreatment. The energy costs of the process are strongly connected to the feed water salinity and the rate of salt removal required. The number of stacks required is approximately equal to the number of times one has to halve the feed water concentration to arrive at the desired product concentration. This has an obvious effect on the capital cost.

3.2 Brackish Water Reverse Osmosis (BWRO)

Reverse osmosis has for some time been the most favoured process for the desalination of brackish waters. Since the early days when RO membranes were only capable of desalinating low salinity waters there have been significant improvements in BWRO membranes. Membrane fluxes, rejections and stabilities have all been improved allowing operation at low pressures, and therefore reduced energy consumptions, whilst still achieving the desired product qualities.

Again in BWRO feed pretreatment is of critical importance in maintaining membrane performance and achieving economic membrane lives.

4.0 Opportunities and Scopes for Improvements in Desalination Technology.

In seawater desalination the multistage flash distillation technology is now relatively mature. There is some scope for improvement in materials, but this is simply a case of trying to use cheaper materials whilst maintaining corrosion resistances. There is room for development of scale prevention chemicals which allow high temperature operation (top brine temperatures in the range 100°C to 120°C) without the problems of demister scaling. There is some work being undertaken into the use of membrane softening as a possible pretreatment for distillation processes. This would, technically, allow operation with top brine temperatures well in excess of the calcium sulphate limit of 120°C, but there is some doubt as to whether this would be economic. Although these higher top temperatures would allow better energy efficiencies, extraction of the steam from power cycles at these elevated temperatures would imply higher steam costs. Additionally, as the temperatures rise beyond the 120°C mark the vapour pressures start to become significantly higher implying higher capital costs for the distiller shells.

Seawater reverse osmosis is now very competitive with MSF distillation in many situations. It is probably not as mature a technology. There is not very much room left for increasing SWRO membrane fluxes without incurring diminishing returns due to concentration polarisation effects. However, there are scopes for improvements in both membrane rejections and, particularly, in membrane stabilities and robustness. Membranes that could tolerate disinfection by chlorine would carry significant advantages. As has been stated above, SWRO energy consumptions have come down dramatically over the past decade. Further progress in this area is more likely to entail capital cost reductions and scale-up of the pressure exchange devices that have delivered these lower energy consumptions rather than further dramatic energy consumption reductions. Simplification of pretreatment, possibly by the use of membrane filtration, probably holds out the greatest prospect for improved SWRO reliability and extension of membrane lives. Membrane restoration and cleaning techniques are another area in which significant progress may be possible.

5.0 The Near Future ??

Over the next decade or so I would expect SWRO to improve its competitiveness vis a vis MSF distillation and increase its market share, but I would expect distillation to retain its niche as the process of choice for highly saline feeds either in the form of MSF for large power/water stations (possibly in hybrid combinations with SWRO), or in the form of Thermocompression MED in stand alone situations.

In brackish water desalination I would expect reverse osmosis to squeeze out electrodialysis a little further. Improvements to RO membrane stabilities, robustness and cleaning techniques probably hold out greater prospects than possible changes in membrane permeabilities. As is the case with SWRO, improvements to pretreatment techniques possibly by the use of membrane filtration may well prove significant.