REVIEW OF OPERATING LWR EXPERIENCE

WITH MEMBRANE TECHNOLOGY

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ABSTRACT

In recent years, several membrane based systems have been designed, tested, and operated in commercial nuclear power plants. These systems include the use of reverse osmosis and ultrafiltration unit operations to process a wide variety of liquid waste generated at PWRs and BWRs.

This paper identifies the domestic and foreign applications of these technologies and describes recent U.S. experience at operating nuclear power plants. Special emphasis is given to recent operating experience, including membrane performance, system performance, and the anticipated role of the applications in a water management program at PWRs and BWRs. Applications of particular interest include boric acid reclamation in PWRs, low quality waste processings in BWRs, and laundry waste processing.

INTRODUCTION AND BACKGROUND

Pressure driven membrane technology has taken giant strides in the past decade. It was not long ago that membrane systems were limited to capacities of under 75,000 gpd. These were used primarily in the food, drug, and chemical process industries. Commercial acceptance of pressure driven membrane systems have risen greatly. In 1971 there were approximately 50 plants. Today there are over 1,500 plants in the world with more than 25,000 gpd capacities. In the next five years it is anticipated that a 300 percent increase will take place. A similar growth of membrane technology is probable in the steam-electric industry where new technology must develop a proven "track record" before wide acceptance occurs. Indeed, an article in the February 1983 issue of Power states "Recent experience underscores the promise of reverse osmosis and ultrafiltration in the generation of high pressure steam." While the future of membrane technology for makeup water is bright, previous failures and unfilled promises still cast a shadow over the use of this technology to process radioactive waste water.[1]

There are two basic membrane processes which utilize pressure as the driving force; namely, reverse osmosis (RO) and ultrafiltration (UF). Both ultrafiltration and reverse osmosis are pressure activated processes where separation of solutes or solute and solvent is on the basis of the molecular size and shape. In operation, a pressurized solution is caused to flow across a membrane surface. The membrane is so designed that water and species smaller in size than the rejection level of the membrane will pass through the membrane, while larger species will be rejected at the membrane surface and be passed downstream by the flowing process stream.

While ultrafiltration and reverse osmosis are related, the difference between the two processes lies in the size of the species their membranes reject. In reverse osmosis, one works with membranes so tight that species of atomic dimensions will be rejected. In ultrafiltration, one works with looser, more open membranes which reject macromolecules in solution and any colloidal or suspended material. Although no clear boundary exists where reverse osmosis ends and ultrafiltration begins, the distinction lies in a combination of the developed osmotic pressure a species exhibits in solution, and the pressure limitations of the ultrafiltration equipment used. The smaller the size of the species, the greater the osmotic pressure generated. For efficient performance, the system operating pressure must be significantly greater than this osmotic pressure. Due to this osmotic effect, reverse osmosis systems will typically operate at pressures of 2 to 10 MPa (300 to 1500 psi), while ultrafiltration systems will perform efficiently at only 0.2 to 1.4 MPa (25 to 200 psi).

Reverse osmosis, a high pressure membrane separation process, has gained increased acceptance as:

- A roughing demineralizer for the production of potable water from high total dissolved solids (TDS) sources.
- A roughing demineralizer followed by conventional ion exchange process to produce high purity water, from high TDS sources.
- A roughing demineralizer on low TDS waters where the concurrent removal of colloidal material is of prime importance.

The use of RO on low solids waters sometimes seemed questionable; however, the removal of large molecular organic and colloidal materials has more than justified the use of reverse osmosis in low TDS applications.

Ultrafiltration has drawn increased attention as a method of removing organics and colloidal material from a variety of water sources. It is a low pressure membrane process which permits the selective separation of organics and colloids from various liquid streams. The degree and quantity of the separation is a function of:

- Pore size of the membrane.
- Size and shape of the colloids and organic molecules.

Ultrafiltration membranes will reject all colloidal material, as well as large organic molecules in solution; however, ultrafiltration membranes will not reject dissolved inorganic solids. While UF has been used primarily in the chemical process industry, it is only now starting to be employed in general water treatment systems. While UF systems are not concerned with salt rejection, they are similar to RO systems since they can be operated by varying pressure to maintain productivity. This allows for optimum operation on highly contaminated streams.

UF applications include:

- Pretreatment of water as protection for conventional demineralizers (and RO units) and final end use.
- Pretreatment of low solids water.
- Wastewater reuse to remove colloidal or organic matter which can then be disposed of more easily because of reduced volume. The treated water may then be returned to the plant.
- Laundry waste treatment.
- Oily waste treatment.

MEMBRANE TECHNOLOGY

The membranes themselves fall into two general commercially available categories; namely, cellulosic and non-cellulosic.

The cellulosic membranes which enabled RO to become economically attractive have been produced from cellulose acetate (CA), triacetate (CTA), and various combinations of these basic formulations. The blended membranes are often referred to as "modified" cellulose acetate. The major drawback for the cellulosic RO membranes is the limited pH range (i.e., 3.5 to 7.5) of the waters which may be treated.

The non-cellulosic membrane systems have been based primarily on polyamides for RO and various proprietary formulations for ultrafiltration. The non-cellulosic membranes have a wide range of moderate to high fluxes and salt rejection. The primary advantage of the non-cellulosic membranes is its ability to operate over a wide pH range (i.e., 3 to 11), while the major drawback to the polyamide membrane is its inability to withstand free chlorine. Recent advances in non-cellulosic membrane technology have produced RO systems capable of relatively high temperature operations under a wide pH operating range. This greatly increases the potential for RO in radwaste applications since variations in waste stream characteristics will have less adverse impact on operations.

Reverse Osmosis Systems

Significant applications of reverse osmosis became possible when economic packaging techniques were developed. The problem was to compactly and inexpensively support a large surface area of thin membranes so that it could be continuously flushed and subjected to high pressure without mechanical damage.

There are three primary RO systems: tubular, spiral wound, and hollow fiber. The choice of membranes is dependent upon an application and water characteristics. A typical comparison of these membrane configurations is given in Table I. Additional information can be found in numerous reports identified in Reference 2.

Table I

Comparison of Membrane Configurations

Commercial Configurations	Advantages	Disadvantages
Tubular	easily cleaned chemically or mechanically	relatively high volume required per unit capacity
	can process "dirty" feeds with minimal pretreatment	relatively expensive
	widest range of operating pressures	
Spiral-wound	compact	susceptible to plugging
	inexpensive	badly fouled membranes difficult to clean
Hollow-fiber	compact	very susceptible to plugging
	inexpensive	badly fouled membranes nearly impossible to clean

Three major types of reverse osmosis modules have been commercially available for quite a few years, and experience to date shows mixed results. Table II compares the characteristics of the three types of reverse osmosis modules: triacetate hollow fibers, polyamide hollow fibers, and cellulose acetate spiral wound types. The first two types can be considered physically together as hollow fibers; however, they do differ in chlorine tolerance, operating pH range, and biological resistance. Both hollow fiber manufacturers claim a more compact installed plant, less pressure seals, and effluent qualities exceeding 90 percent rejections. The triacetate hollow fibers boast higher quality effluents, higher static permeate back pressure and resistance to biological attack (because of higher chlorine tolerance). The polyamide hollow fibers can stand higher operating pH values, but in water treatment it appears the high pH advantage is limited to the cleaning cycles. A low operating pH at 5.5 appears to be a beneficial factor in preventing fouling by heavy metal deposition on the membranes.

The major advantage of spiral wound cellulose acetate RO is that the salt passages are larger and are rather easier flushed both during service or during cleaning cycles. Because of this, the influent quality Fouling Index (FI) for the spiral wounds are tolerant at higher values up to 15. Whereas, for the hollow fibers, the influent is recommended to be below a value of 3 or 4. In terms of turbidity, the spiral wounds can tolerate turbidities of "1 JTU" whereas the hollow fiber must stay under "0.5 JTU".

Table II

Comparison of Three Major Types of Reverse Osmosis Modules

	Triacetate Hollow Fibers	Polyamide Hollow Fibers	Cellulose Acetate Spiral Wound
Module Sizes & Flow	5"x48" 4000 gpd 10"x48" 20,000 gpd	4"x48" 4200 gpd 8"x48" 14,000 gpd	4"x21'(6) 4200 gpd 8"x21'(6) 24,000 gpd
Recommended Operating Pressure	2.4 MPa (400 psi)	2.4 MPa (400 psi)	2.4 MPa (400 psi)
Flux, Permeate Rate gpd/ft^2	1.5	2	15-18
Recommended Maximum Operating Temperature	86°F	95°F	86°F
Effluent Quality (Guaranteed % rejection)	90%	90%	90%
pH Range	4-7.5	4-11	4-6.5
Chlorine Tolerance	0.5-1.0	0.1-0.25	0.5-1.0
Influent Quality (Relative-FI*)	FI<4	FI<3	FI<15
Recommended Influent Quality	FI<3	FI<3	FI<3
Biological Attack Resistance	Resistant	Most Resistant	Least Resistant
Flushing Cleaning	Not Effective	Not Effective	Effective
Field Membrane Replacement	Yes	No (future yes)	Yes

* FI = Fouling Index

For normal commercial applications, most of the membrane manufacturers offer 3 year performance warranties with either special pricing or with special influent water analytical tests, and special controls. All have suggested that with "proper pretreatment" the modules should experience a 3 year life. Although there may be some cases of a 3 year life, so far it appears that a 2 year life would be more realistic. Radiation damage is not a problem because of the short lifetime of membrane modules. Many small, and some large RO installations that have not had the "proper pretreatment" or have not been operated with proper safeguards, have failed or modules have been replaced within 1 year.

A few years back, many of these failures left a sour taste in the nuclear RO market; but, it is now recognized that RO needs "proper pretreatment" and proper instruments and operator training for successful operation.

It is important that the waste characteristics of a particular stream dictate the type of membrane to be utilized. This factor would suggest that the full spectrum of membranes be offered for water and waste water treatment.

A reverse osmosis system usually consists of six elements:

- Pretreatment hardware.
- High pressure pumps and associated motors.
- Pressure vessels which contain the membranes.
- Necessary valves and piping.
- Gauges and instrumentation.
- Cleaning equipment.

The pretreatment varies widely with the nature and condition of the feedwater, the type of membrane used, and the ultimate use of the water. The hardware may include filters to keep large suspended solids out of the pumps and away from the membranes or special filters to remove specific materials, such as iron, calcium, chlorine, etc., which may cause membrane fouling or which may damage the system materials. Injector pumps may be required to add chemicals for specific purposes, such as acid for small pH reduction, and a polyphosphate which may act as a chelating agent, a surfactant, and a sequestrant.

The use of a UF membrane ahead of reverse osmosis is recognized as an effective particulate filter in removal of colloids, high molecular weight substances, oils, etc.; but the capital cost of these units is nearly as much as the reverse osmosis membranes. Therefore, this approach is only practical in small applications where pretreatment costs and labor are high, and reliability low. Ultrafiltration is a reliable, effective pretreatment for RO, but fouling of these UF membranes may be sacrificed in place of RO.

Ultrafiltration Systems

There are three primary UF systems: tubular, spiral wound, and hollow fiber. The choice of system depends on the nature and concentration of the foulants in the feed stream.

However, the basic operating philosophy is the same for all systems. The operation of a UF system can be defined as planned fouling. The UF system is operated at the highest flux possible under a given fouling environment. This optimum operation is achieved by employing the maximum operating pressures and/or temperatures possible for a given system. Much of the discussion concerning RO, above, is directly applicable to UF.

MEMBRANE TECHNOLOGY APPLICATIONS IN NUCLEAR POWER PLANTS

Applications for membrane technology include pretreatment of makeup water before use within the power plant, process water treatment, including laundry waste and the potential of processing floor drain and equipment drain wastes, as well as specialty applications such as boric acid reclamation.[2]

The radioactive waste processing system collects various miscellaneous waste sources including floor drains, outdoor controlled area wastes, sampling station radioactive waste, aerated systems and equipment drains, auxiliary system ion exchanger and filter waste, residual heat removal systems, reactor coolant auxiliary systems, emergency core cooling systems, reactor containment cooling systems, process and component cooling systems, fuel handling systems, waste disposal systems, and steam generator blowdown. Miscellaneous wastes which originate from reactor coolant systems are normally further segregated during collection. These wastes are processed separately and are normally recycled within the plant.

The plant chemical wastes include radiochemistry laboratory drains, chemical cleaning wastes, decontamination wastes, primary and secondary system ion exchanger regenerant solutions and other liquid radioactive wastes which contain high concentrations of chemicals. The detergent waste streams are generated from laundry, personnel decontamination, and other liquid radioactive wastes containing detergents and soaps.

Sources of secondary system wastes are the steam generator blowdown, turbine building drains and secondary system ion exchange spent regenerant, and filter waste.

The requisite cleanup or decontamination of radioactive process or waste streams is obtained by the combination of numerous chemical and physical unit operations including filtration, evaporation, and demineralization. While RO is readily considered for processing detergent wastes, numerous other applications are possible including steam generator blowdown, treatment of floor drains, equipment drains, boric acid reclamation, and preconcentration of regenerant chemicals. UF could be utilized in a filtration mode either as part of a steam generator blowdown system, laundry waste, and other high suspended and colloidal solid waste streams; as a side stream filtration technique for reducing the suspended solids level in the reactor coolant system; and as an evaporator pretreatment process.

Reverse Osmosis Applications

Reverse osmosis applications in PWRs include: makeup water treatment, laundry and floor drain processing, process water preconcentration, and boric acid reclamation; for BWRs: makeup water treatment, laundry, floor drains, waste collector systems, and process water preconcentration.

Makeup Water Treatment

The use of reverse osmosis as makeup water treatment for either a BWR or PWR is similar to an application for fossil fuel boiler makeup. RO is presently being utilized in this application.

As requirements for higher and higher quality water have developed, the relatively simple systems of dual- and mixed-bed ion exchange resins have evolved into complex trains, including several pre- and post-treatment units. While a typical high quality makeup water system usually demands two-stage demineralization, mixed bed polishing and carbon column clarification plus possible upstream clarification, filtration, and sterilization, the potential role of RO is such that only a small mixed-bed polisher (regenerated at infrequent intervals) may be required. Final effluent will be practically free of organics and will not contain any particulate matter. The choice of reverse osmosis as a makeup water treatment technology is strictly a matter of economics. When total dissolved solids (TDS) is below 125 ppm, the economics of reverse osmosis may not be clearly favorable; however, it is believed that RO can be justified for TDS levels as low as 75 ppm.

For nuclear power applications, RO for makeup water treatment is receiving wide acceptance. This is emphasized for nuclear facilities since greater scrutiny has been placed upon them by the EPA and NRC.

Process Applications

Reverse osmosis has been in use at the Rochester Gas and Electric Ginna Nuclear Power Plant since 1972. This unit has successfully processed laundry waste at 0.13 l/s (2 gpm) for the past decade. Prototype and test units have been tested at various nuclear facilities, including Carolina Power and Light's H.B. Robinson Unit 2, Wisconsin Electric Power's Point Beach Nuclear

Station, Mound Laboratory, and numerous power plant applications in Canada, Japan, and Europe. Larger commercial systems have been purchased by Carolina Power and Light, Commonwealth Edison, Cincinatti Gas and Electric, and Texas Utilities, but little or no information is available yet on their operation. These are given in Fig. 1. A good review of reverse osmosis as of 1978 is available as NUREG/CR-0724, "A Study of Reverse Osmosis Applicability to Light Water Reactor Radwaste Processing."

RADWASTE MEMBRANE SYSTEM STATUS

Organization	Plant	Capacity l/s	Type	Stream	Vendor	Status
RG&E	Ginna	0.13	RO	Rad Laundry	Westinghouse	On-line May 1972
Comm. Ed.	LaSalle	0.25	RO	Rad Laundry	Union Carbide/ Permutit	Purchased - startup
Cin. G&E	Zimmer	0.25	RO	Rad Laundry	Union Carbide/ Permutit	Purchased - not on-line
Texas Util.	Commanche 1 & 2	0.63	RO	Rad Laundry	Union Carbide/ Helix	Purchased - not on-line
SNUPPS	several plants	0.25	RO	Rad Laundry	Permutit	Purchased - not on-line
DOE	Idaho Falls	1.6	RO	Fuel Pool Pond	Polymetrics	On-line October 1976
DOE	Mound Laboratory	0.13	UF	Rad Laundry decon. Wastes Floor drains	Abcor	On-line June 1977
Japan Atomic Power	Tsuruga	4.7	UF	Equipment Drains	Abcor	On-line August 1977
RG&E	Ginna	0.13	UF	Waste Hold-Up Tank	Abcor	On-line 1979
Comm. Ed.	Zion	0.26	UF/RO	Floor Drains	Abcor	On-line late 1980
CP&L	Brunswick	3.4	RO	Floor Drains	Gulf Degremont	On-line November 1975 Prototype
CP&L	Brunswick	2.6	RO	Low-Quality Drains	DuPont	On-line Prototype 1981
CP&L	Harris 1 & 2	1.9(3)	RO	Floor Drains Rad Laundry	Helix	Purchased - not on-line

Fig 1. Radwaste Membrane System Status

Floor Drain and Equipment Drain Waste

The treatment of floor drains in a PWR or BWR by reverse osmosis is being seriously pursued at several plants. Carolina Power & Light Company (CP&L) uses this processing in both its BWRs and PWRs.

The role of reverse osmosis in the treatment of waste from a BWR has been developed for the Brunswick Steam Electric Plant (BSEP) of CP&L. The use of RO at BSEP was based upon a situation very similar to retrofit applications in nuclear power plants. When RO was chosen, the engineering of Brunswick was nearly 80 percent complete and the liquid radwaste facility was more than 95 percent finalized. It was therefore necessary to backfit sufficient augmentary equipment to meet the then new criteria of Appendix I to 10CFR50 with a minimal disruption on startup schedules. The technologies considered included evaporation, demineralization, electrodialysis, and reverse osmosis. As discussed in Reference 3, for a variety of technical and economic reasons, RO was chosen.

The BSEP reverse osmosis unit was placed downstream of the floor drain sample tank. This allowed the water to be prefiltered before the RO unit. Permeate was collected in the waste collector tank for subsequent demineralization. The brine cut was collected in one of the neutralizer tanks from where it may be recycled through the RO unit, sent to the waste evaporator for further concentration (RO acts as a preconcentration step), or sent to the concentrated waste tanks for solidification. In addition, a piping interconnection was provided to allow detergent drain wastes to be fed to the RO unit. System operations were mixed; however, within the past two years, a new system has been designed and operated for processing low quality waste. Performance has been good to excellent for this application, as indicated in the paper by Hobbs and Fennell "Experience with Reverse Osmosis in BWR Radwaste Treatment."[4]

This paper detailed the use of a 2.6-l/s (4.2 gpm) "low quality waste stream" treatment system for processing floor drains and other off quality streams. This system included an inclined plate separator for removal of coarse material such as resin, sand, and free oil, and a backflushable filter for fine (5 micron) suspended particles removal. These two pieces of equipment also provided pretreatment for low-pressure, hollow fiber, cartridge type RO modules manufactured by Dow. The RO cartridges were suspended from a removable top plate inside a 1.8 m diameter by 1.8 m high radwaste liner. All connections between modules were made inside and brought to inlet and outlet connections at the top plate. These had quick-connect hose fittings for easy disposal and replacement of either the entire liner or alternately, one or more of the cartridges. This "throw away" arrangement developed from previous experience with a spiral-wound RO installation. Short run times were expected, with loss of the modules to organic and iron fouling occuring in as little as 945,000 liters (250,000 gallons) of throughput. The economics for this operation were given as $.03/liter ($0.12/gallon) for RO versus $0.20/liter ($.75/gallon) for portable demineralizers, $0.13/liter ($0.50/gallon) for evaporators, and $0.07/liter ($0.25/gallon) for nonregenerated demineralizers. These costs include capitalization, maintenance, operating costs, and disposal charges.

When the module became completely plugged, the radiation readings just above the top plate were found to be 25 mrem/hr. Modules read 150 mrem/hr when they were torn open for inspection. Each module appeared to be uniformly coated with a brownish gray material which apparently consisted of organic slime and iron colloid. The uniformity of the coating indicated that the particle size of the coating material was smaller than the distance between the RO fibers. Because of the relatively low radiation readings for the modules, disposal was made without special treatment.

Typical DFs for gross gamma activity ranged between 10 and 30 with volume reduction factors ranging between 7 and 10.

The use of RO to treat PWR steam generator blowdown was a viable application until water chemistry changes eliminated the need for such processing. The potential of boric acid recovery in a PWR via RO has been proven at Zion and is discussed below.

Extensive testing of RO and UF has occurred at Mound Laboratory. RO was found to be an effective decontamination process with a large number of radioisotopes found in a floor drain application. In 1982, RO development concluded with a plant design for a 2.5-l/s (40 gpm) RO unit.[5]

Laundry/Shower Water Systems[6-8]

The first prototype laundry waste processing system was installed at the Ginna Station of the Rochester Gas and Electric Company in April 1972. The unit, rated 7,560/l/day (2000 gal/day), consists of a batch feed tank, heat exchanger, pressurized pump, 18 RO modules, and associated control system. Fresh laundry water is added to the feed tank with the RO unit cycling on and off as required. The system is operated at 2.8 MPa (400 psi), 32°C, and the flow rate is controlled to 0.25-l/s (4 gpm) per tube. Typical volume reduction has been 400 for this system. DFs ranged from 30 to 100+ for various radionuclides.[6] Similar good results (DF-1,000 and VR-1,000) were obtained in Japan on laundry waste. The system was a tubular membrane with a sponge ball cleaning system. The sponge balls were used periodically to remove scaling of suspended solids and calcium sulfate from the membrane by a combination of scraping and turbulence. No damage to the membrane was noted after over 500 cleaning cycles.[8]

Based upon the excellent experience at Ginna, numerous other systems were purchased. The typical system was sized for 0.24-l/s (4 gpm), while systems such as Shearon Harris were designed for 1.9-l/s (30 gpm).

Process Water Preconcentration

The use of reverse osmosis as a preconcentrator to an evaporator has been postulated for both PWRs and BWRs. This application has been primarily associated with the treatment of condensate demineralizer chemical wastes.[9] In particular, the RO unit would provide a means for using a smaller evaporator or for the more probable case, a means of supplementing an inadequate existing evaporator capacity. The possibility of effectively increasing the capacity of a presently inadequate evaporator by the use of RO in a preconcentration mode will be most cost effective when building cost, installation cost, capital cost, and operating and maintenance costs are considered. In addition, the probable ease of installation into an existing facility relative to accessing pipes, tanks, etc., will be an additional positive factor. Process sizes for PWRs will probably be around 1.25-l/s (20 gpm) per unit, while BWRs may have process capacities of 2.5-l/s (40 gpm) per unit. This application is being installed at Shearon Harris, where the floor drain system is a 1.9-l/s (30 gpm) RO unit which then feeds a small forced circulation evaporator for further treatment before the concentrates are processed in a fluidized-bed dryer.

Boric Acid Reclamation

A particular variation of the process water preconcentration application is boric acid reclamation. The concept of using cellulose acetate RO membranes to treat borated wastes evolved from basic work performed by the Westinghouse Membrane Technology Division in 1971 for Public Service Electric & Gas (PSEG). Test programs were initiated and carried out at the Burlington Station of PSEG to investigate the behavior of their RO membranes on simulated PWR borated blowdown. Test results revealed the relationship of boron rejection to pH variations with respect to typical cellulose acetate (CA) membrane material. Additional technical details are given in Reference 10.

The major incentive to the use of a waste boric acid recovery system is the cost savings due to reduction in waste solidification and disposal. PWRs have experienced leakage of boric acid liquid sources into radwaste. The treatment of such radwaste systems has been by the use of evaporators which have resulted in large quantities of concentrated liquid wastes. The cost of waste solidification and disposal has been high, and because of ever-increasing environmental and political pressures, the cost will continue to increase substantially in the future.

A boric acid reclamation system is based on two membrane technologies, UF and RO. The sucessful demonstration at Zion, both technically and economically, of the concept was based on the boron rejection characteristics of cellulosic RO membranes. The UF enhances this performance by protecting the RO from adverse feed conditions found in wastes containing colloidal and high molecular weight organic materials.

The objective of the 0.25-l/s (4 gpm) pilot demonstration was to provide data that would indicate the feasibility for providing significant plant volume reduction of wastes, while producing a recyclable grade of boric acid at an economic rate. This proved successful.[11] This program proved the viability of the process design; the cost advantages of boric acid reclamation; simplicity of the technology; and Zion support for additional work on this technology to bring it from a test and prototype unit to a fully operational system.

Besides the improved waste management capability, the economics of this technology are quite impressive. An analysis for Zion based upon disposal costs for early 1983 indicated that based upon a processing rate of 7.5 gpm with 500 ppm boron concentration and a waste disposal cost of approximately $6.50/liter ($19.00/gallon) of 12 percent boric acid, a cost savings of $1,862,000 could be realized. While each PWR operates under different conditions, substantial benefits can be expected at any PWR which has not been effective in processing and recycling boric acid. A second similar application is the processing of borated primary coolant which is processed by the boron recycle evaporator. Experience at numerous plants has shown that the quality of the boron is inadequate for recycling.

Ultrafiltration Applications

Ultrafiltration (UF) application in nuclear power plants include: reactor coolant system filtration and as a prefilter to RO units where oil, suspended, and colloidal material must be removed.[12-15]

Process Applications

Ultrafiltation is a unit operation available for the processing of macromolecules and colloids and the treatment of plant influent and effluent. Wherever colloidal suspensions or aqueous solutions with solutes of greater than 500 molecular weight exist, ultrafiltration can effectively and efficiently process them. The role of ultrafiltration in nuclear power plants includes applications for the treatment of waste water and plant process water.

Reverse osmosis has been increasingly used in recent years, especially when its salt rejection characteristics are required. However, many RO systems foul irreversibly with high colloid content. When the goal is to remove total suspended solids, UF is far more economical. This is especially true when UF is used as a polishing filter for demineralized water systems. Ultrafiltrations of demineralized water have been shown to reduce turbidity from 0.5 to 0.21 JTU (distilled water standard is 0.20 JTU), reduce suspended solids to less than 1 ppm, reduce total plate count from 8,000-10,000/ml. to less than 1/ml. while increasing resistivity from 3-5 megohms to 10-15 megohms. Application for ultrafiltration systems has included totally removing silica from boiler feedwater.

Membrane ultrafiltration has been used successfully as an effective process for the treatment of a large number of industrial wastes. The processes appropriate for applications include water recycle and reuse, and particularly for systems in which the very high rejection of low molecular weight solutes is not warranted. Some of the water reuse applications involving ultrafiltration include electro-deposition primers, oil-water separation and metal cutting operations, and the removal of sewage effluents.

The potential role of ultrafiltration in nuclear power plants includes applications where ultra-pure water is required, and the colloidal and suspended solid level must be effectively zero. The use of UF in a processing technique will therefore be limited successfully to side-stream filtration of the reactor coolant system letdown system. This application has been implemented at the Tsuraga BWR to replace the filter/demineralizer on the Reactor Water Cleanup System but not on a PWR.[14] However, the capability of UF could result in a situation where such an application is not only feasible, but practical in the immediate future. The application of UF would be to remove the radioactive corrosion products and thus minimize the buildup of high radiation levels throughout the piping and components in the reactor coolant system. Present techniques utilize filters and demineralizers; however, these are limited in removal of suspended solids to approximately 1 micron. The suspended solid particles in the reactor coolant system, however, are submicron in nature, and thus, radiation levels have been building up in all operating PWRs.

Ultrafiltration is also used as a prefilter to an RO unit, such as in boric acid reclamation discussed above. This will be especially important where soluble oily or other organic wastes might adversely impact an RO unit. This particular application of UF would be determined on a case-by-case basis.

In addition, it might be possible to utilize UF during refueling operations on PWRs and BWRs in an effort to improve the water quality and clarity associated with the refueling operation itself. Typically, the reactor head area and refueling canals are flooded and, because of the physical/chemical characteristics of the crud material, crud bursts of fission and corrosion products are common. This consequently clouds the refueling water and has had adverse impact on several refuelings. Present practice is to provide conventional filtration of this water initially with a 25 micron roughing filter and finally with a 1-5 micron polishing filter. UF would provide absolute filtration and would substantially reduce the contamination and consequent clean-up of the various surfaces in contact with this water after refueling. This typically is a very time consuming and high radiation and contamination job. Discussion is underway with one BWR for this application.

Based on the assessment of the operational difficulties experienced in the nuclear industry for concentrating liquid radwastes, EPRI sponsored a demonstration program that evaluated the technical performance and economic viability of improved prefiltration of liquid wastes designated for processing trhough the radwaste evaporator. A retrofitted ultrafiltration system was utilized as the pretreatment step to the evaporation process.[13]

The program was designed to quantify the performance of UF in a nuclear plant environment in terms of solids removal (suspended and colloidal), decontamination factor (DF), and cost/benefits. The cost/benefits evaluation was associated with an assessment of the system regarding the control of radiation buildup in the waste hold-up tank, the effect of downstream evaporator performance with respect to overall volume reduction, operating efficiency (including corrosion rates), reduction of operator exposure to radiation, and availability. EPRI Report NP-2335 "An Application of Ultrafiltration to Radwaste," indicated that while little change was seen in the performance of the waste evaporator, downstream of the 0.13-l/s (2 gpm) tubular UF system a significant reduction in evaporator maintenance and associated exposure was noted, as shown in Table III. During the test period, 6.0 x 10^5 liters (1.6 x 10^5 gallons) of waste were processed with membrane DFs for filterables of 10^5 and DFs for nonfilterable species between 1 and 20. Volumetric concentration factor ranged between 380 and 2,400.

Table III

Ginna Radwaste System Repair, Maintenance, and Inspection (UF and Cartridge Filter System Comparison)

Task*	Pre UF Operation (1/78-7.79) man-hour per 10,000 gallons	Pre UF Operation (1/78-7.79) man/mRem per 10,000 gallons	Post UF Operation (7/79-9/80) man-hour per 10,000 gallons	Post UF Operation (7/79-9/80) man/mRem per 10,000 gallons
Waste Hold-up Tank	0.6	27.5	1.9	16.5
Waste Evaporator	15.8	314.0	6.9	78.2
Drumming Station	1.5	6.6	1.5	6.2
Waste Condensate System	3.9	13.4	0.9	2.3
Filter Replacement	2.7	37.3	2.4	28.2
Ultrafiltration System	--	--	13.3	204.0
Totals:	24.5	398.8	26.9	330.4

* Total radwaste processed 532,000 gallons. Volume processed by UF 152,000 gallons.

The treatment of laundry wastes by membrane processes for the purpose of water reuse is a very promising application. The use of reverse osmosis for the treatment of laundry wastes containing ionic and anionic surfactants is practiced within the nuclear plants. UF can be utilized to remove anionic surfactants and other laundry wastes.

Mound Laboratory has performed a series of tests with various hollow fiber ultrafiltration membranes in the treatment of laundry waste and decontamination wastes. DFs for laundry waste water were up to 500 depending on the waste species (ionic or suspended/colloidal). A volume reduction of 200 with DFs up to 500 was achieved with an average flux rate of 25-35 gfp. The waste included various transuranic isotopes. In addition, other waste streams, including alpha-contaminated floor drains and decontamination waste were processed.[5]

Ultrafiltration is also capable of treating oily waste streams. In the UF process, the waste oil feed stream is pumped through the center of a porous tube on which a membrane has been integrally cast. The hydraulic pumping pressure causes only the water and some dissolved low molecular weight materials through the membrane. Emulsified oil, free oil, suspended solids, and bacteria are retained and concentrated inside the tube. Thus, only small molecular material in true solution may pass through this membrane.

In one industrial UF flow process, waste water in the 1-5 percent oil (soluble) range has been concentrated to 50-60 percent oil. As a 2 percent oil feed is recirculated through the UF, it would have 96 percent of its volume become permeate in order to be concentrated to 50 percent oil. Thus, two streams would be produced: a 4 percent by volume concentrate containing 50 percent oil, and a 96 percent by volume purified water stream that would be discharged or reused. The concentrate is such that its Btu value is in excess of that needed for self-combustion. This concentrate is disposed of by burning or hauling.

Waste lubricating oil from nuclear power plants contains a low level of radioactive contamination such that an expensive disposal process is ordinarily required. This radioactivity can be effectively removed by an ion-exchange process which is fairly expensive (e.g., $9-11/liter for disposition at Beatty or Hanford). Disposal records indicate that the levels of radioactivity in typical waste oil are relatively low. Ninety percent of the oil had a total specific activity of less than 5 x 10^{-3} uCi/ml. The nuclides most frequently present were Mn-54, Co-58, Co-60, Cs-134, and Cs-137. The radioactivity of the oil is postulated to be present in two forms: as solid particles and as ion in the aqueous phase of water/oil emulsions. Both of these forms lend themselves partially to mechanical separations, but below certain levels, such devices become ineffective. Particulate matter ranges in size from large globules to particles of the 5 to 10 micron range. Their specific gravity may or may not be greater than that of the oil, as is the case with resins. The second source of activity, ions trapped in water/oil emulsions, poses a more difficult problem. The water droplets in the oil generally have a diameter of less than 0.1 micron and a specific gravity of 0.85. As this diameter decreases, the stability of the emulsion increases. Mechanical separation of these finer emulsions is not possible.

The use of ultrafiltration membranes having a moderate porosity and a tight porosity has, in a series of tests, removed over 90 percent of the radioactivity in a low-cost process which concentrates the radioactivity into a small volume. Depending upon the specifications which are applied to these processes, either ultrafiltration alone, or an ultrafiltration-resin process are capable of the virtually complete decontamination of this oil. Preliminary cost estimates for this technology indicate that costs could be reduced to the range of $0.10-$0. 40/liter.[15]

SUMMARY

Membrane technology, whether RO or UF, has the advantage of compact size, minimal auxiliary needs, and simplicity in installation. Thus, RO should be stressed as unit operations which can "extend" the operating cycle of radwaste demineralizers and can "add capacity" to an existing evaporator by acting as a preconcentrator.

An RO system will have a lower capital cost than an equivalent evaporator. In addition, the installation cost and operating cost will be substantially less than the evaporator. Further, the RO or UF unit can be placed in a hallway or other similar area. This is not possible with an evaporator. Since most plants do not have extra steam or cooling water available, the support auxiliary services will add large, if not prohibitive, cost and space penalties. Also, delivery time and impact on plant operations, especially radwaste system operations, should be substantially less for RO and UF.

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