BACKFIT OF HYPERFILTRATION SYSTEMS AT
SEQUOYAH AND
WATTS BAR NUCLEAR PLANTS

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ABSTRACT

The use of hyperfiltration in a nuclear application was the purpose of pilot tests conducted at TVA's Sequoyah Nuclear Power Plant in 1982. Using the pilot tests as the basis, a full scale 90 gpm HF system has been designed and fabricated for TVA's Watts Bar Nuclear Power Plant. A duplicate system was concurrently designed and fabricated for Sequoyah Nuclear Power Plant.

The TVA Hyperfiltration System will be achieving the dual objectives of preconcentration of the radwaste evaporator feed stream and processing of the fluid stream to meet the discharge criteria of 10CFR20 after taking credit for the minimum cooling tower blowdown dilution flow. Floor drain wastes, tritiated drain waste and condensate demineralizer regeneration wastes can all be preconcentrated to a reduced volume as little as 5% of the initial waste feed stream. The decreased volume to be processed for solidification significantly increases the capacity of the radwaste disposal system while reducing the load, maintenance and operating costs associated with the evaporator.[1]

HYPERFILTRATION

First, in order to better understand hyperfiltration and its wide range of possible applications, a technical description is necessary.

Reverse Osmosis using cellulose acetate membranes had long been the only method of membrane separation in wide use. As technology has advanced and new membranes have developed, a branch in membrane separation called hyperfiltration (HF) has also developed. It is similar to reverse osmosis (RO) in that it removes solute molecules from an aqueous stream. However, hyperfiltration goes a step beyond by its ability to tailor membranes to selectively remove certain ionic species while passing others. Also, by their design, hyperfiltration tubular membranes are less susceptible than RO to fouling by suspended solids. Because of these features specific to HF, it can meet the more specialized needs of industry.

Hyperfiltration is a form of filtration which can separate down to the molecular level (see Fig. 1). Ultrafiltration's capabilities stop at large molecules, but HF is able to remove molecules down to the size of a chloride ion. Also shown in Fig. 1, flux (the flow rate through the membrane based on the membrane area) declines with the filterable molecular size. This is because the tightness of the membrane matrix required to retain these minute molecules also impedes the flow of water through the membrane.

Hyperfiltration Module Design

The design of an HF module is vastly different from an RO module (see Fig. 2). Its shell is constructed from a stainless steel pipe, and inside the shell is a serpentine porous stainless steel tube. The porous tubes can be made from any metal available in powdered form; the TVA systems will utilize 5/8 inch diameter stainless steel tubes. After forming under high pressure, the tube is sintered under a controlled atmosphere, time, and temperature which results in a strong, durable filter tube with controlled pore size and porosity. Pore size can be controlled from 50 microns to 0.2 microns. The porous sintered tubes are welded into a single long tube which is assembled into a tube bundle then placed in an 8 inch pipe shell 11 feet long.

In hyperfiltration applications, the tubes are used as support material for high temperature (greater than 100°C) formed in place membranes. In this case, formed in place membranes is defined as physically forming the membrane by simply pumping chemicals into the system where they deposit on the inside of the porous tubes.

Hyperfiltration Processing

The feed is supplied at pressures up to 1250 psi to the interior of the tube. The pressure forces the clean water (permeate) through the walls of the porous tube where it is collected in the shell. The solute molecules are retained by the membrane and as the permeate is withdrawn, the solute concentration increases inside the tube. This stream is then termed the concentrate.

Conventional membrane separation processes cannot tolerate suspended solids in the feed because the flow passages are very small. In hyperfiltration the flow passage is the internal diameter of the tube (5/8 inch). Because of this unique design the hyperfiltration membrane separation process can separate molecules at the same time it is filtering suspended solids. This in essence combines the two

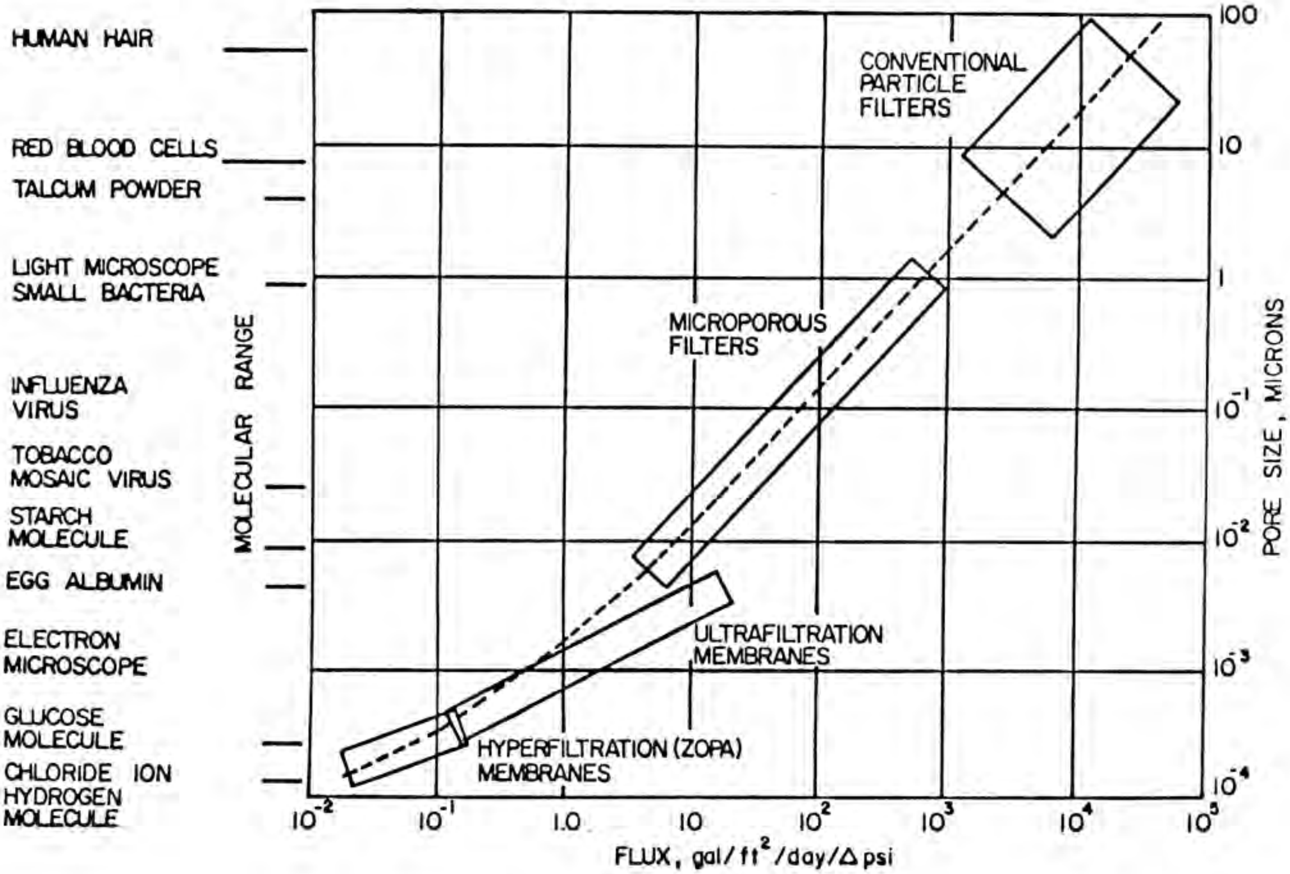

Fig. 1. Filtration Flux vs. Molecular Range

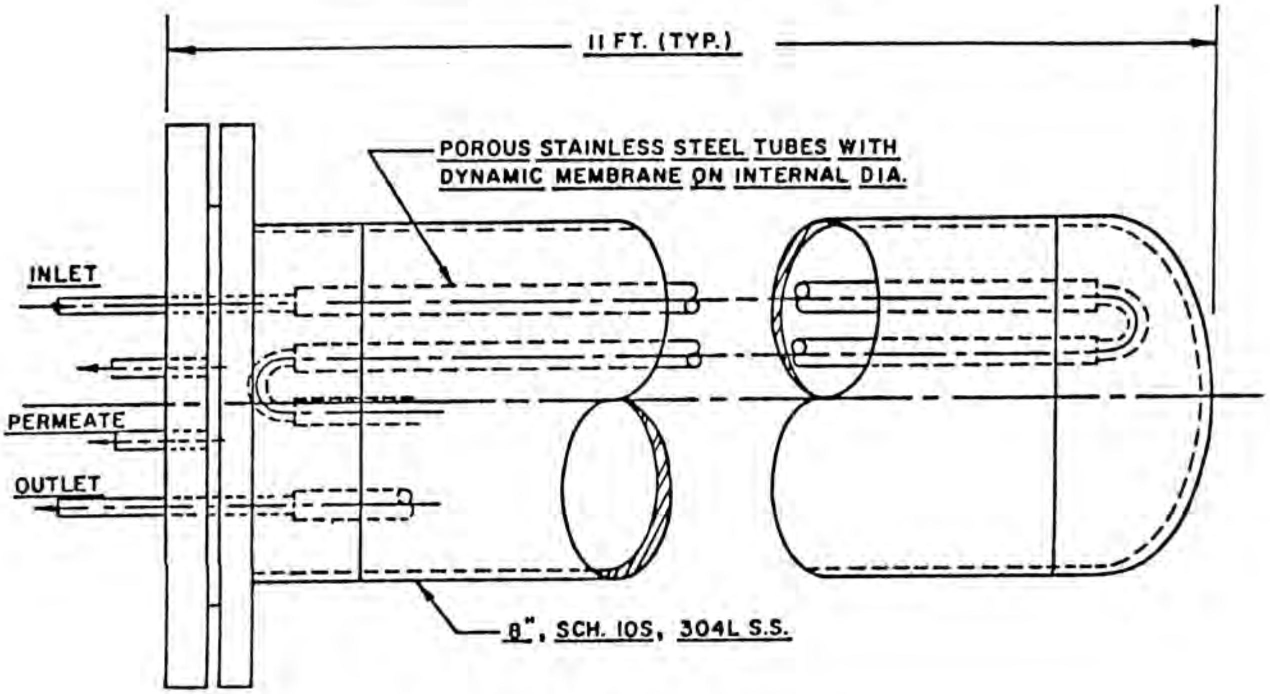

Fig. 2. Typical Recovery System Module

unit processes of filtration and reverse osmosis into one unit process, hyperfiltration (HF).

An array of modules in parallel is termed a "stage," and a series of stages form a system which is usually designed for a 90% or better recovery. Recovery is defined as the permeate flow rate divided by the feed flow rate. A 90% recovery means that most of the solute molecules are concentrated in 10% of the original volume. Another term used in characterizing a HF system is "rejection." "System rejection" is the difference between the feed and permeate concentrations, divided by the feed concentration. It is a measure of the system's ability to concentrate the feed solids in the concentrate stream. The membrane does not reject 100% of all solute molecules. Different membrane materials are developed to give a higher rejection for the species of interest. Most systems employ membranes with 80 to 90% rejections depending on how many species are present in the solution and which ones are to be removed. HF membranes give better than 99% rejection of all suspended solids and colloids. Because of its good filtration ability and the fact that the membrane characteristics are alterable, HF is finding many applications in the nuclear industry.[2]

PLANT MODIFICATIONS

Plant modifications required for the backfit of the HF systems are divided into two primary categories: area preparation and process support equipment.

Area Preparation

The rooms selected for the HF system include a spare 1400 square foot filter storage room and the rooms previously used for the waste and auxiliary waste evaporator packages, all of which are located two stories below the spent fuel pool in the auxiliary building. The evaporator packages were disassembled and removed as was all excess process piping and electrical controls. Existing concrete and block walls that could not be utilized were also removed.

New walls are to be added for shielding purposes around the membrane servicing tank, the membrane service pump and the demineralizer vessels. A nine foot high shadow wall is also being added to parallel the hyperfilter valve galleries and sampling stations.

For installation and maintenance purposes, monorails are to be added over the HF module racks and the high pressure feed pump. Both monorails, by penetrating through knock-out block walls, will provide full access for equipment removal.

The air handling units for the equipment rooms are to be upgraded in order to handle the additional loads. The fire protection system for the filter storage room is also being improved.

Process Support Equipment

Several surplus equipment items were converted over for usage in support of the hyperfiltration radwaste treatment process. Three existing clean water hold-up tanks have been relocated and are now being used as the recycle tank and the concentrates receiving tanks. An existing centrifugal pump is to be used for the recycle feed pump. The booster pump for sluicing demineralizer resin has also been supplied by TVA from their excess equipment.

Utility services for the system required an additional booster pump for the demineralized water supply. Other utilities included cooling water, service air and power, all of which were readily available.

EQUIPMENT ARRANGEMENT

The HF System is laid out to facilitate maintenance on equipment such as pumps and the HF modules while minimizing the radiation exposure to the operators. The arrangement of the primary processing equipment is shown in Fig. 3 and Fig. 4.

High Pressure Feed System and HF Modules

The High Pressure Feed System consists of the in-line static mixer, pH probes, duplex strainers and the high pressure feed pump. All these items are efficiently arranged into an area which is not considered a high radiation area. A flush line is connected to the waste feed piping opposite each pH probe in order to flush the probe intermittently. The duplex strainer is located in the lower radiation zone since it is rated at 200 mesh and not expected to retain a significant amount of radioactive particulate. The high pressure feed pump is situated to allow easy replacement of the pump diaphragms in the event of a diaphragm rupture.

The hyperfiltation modules are located in racks (see Fig. 5) perpendicular to an existing wall. The racks are designed to facilitate removal of a single housing if it is required. Each housing can be isolated from the system by hand valves, drained, the unions disconnected and the housing lifted by a monorail to a remote location. The need for removing a housing should be very infrequent. However, the ability to do so is beneficial in the event of a HF tube failure or similar type of problem.

A new shield wall will be erected perpendicularly to the piping end of the HF module racks. On the opposite side of the wall from the racks, the control valve gallery will be mounted (see Fig. 6). The gallery also contains the sample valves and sample boxes. The hose connections for remembraning will be located underneath the sample boxes. By remotely locating these valves from the modules, the operator can perform operational duties such as membrane reapplication preparation and individual module sampling without entering the higher radiation area of the HF modules.

Membrane Services Subsystem

The membrane services subsystem consisting of the makeup water pump and ultrafilter, and the membrane services cooler, tank and pump is arranged for operator ease in performing the cleaning, flushing and remembraning functions. The reagents for cleaning, stripping and remembraning the HF modules are added manually to the tank. To facilitate this, an access platform is located next to the tank.

The membrane services pump and motor, mounted on a common baseplate, are located in its separate

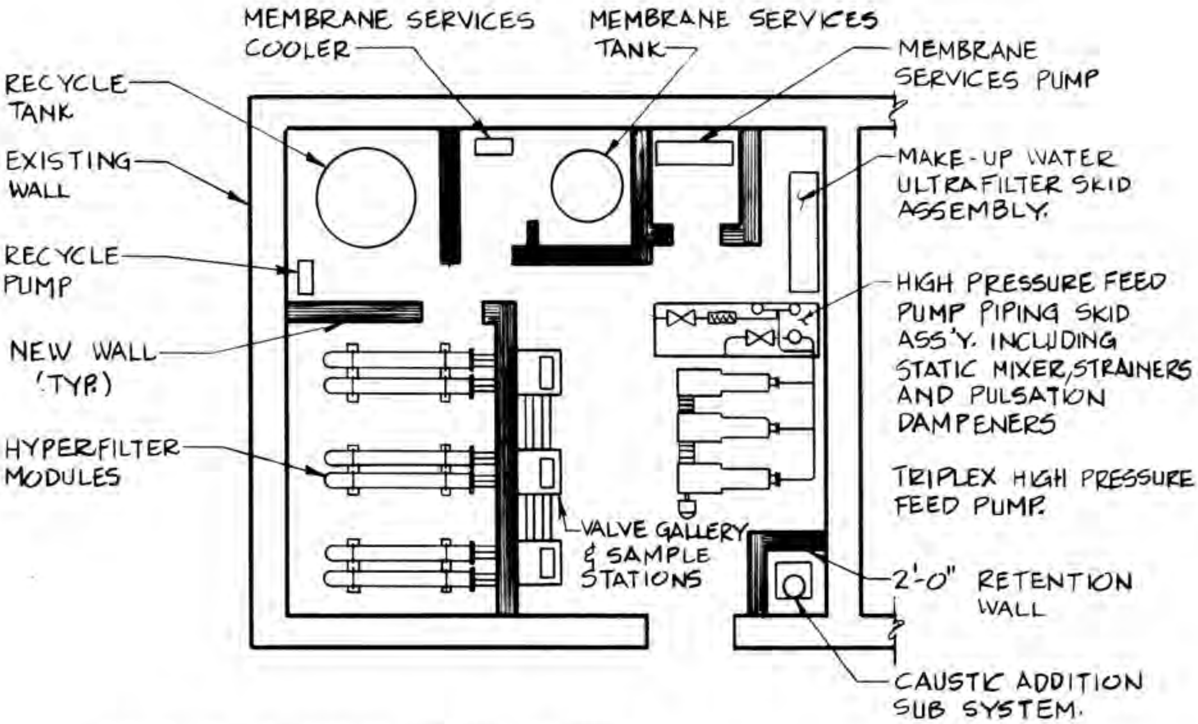

Fig. 3. Hyperfiltration Equipment Arrangement.

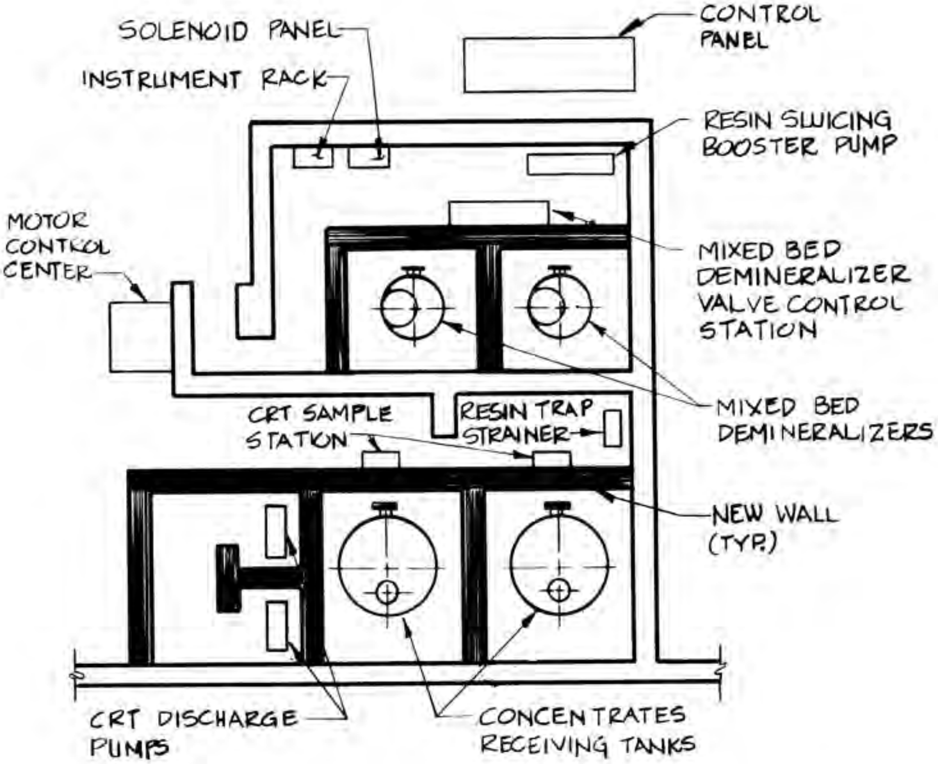

Fig. 4. Hyperfiltration Demineralizer Concentrates Receiving Tank.

Fig. 5. Rack Mounted HF Modules

shielded enclosure. The makeup water pump and the makeup water ultrafilter, required for the purification of demineralized water, are located in a non-shielded area on a common skid with interconnecting piping.

Mixed Bed Demineralizer

The mixed bed demineralizers are located behind a shield wall and can only be accessed by a ladder (see Fig. 4). Because it is expected that the demineralizers will accumulate a considerable amount of radioactivity, access is limited. The only reason to be within the demineralizer shield walls is to inspect the vessels and then only when the spent resin has been sluiced out. The control valves for the demineralizers project through the shield wall and are located in a valve gallery.

Caustic Addition Subsystem

The caustic addition subsystem is totally skid mounted and includes the tank, metering pump, agitator, fill and discharge control valves, along with the flow and level controls. For ease of operator access it is located immediately inside the room and sets in a spill retention basin.

WASTE DESCRIPTION

Each of the TVA plants is a two-unit Westinghouse PWR. Sequoyah Nuclear Plant is rated at 1221 megawatts electric (MW^e) per unit and Watts Bar Nuclear Plant is rated at 1270 MW^e per unit.

The plant's liquid waste storage system consists of a floor drain system for liquids low in tritium content and a tritiated drain system for collecting liquids relatively high in tritium content. The chemical characterization of the drain wastes is shown in Table I.

Fig. 6. Connections between Valve Station and HF Modules

TABLE I

Liquid Drain Radwaste Feed

	Approximate Normal Values
Conductivity	150 µmhos
Boron	500 ppm
Chloride	1.0 pm
Fluoride	0.5 ppm
Silica	1.0 ppm
pH	4 - 9
Total Suspended Solids	50 ppm
PO_4	2 ppm
Na	10 ppm
Li	2 ppm
Oil and Grease	5 ppm
Gross Beta Gamma Activity (52 isotopes)	10^{-2} µCi/ml
Temperature	80°F

Each plant also includes a condensate polishing demineralizer system capable of treating the total condensate flow and injected steam generator blowdown. The condensate passing through the condensate demineralizer services vessels will contain radioactivity in the event of a steam generator tube leak.

The condensate demineralizer regeneration waste water resulting from the condensate polishing demineralizer system resin regeneration process is the second type of waste feed to the hyperfiltration system. Its chemical characterization is shown in Table II.

TABLE II

Regeneration Waste Water Characteristics

pH	6.0 - 8.5
Conductivity	15,000 μmhos
SO_4	6,000 ppm
Cl^-	100 ppm
Na^+	
Total dissolved solids	10,000 ppm
Total suspended solids	400 ppm
Fe	50 ppm
Mg	15 ppm
Ca	25 ppm
Silica	10 ppm
Temperature	80^oF - 90^oF
Activity:	
Total Class 1	0.0 mCi/gallon
Total Class 2	7.5 mCi/gallon
Total Class 3	5.0×10^2 mCi/gallon
Total Class 4	3.6×10^2 mCi/gallon
Total Class 5	2.9×10^1 mCi/gallon
Total Class 6	9.9×10^2 mCi/gallon
Total all Classes	1.9×10^3 mCi/gallon

Waste Processing

When processing either floor drain waste, tritiated drain waste or recycled permeate, the system operates at approximately 30 gpm. Feed from the supplying tank is pumped to the HF system. Based on the feed rate to the system and the desire to increase boron rejection by the membrane, caustic is metered into the feed line in order to increase the pH. An increased pH improves the HF membrane's ability to reject boron thus more of the boron remains in the concentrate stream, ultimately being solidified with other rejected species. If the feed pH is not adjusted, more boron will pass through the membrane with the permeate and can be recovered by the boron recovery system.

When processing condensate demineralizer regeneration waste, the system operates up to a 90 gpm feed rate and pH adjustment is not required.

Both waste feed types are pumped through a 200 mesh duplex strainer which has been sized to remove large particulate that could damage the feed pump. To replace strainer bags, three-way inlet and outlet valves allow isolation of the dirty strainer without interrupting system operation.

After the duplex strainer, the triplex high-pressure feed pump (see Fig. 7) boosts the pressure to as high as 1440 psig. A back pressure control valve reduces the pressure to that required for system operation. This higher pressure is to optimize the dampening of the pump pulsations. The feed is then supplied to the first stage of the HF modules. A pressure relief valve on the discharge line prevents over pressurization of the feed to the HF modules. When operating at 90 gpm, the modules are staged in the 9-5-2-1 configuration. The feed flows to the first nine modules in parallel, and the concentrate from the first stage flows through the concentrate header to the second stage as the feed. In the second stage, the feed enters the five modules in parallel. The concentrate from Stage 2 then becomes the feed for Stage 3. The feed for each subsequent stage is the concentrate from the preceding one.

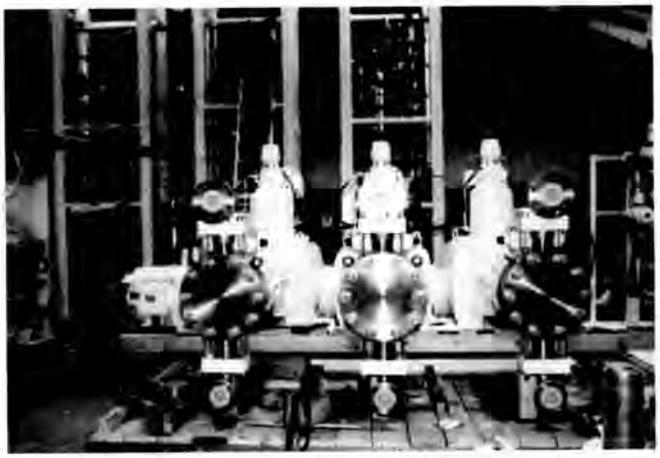

Fig. 7. High Pressure Feed Pump - Front
Valve Gallery and Sample Station - Rear

For processing the drain waste on the recycled permeate the HF modules are changed to the 6-4-3-2-1-1 staging configuration, as shown in Figure 8. The staging change is accomplished when the waste feed source is chosen with the "Feed Select" switch at the control panel. This switch will automatically align the valves in the two concentrate headers (ladder valves) for the correct staging.

The permeate from each module in the system is withdrawn in parallel. The conductivity is then measured and, based upon the range it falls within, the permeate is automatically routed to one of three locations: (1) through the demineralizer bypass to the storage tanks; (2) to the mixed bed demineralizers for polishing; or (3) to the recycle tank for reprocessing through the HF system.

The mixed bed demineralizers, although normally operated in series, can each be operated alone or in parallel. When in series, the bed containing the least exhausted resin is the second in the series. When the resin in one bed is changed out, that bed becomes the second in line. The resin is replaced based on high differential pressure or high outlet conductivity. When replacement is necessary, the demineralizer resin sluicing booster pump supplies water to the demineralizer to sluice the spent resin to the spent resin storage tank. The fresh, non-regenerable, nuclear grade resin is loaded by gravity at the top of each demineralizer. Hard-piped connections are also provided to back-flush or air fluff the resin bed.

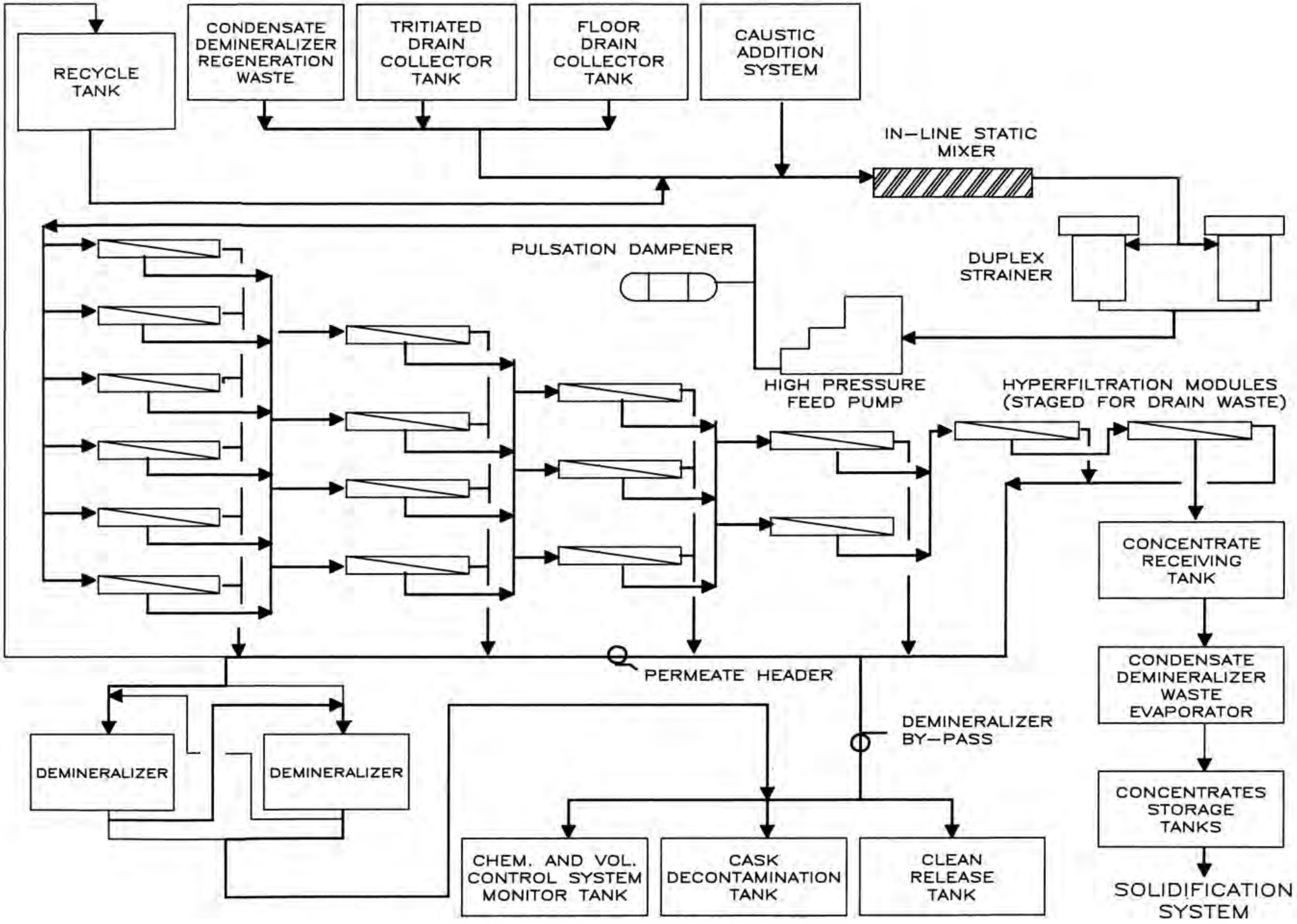

Fig. 8. Hyperfiltration Process Flow Diagram

The concentrate produced by the last stage of the HF modules is the concentrate for the entire system. If the system is operating at 95% recovery, the concentrate flow rate will be only 4.5 gpm of the initial 90 gpm feed or 1.5 gpm at the 30 gpm feed rate. The recovery is controlled by adjusting the high pressure feed pump to the desired feed rate while controlling the concentrates throttling valve at the downstream side of the modules. The concentrate is sent to one of two concentrates receiving tanks where it is held until processed by the condensate demineralizer waste evaporator prior to solidification.

Process Sampling

Samples of the various process streams can be taken at numerous locations throughout the radwaste processing system. The feed inlet, concentrate outlet and permeate outlet of each HF module can be sampled at one of the three sampling stations (see Fig. 9). During normal operation, these samples enable determination of individual module performance and thus the need for membrane cleaning or reapplication.

System Cleaning

Periodically it may be desirable to clean the system of modules simultaneously with a heated cleaning solution. Regular cleaning of the system membranes helps to maintain the performance of the system by removing impurities which could interfere wth the permeability or rejection characteristics of the membrane material.

The cleaning solution is mixed and heated in the membrane services tank. It usually contains surfactants to lift and bind any surface contaminants which are on the membrane.

The cleaning solution is introduced into the suction header of the high pressure feed pump which is set at 90 gpm. The solution is distributed to the modules in parallel and flows through the tubing in each module at a high velocity in order to scrub the membranes. The velocity is kept high by not throttling the concentrate valve. Because no significant pressure is built up in the tubes, no permeate is forced through the membrane. Therefore, nearly all of the feed is recovered in the concentrate header. Both the permeate and concentrate streams are recycled back to the membrane services tank.

Membrane Servicing

Each hyperfiltration module can be individually serviced in its installed location. The module to be isolated is removed from the process stream by closing the valves located on the feed inlet, permeate discharge and concentrate discharge lines. Membrane service hose assemblies then interconnect the HF module with the membrane service headers and the membrane service subsystem.

A chemical stripping solution is made up in the membrane services tank which is then circulated through the individual module until the membrane is completely dissolved. This is indicated by the reduced feed pressure of the solution to the module. As the membrane is dissolved, its permeability increases, thereby reducing the feed pressure required to flow through the membrane.

Once the membrane has been removed, the system is flushed and drained and a membrane solution is prepared in the tank. It is deposited on the tubes during pumped recirculation of the solution until the feed pressure increases to its required level. When this pressure is reached, the new membrane is

Fig. 9. Sampling Station

Fig. 10. HF System Control Panel

in place and the system is flushed, drained and then placed back into service.

System Controls

The control panel (Fig. 10) provides a graphic representation of the complete process and has provision for remote manual operation of any automatic function. The system provides automatic operation by using a programmable logic controller (PLC) which monitors the process by receiving input from instruments shown on the P&IDs. The PLC continually checks the process parameters and compares these readings against predetermined set points. If these set points are exceeded, the PLC will issue an alarm and take a course of action to correct the process deviation or to automatically bring the system off-stream in a safe and controlled manner.

PROJECT STATUS

The hyperfiltration system destined for Watts Bar is to be fully assembled and tested prior to its delivery in March 1986. In addition to complete functional testing, both the drain waste and the condensate demineralizer regeneration waste will be simulated, processed, and analyzed. Installation of the hyperfiltration system at Watts Bar is scheduled for 1986 with a start up target date of December 1986.

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