DESIGN AND FABRICATION OF A 40 GPM ULTRAFILTRATION SYSTEM FOR SAVANNAH RIVER PLANT

Deborah Swindlehurst
Associated Technologies, Incorporated
Charlotte, North Carolina 28281

ABSTRACT

Savannah River Plant is currently installing a 151 l/min (40 gpm) pilot system to process low level radioactively contaminated water for discharge from the site. The experience gained in operating this pilot system will aid SRP in determining the subsystems which will comprise the final 946 l/min waste effluent treatment facility. The 151 l/min pilot system consists of ultrafilters, reverse osmosis permeators and demineralizers. This paper discusses the design and fabrication of the ultrafilters for the pilot system.

BACKGROUND

In January 1984, DuPont's Savannah River Plant (SRP), in Aiken, South Carolina, began investigating potential unit processes for a 284 l/min pilot unit to process a high dissolved and suspended solids, low radioactivity waste stream. The original conception of the system was to include the listed equipment in the following order: five-micron cartridge filters, a carbon adsorption column, an iron removal column, a multi-media filter, a backflushable filter, spiral-wound reverse osmosis permeators and ion exchange columns. The waste components to be removed in each of these stages were, respectively: large particulate, organics, iron, smaller particulate, fines from the preceding beds, a majority of the dissolved solids and radionuclides, and the TDS and nuclides that passed the RO. The concentrate (brine) stream from the RO will be condensed for solidification in an evaporator. However, late in the design phase of the system, DuPont began investigating the dynamically formed ultrafiltration membranes manufactured by CARRE Incorporated.

Ultrafiltration (UF) is a form of membrane separation, as is reverse osmosis (RO), which is capable of removing suspended solids, colloids and macromolecules from liquid streams. The design of the UF module manufactured by CARRE makes it especially suited for processing streams containing suspended solids because of its large diameter flow paths.

The UF module shell is constructed from a capped and flanged stainless steel pipe, and inside the shell is serpentine porous stainless steel tubing (Fig. 1). This tubing is sintered from 316SS powdered metal. It forms the support for the UF membrane which is applied as a coating to the internal surface. The feed to each module is supplied at approximately 68 atm to the interior of the 5/8" I.D. tube. The pressure forces the clean water (permeate) through the membrane and the walls of the porous tube where it is collected in the shell. The stream solids are retained by the membrane and as the permeate is withdrawn, the concentration of the solids in the tubing increases. This stream is termed the "concentrate." A number of modules is required to produce a system with a high volume reduction (feed volume/concentrate volume). An array of modules in parallel is termed a "stage," and a series of stages forms a system which is designed for the desired volume reduction. The flow throughout the system is designed to remain highly turbulent in order to reduce the tendency for the solids in the tubing to settle.

Feasibility tests were run by CARRE to determine what constituents in SRP's waste stream could be effectively removed. The waste stream was simulated according to a formulation determined by DuPont and it contained the following ionic species: sodium, zirconium, ammonium, calcium, magnesium, barium, carbonate, nitrate, nitrite, chloride, sulfate, silicate and tributyl phosphate. Tests were run at concentrations up to 50 times the original formulation. The test results indicated that 100% removal of suspended solids and greater than 99% removal of iron at pH 6.7 and above were achievable.

The next phase of testing was performed by DuPont at the Savannah River Plant on a single module pumping skid with simulated waste. Tests were run to model a high VR system by returning the concentrate to the feed tank while withdrawing the permeate stream, thereby concentrating the contents of the tank to the desired VR. Concentrations of iron and silica up to six times the expected feed concentrations were processed to a VR of 15 to determine fouling rates and cleaning procedures. After performing these concentration runs, DuPont felt that VR's of 1000 would be achievable with the UF System. Simple cleaning solutions were found to restore 90% of the membrane's flux rate. The UF consistently produced water with a Silt Density Index of less than 1, much better than the required SDI of 3 for RO feed. With the results of the feasibility test and the pilot tests indicating good solids removal and easy membrane maintenance requirements, DuPont proceeded in incorporating the ultrafilters into the design of the waste effluent pilot system.

SYSTEM DESIGN

Including the ultrafilters in the pilot system may allow the removal of the 5 micron cartridge filters, the carbon adsorption column, the iron

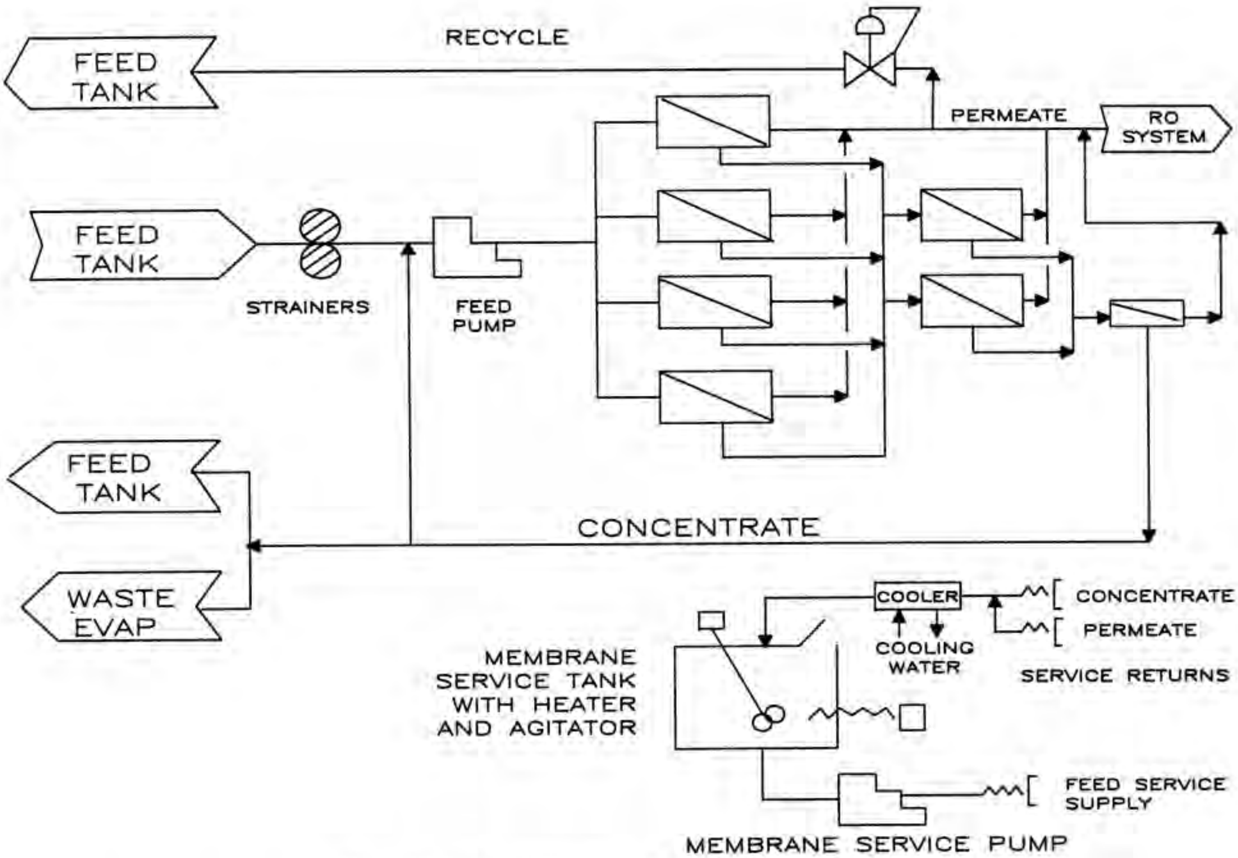

Fig. 1. Ultrafiltration System Flow Diagram

removal column, the multi-media filter, and the backflushable filter. The ultrafilters, however, did require the addition of auxiliary equipment for maintenance of the UF membranes.

The design of the Ultrafiltration System (Fig. 2) is compact, fitting entirely on three skids. The system consists of two 200 mesh basket strainers, a high pressure feed pump, seven ultrafiltration modules, and a service tank and pump for membrane maintenance. The feed is pumped from an SRP storage tank and through one of the duplex strainers by the high pressure feed pump which operates at 170 l/min. (The pilot system was scaled down by DuPont to a nominal 151 l/min.) The dual-head positive displacement pump increases the stream pressure to 71 atm and supplies the feed to 4 UF modules piped in parallel. The concentrate stream produced by this first stage is recombined and fed to the two modules in the second stage, which, in turn supplies a single-module third stage. The modules, in this arrangement, operate at a 90% recovery (permeate flow/feed flow). To further increase the recovery to 99%, 15 l/min concentrate is recycled to the suction of the high pressure feed pump. The remaining 2 l/min concentrate is returned to the tank feeding the system. The permeate from all three stages is combined and supplies the suction of the RO feed pump. In order to ensure that the RO pump has sufficient supply flow, a recirculation line returns some of the permeate to the feed tank. A back-pressure control valve on this recirculation line maintains a suction pressure for the RO pump. As the UF membranes become fouled, the control valve closes in order to keep the flow rate to the RO pump constant.

One feature of the ultrafilters which particularly interested DuPont was the UF's remote maintainability. Membrane cleaning is an integral part of system operation because it sustains system throughput by removing membrane foulants. However, cleaning requires no intimate contact by the operator with radioactive fluids or materials, unlike the maintenance required on the units replaced by the UF's. As auxiliary equipment, the Ultrafiltration System has a 1700 liter service tank and 95 l/min pump. The tank is equipped with an agitator and tank heater for mixing and heating cleaning solutions. On a weekly basis, a cleaning solution is prepared in the service tank and pumped at high velocity and low pressure through the module tubing. The used cleaning solution can be sent to the feed tank and processed through the system with the waste.

It is estimated that on a yearly basis an ultrafilter membrane will require replacement. Rather than having to remove a membrane bundle from the housing, the membranes are stripped and re-formed in place using the membrane service tank and pump. To strip a membrane, a heated chemical solution is recirculated through the tubing until the membrane is removed, then the module is flushed with clean water. To reform a membrane, the membrane solution is recirculated through the tubing until the flow through the tubing has decreased to such an extent that the membrane is considered formed.

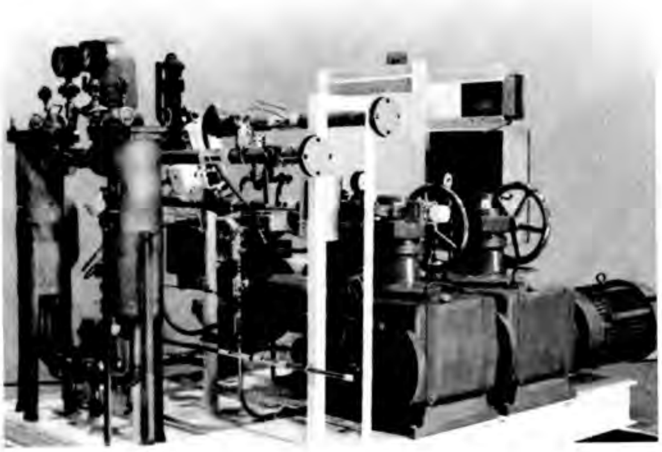

Fig. 2. Feed Pump Skid

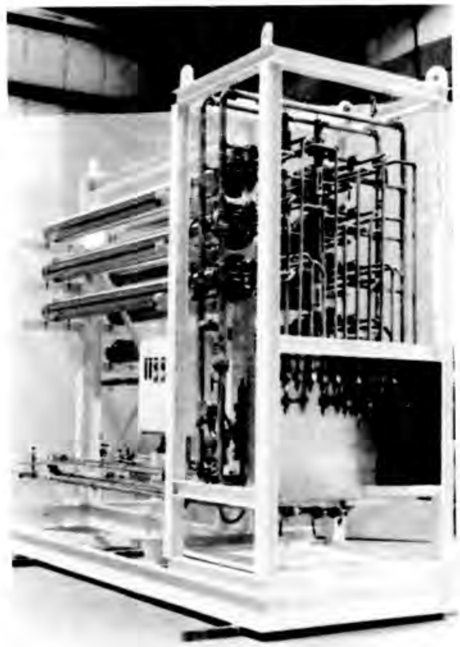

Fig. 3. Ultrafilters Skid

FABRICATION

The entire system is mounted on three skids: a feed pump skid, an ultrafilters skid and the service skid.

The feed pump skid (Fig. 2) is 1.9m w x 2.4m l x 1.5m h and contains the duplex strainers, the feed pump, the suction and discharge pulsation dampeners and all the associated interconnecting piping.

The ultrafilters skid (Fig. 3) is a tall rack 1.5m w x 4.5m l x 3.6m h built to support the seven modules. The majority of the system's piping is on this skid because it contains the feed, permeate and concentrate piping for the modules, plus recirculation piping for both the concentrate and the permeate and also piping for the service connections from the service tank skid. The service connections for membrane cleaning and reformation are made by attaching braided stainless steel hoses equipped with quick-disconnects to the service feed, concentrate and permeate headers and the corresponding module connections. The module quick-disconnects are all piped to a common sample sink for easy access.

The membrane service tank skid (Fig. 4) is a square skid 2.6m w x 2.6m l x 2.4m h on which the 1700 liter membrane service tank and 95 l/min pump are mounted. The skid is equipped with a multitude of valves for different cleaning flow paths. The subsystem is designed to allow forward flow through the module tubing, reverse flow through the tubing, and flow through the tubing with simultaneous backflow through the membrane which is supplied by

Fig. 4. Membrane Service Skid

the RO System's cleaning pump. Although the pilot tests indicated that normal, high velocity cleaning through the tubing effected acceptable membrane performance recovery, DuPont required the more elaborate cleaning flow paths in order to have many options should fouling during operation prove more extensive than that seen in testing.

A small heat exchanger is installed on the combined return of the permeate and concentrate service headers. The exchanger is provided to remove additional heat added to the recirculating solutions by the service pump in order to avoid cavitation of the pump.

The membrane service tank is equipped with a heater and an agitator which are required for making solutions in the tank. The tank is also equipped with a square, hinged-lid hatch for chemical addition.

Low pressure piping terminates in flanges at the edge of each skid so that DuPont can flange PVC piping to it. High pressure piping ends with butt weld ends to provide a leak-proof connection. DuPont is responsible for the interconnecting piping between the skids.

SUMMARY

The RO pilot system is currently in operation at SRP with a backflushable filter upstream of it. When the Ultrafiltration System is installed in March of this year, it will replace the backflushable filter and the UF's will be evaluated for their performance and ease of operation. While it is processing, the UF/RO/Demin/Evaporation System consumes 28% of the energy required for evaporation alone.

DuPont chose to incorporate the ultrafilters into the pilot system for several reasons, the first being their performance. Separate testing has indicated absolute removal of colloids, bacteria, macromolecules and solids larger than 10^{-2} microns. In the SRP pilot studies, the ultrafilters consistently produced permeate with a silt density index les than one, regardless of the degree of membrane fouling. Since the RO permeators require an SDI of 3 or less, DuPont felt that the UF's would produce a high quality permeate throughout the intervals between cleanings.

Secondly, the ultrafilters will perform the duties of 5 filters previously intended for the system. Iron, particulate and colloid removal could be achieved without investing in five different filters and without the added expense of replacing their filter media on a frequent basis. Each ultrafilter requires a weekly cleaning with a chemical solution. This cleaning along with its associated manpower requirements are the only costs incurred after the initial investment in the Ultrafilter System.

Thirdly, the maintenance of the ultrafilters is more in line with ALARA concerns than the five original filters. Also, the secondary waste generated by the UF is readily handled by the waste effluent treatment pilot unit. Maintaining the five filters requires an operator's handling of the spent filter media. The ultrafilter's maintenance is performed more remotely. An operator must prepare a cleaning solution in the tank, and turn valves, etc., but no actual handling of radioactive material is required. The waste generated by this cleaning can be sent to the system feed tank to be processed and concentrated by the UF/RO/Demin System, or it can be sent directly to the waste evaporator which handles the concentrate stream from the RO. The used filter media and bag filters generated by the filters, however, would require special handling and disposal activities. Unlike the five filters, no additional handling or processing capabilities are required by the plant for this secondary waste generated by the UF System.

The actual proof of the ultrafilters will be in their operation in the pilot system beginning in March. The benefits of the system now appear to make them a viable candidate for the final 946 l/min waste effluent treatment facility.

BIBLIOGRAPHY

1. "Assessment of Hyperfiltration and Ultrafiltration for Treatment of Waste Water at the Savannah River Plant - Laboratory Scale Feasibility Tests with Simulant Waste Water," CARRE, Inc., April 20, 1984.