BWR Iron Control: Volume 2

Filters

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REPORT SUMMARY

Control of feedwater iron levels is essential to maintaining a sound strategy for minimizing dose rate buildup and activity transport in the BWR. Field data pertinent to iron control strategies were surveyed for U.S. BWRs. Recent results for plants operating with pleated filter septa in filters in series with deep bed polishers or with precoated pleated filter septa in filter demineralizers are compiled in this report.

BACKGROUND

Detrimental effects of corrosion products on BWR radiation buildup and activity transport occur at both low and high concentrations of iron. The 1996 revision of the BWR Water Chemistry Guidelines specifies an optimal feedwater iron level of 1.0 +/- 0.5 ppb. BWR iron control practices have recently undergone major changes in an attempt to approach the optimal iron target. Much development work on advanced filter technologies and on enhanced crud removal cation exchange resins was undertaken via both pilot studies and in-service trials. Data from the pilot studies were obtained at the PSE&G Hope Creek Nuclear Generating Station test skid; an interim report is published (EPRI-TR-102929). Data from the field trials are collated in the present report for plants currently operating or retrofitting for operation with pleated septa filters in series with deep bed polishers or with precoated pleated septa filter demineralizers. The data pertinent to deep beds was compiled in Volume 1.

OBJECTIVES

- To compile recent U. S. BWR operating history and available design data pertinent to iron control and condensate polishing field trials using pleated filter septa media
- To examine key trends in data from pilot-scale tests and full field trials of pleated filter septa media for BWR corrosion product control
- To identify major operational issues and their current field status that could impact design decisions in contemplated pleated filter septa applications
- To provide guidance on selecting relevant full-scale operating experience for projecting performance in those cases

APPROACH

A standardized survey was completed by plant chemistry and engineering staff at thirty-six U. S. BWRs. Key data on basic plant operation, materials of construction, condensate system design and operation, and field trials of novel filters and resins were compiled and analyzed. The data are current as of September 1996.

RESULTS

The survey indicated that the majority of U.S. BWR plants currently exceed the optimum iron range (1.0 +/- 0.5 ppb in feedwater) with the highest plants generally being those having only deep beds for condensate polishing. High efficiency condensate filters were found to be the singular practical means of consistently achieving the lower feedwater iron level, though operation substantially below 0.5 ppb was common. Pilot studies at the Hope Creek test skid identified fiber matrix pleated filter septa media from three vendors with acceptable iron removal efficiency, mechanical integrity, run length, facility for efficient backwash, and apparent useful life. Full scale trials at thirteen domestic BWR units are underway, seven of which employ powdered resin precoats for ion exchange.

Iron removal in full-scale applications has been very good. In precoat applications, reductions in material purchase and disposal costs have also been realized. The maximum service time experience, however, is less than 18 months, making definitive assessments of ultimate useful septa life or precoat ion exchange performance imprudent. Speculating nonetheless, an estimate of ultimate useful life is one to two years, significantly less than first expected by users or suppliers.

EPRI PERSPECTIVE

Control of feedwater iron levels is essential to maintaining a sound strategy for minimizing dose rate buildup and activity transport in the BWR. It seems clear that most BWRs will continue to operate well above the currently agreed upon upper limit, 1.5 ppb. Cost justifications for solving this problem by either installation of filters (or by development of better crud removing resins and alternative resin cleaning schemes covered in Volume 1) are plant-specific. Typical operation with pleated filter septa may actually bring feedwater iron levels substantially below the 0.5 ppb suggested lower limit. Even though in-service experience times are still short, the full-scale applications to date suggest that continued monitoring of pleated filter septa operation and development of improvements leading to extension of useful life and better ion exchange performance (in precoat uses) are warranted.

ABSTRACT

The impetus for the use of pleated filter septa in Boiling Water Reactor (BWR) condensate filters is feedwater iron concentration reduction. Pleated filter septa were selected over other filtration devices on the basis of performance at the Hope Creek Nuclear Generating Station Test Stand, and economic considerations.

Pleated filter septa are currently used in one or more condensate filter vessels at thirteen U.S. BWR units. Powdered ion exchange precoats are used on the septa at seven of these units, where reductions in precoat material purchase and disposal costs have been realized in addition to reduced effluent iron concentrations.

A brief review of filtration fundamentals precedes a summary of Hope Creek Test Stand results with emphasis on recent testing of the filter septa types currently used in full-scale condensate applications. Full-scale operating experiences with pleated filter septa at ten BWR stations (13 units) are discussed, with operating performance data presented for septa at six of the ten stations. Recommendations addressing major unresolved issues concerning the use of pleated filter septa are presented, and a brief guide for the use of available full-scale operating experience with pleated filter septa is provided.

Ultimate useful life, normally limited by increasing backwash frequency requirements, is perhaps the major outstanding issue for pleated filter septa; it is a strong determinant of operating cost. Although the number of BWR units using pleated filter septa for condensate filtration represents about 36% of the domestic operating BWR units, the maximum longevity of service time at this writing is less than eighteen months. Therefore, standard trending methods could not be used to estimate ultimate useful lives for the various types of pleated filter septa. Furthermore, the current full-scale operating experiences do not encompass the more severe operating conditions anticipated for future condensate applications of pleated filter septa. Nonetheless, performances to date do at least allow some speculation that would suggest a useful life of about two years for septa in use at several sites, and possibly beyond three years for septa operating under favorable conditions.

In addition to ultimate useful lives, the performance of ion exchange precoats on pleated filter septa is an unresolved issue. First, available performance test data are limited. Second, the practical significance of the ionic leakage will be site specific,

depending primarily on cooling water concentrations and condenser tube integrities at each site.

Other unresolved issues are; effluent iron concentrations which are generally too low in relation to revised optimum feedwater chemistry guidelines (EPRI 1996 BWR Chemistry Guidelines), and backwash methods which may not be adequate for achieving the economically desirable 3 to 4 years useful lives for pleated filter septa under all anticipated operating conditions. Another issue is potentially shorter radwaste filter run lengths when processing the high iron concentration waste backwash waters from condensate filters after the longer run lengths provided by the pleated filter septa.

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INTRODUCTION

The use of pleated filter septa in Boiling Water Reactor (BWR) condensate filters evolved from the Electric Power Research Institute (EPRI) BWR Feedwater Iron Reduction Program. The impetus for the program were the 0.1 to 0.5 ppb feedwater iron limits stipulated in the GE Optimum Water Chemistry guidelines (1) to control radiation field buildup. Although recent evaluations of radiation data may indicate 0.5 to 1.5 ppb iron as an optimum feedwater iron range (2), the continued use of pleated filter septa for condensate filtration is expected.

Under the BWR Feedwater Iron Reduction Program, two paths were explored for reducing feedwater iron concentrations; non-precoat filters, and special iron removal cation ion exchange resins. Although the special resins, described in the companion Volume 1 of this report (3), were successful in achieving low effluent iron concentrations, they were determined to be sources of unacceptable sulfate levels and anion resin fouling (4). Volume 1 also reported field studies of resin cleaning improvements, but only 1.0 to 3.0 ppb feedwater iron was typically obtained. Therefore, high efficiency condensate filters currently are the singular practical means of consistently achieving the low feedwater iron levels, whether they be 0.1 to 0.5, or 0.5 to 1.5 ppb.

The use of filters to reduce feedwater iron concentrations is the subject of this Volume 2 of the BWR Iron Control report. After a brief Review of Filtration Fundamentals, a section on Pilot Plant Tests summarizes testing at the Hope Creek Test Stand and ion exchange performance tests at a filter septa vendor's laboratory. The sections; Full-Scale Applications, and Major Issues And Their Current Status contain the main focus of the report. These sections concern full-scale operating experiences and the major issues identified therefrom. The report concludes with a Guide To Use Of Full-Scale Operating Experience. This guide is directed at selecting the most appropriate full-scale operating experiences for projecting performance of pleated filter septa in contemplated future uses of the septa in BWR condensate filter applications.

Initial investigations of various types of filters were carried out on a specially constructed test stand at PSE&G's Hope Creek Nuclear Generating Station under an EPRI Tailored Collaboration (TC) program (Interim Report TR 102929). The various types of filters tested are listed on Table 1-1. Many of the filtration devices evaluated were eliminated from consideration for full-scale applications on the basis of performance or cost. Test performance data for the pleated filter septa types in full-scale operation are presented.

Table 1-1
Hope Creek Test Stand - Filter Devices Tested

TEST ID	SUPPLIER	FILTER TYPE	MEDIA MATERIAL	PARTICLE RETENTION (μ m)	FILTER AREA (ft^2)	FILTER LENGTH (in)	TEST FLUX (gpm/ft^2)
A	Toshiba	HFF	PE	0.1	143.2	39	0.08&0.1
B	Organo	HFF	PE	0.1	15.4	87	0.12&0.2
C	Kurita	Ult-F	PS	0.03	10.8	53	0.16
D	Koch	Micro-F	Nylon	0.1	35	21	0.04-0.12
E	Pall	FMF-C	PP	5	1.44	58	1.56
F	Graver	FMF-P	PES	1	24.5	70	0.47
H	Pall	FMF-P	PA	1.4	28	40	0.5
I	Graver	FMF-P	PES/PP	1	19.25	52.4	0.5
J	Memtec	PPMF	PS	0.5	55	49	0.18
K	Pall	FMF-P	PA	1.4	28	40	0.5
L	Graver	PPMF	PES/PP	0.6	24.5	50	0.5
M	Organo	HFF	PS	0.2	15.4		0.21
N	Toshiba	HFF	PE	0.1 - 0.2	53.8		0.16
O	U.S. Filter	CMF	Ceramic	1.4	2.1	33.5	0.5&1
P	Pall	FMF-P	Polyolefin	1	39	40	0.36
Q	3M	DDF		2	0.57	-	0.2
R	Graver	PPM-F	PES	0.5	27	50	0.44
S	Pall	PPM-F	Polyolefin		39	40	0.29
T	Memtec	FMF-P	PP	4	55	49	0.18

ABBREVIATIONS

Filter Types		Media Materials	
CMF	Ceramic membrane filter	PA	Polyaramid
DDF	Disposable disk filter	PE	Polyethylene
FMF-C	Cylindrical fiber matrix filter	PES	Polyester
FMF-P	Pleated fiber matrix filter	PP	Polypropylen e
HFF	Hollow fiber filter	PS	Polysulfone
Micro-F	Micro filter		
Ult-F	Ultra filter		
PPMF	Porous pleated membrane filter		

Based on test stand results, pleated filter septa were selected for full-scale trials at a number of BWR stations. At several of these stations the use of pleated filters has been extended to all or most of the stations filters. BWR units that recently added or are in the process of adding filter vessels to their condensate polishing system have all selected pleated filter septa. BWR units with current or planned full-scale condensate applications as of September 1996 are listed in Table 1-2. Quantitative performance data were available from six of the BWR stations with full-scale applications, and the experience from these plants are discussed first in the Full-Scale Applications section, in alphabetical order. Experiences from plants for which only performance summaries were available are discussed next, again in alphabetical order.

Table 1-2
Full-Scale BWR Condensate Applications of Pleated Filter Septa - BWR Site Information

UNIT	TUBESHEET	PRECOAT	CDI IRON (ppb)	FWPD	REHEAT	D.O (ppb)	CDI TEMP. (°F)	BW METHOD
NON-PRECOAT								
Brunswick 1	Bottom	NO	11	YES	YES	55	90 - 135	GRV MOD III
Brunswick 2	Bottom	NO	11	YES	YES	55	90 - 135	GRV MOD III
Limerick 1	Bottom	NO	14	NO	NO	35	115 - 135	Air Surge
Limerick 2	Bottom	NO	14	NO	NO	35	115 - 135	Air Surge
Perry	Top	NO	8-12	YES	YES	40	95 - 130	Air Bump
Clinton	Top	NO	15	NO	YES	30	90 - 110	Proprietary
Susquehanna 1	Top	NO	20-30	NO	NO	22	96 - 137	Air Bump
Susquehanna 2	Top	NO	20-30	NO	NO	33	98 - 138	Air Bump
Hope Creek	Top	NO	22	NO	NO	24	95 - 135	Not Selected
PRECOAT								
Quad Cities	Bottom	YES	14	NO	NO	46	60 - 140	Air Surge
Hatch 1	Bottom	YES	15	NO	YES	30	110 - 125	Water/Air
Monticello	Bottom	YES	15	NO	NO	40	100 - 135	Air Surge
Peach Bottom 2	Bottom	YES	15	NO	NO	35	80 - 120	Air Surge
Peach Bottom 3	Bottom	YES	15	NO	NO	35	80 - 120	Air Surge

Table 1-2
Full-Scale BWR Condensate Applications of Pleated Filter Septa - BWR Site Information

Browns Ferry 2	Bottom	YES	17	NO	NO	35	80 -130	Air Surge
Duane Arnold	Top	YES	12.5	NO	YES	35	90 - 135	Air Bump

Thus far, the pleated filter septa provided for the full-scale applications have been supplied by either Graver Chemical (Graver), Memtec America (Memtec) or the Pall Corporation (Pall). Descriptions of the septa used at each full-scale application site are given in Table 1-3.

Table 1-3
Full-Scale BWR Condensate Applications of Pleated Filter Septa - Septa Information

UNIT	INITIAL USE	SUPPLIER	MEDIA MATERIAL	PLEAT TYPE	PARTICLE RATING (µm)	NOMINAL		SEPTA PER VESSEL	PLEATED AREA/ SEPTUM (Sq ft)	AVG FLOW PER VESSEL (gpm)	AVG FLUX (gpm/ft^2)
						O.D. (in.)	LENGTH (in)				
Browns Ferry 2	April 1996	Memtec	Polypropylene	Upright	2	2.5	60	302	50	3150	0.209
Brunswick 1	August 1994	Graver	Polyester	Upright	0.6	2.5	70	420	26	4800-5000	0.44-0.46
Brunswick 2	January 1995	Graver	Polyester	Upright	0.6	2.5	70	420	26	4800-5000	0.44-0.46
Clinton	July 1995	Pall	Polyaramid	Fold-Over	1.4	2.5	60	233	42	2400-2900	0.25-0.30
Clinton	December 1995	Graver	Polyester	Upright	1.0	2.5	50	253	19	2400-2900	0.50-0.60
Clinton	September 1995	Memtec	Polsulfone	Upright	0.5	2.5	50	299	55	2400-2900	0.15-0.18
Duane Arnold	March 1995	Pall	Polyaramid	Fold-Over	1.4	2	58	336	20.7	2850	0.41

Table 1-3
Full-Scale BWR Condensate Applications of Pleated Filter Septa - Septa Information

Hatch 1	January 1995	Pall	Polyaramid	Fold-Over	1.4	2	80	302	28.6	3400	0.39
Hope Creek	Bid Evaluation Stage										
Limerick 1	October 1994	Pall	Polyaramid	Fold-Over	1.4	2.5	70	240	50	3857	0.32
Limerick 1	December 1995	Pall	Polyolefin	Fold-Over	1	2.5	70	240	68	3857	0.24
Limerick 2	May 1995	Pall	Polyaramid	Fold-Over	1.4	2.5	70	240	50	3857	0.32
Limerick 2	June 1996	Pall	Polyolefin	Fold-Over	1	2.5	70	240	68	3857	0.24
Limerick 2	June 1996	Pall	Polypropylene	Upright	10	2.5	70	240	26	3857	0.62
Monticello	February 1996	Memtec	Polypropylene	Upright	4	2.5	60	302	50	2750	0.18
Peach Bottom 2	April 1996	Memtec	Polypropylene	Upright	10	2.5	70	302	65	2880	0.15
Peach Bottom 3	May 1995	Memtec	Polypropylene	Upright	4	2.5	70	302	65	2880	0.15
Peach Bottom 3	May 1995	Memtec	Polypropylene	Upright	2	2.5	70	302	65	2880	0.15
Peach Bottom 3	March 1996	Memtec	Polypropylene	Upright	10	2.5	70	302	65	2880	0.15
Perry	August 1991	Graver	Polyester	Upright	0.6	2.5	49	294	18	2786	0.53
Perry	May 1995	Memtec	Polypropylene	Upright	4	2.5	50	522	55	2786	0.10
Perry	May 1995	Memtec	Polypropylene	Upright	2	2.5	50	522	55	2786	0.10
Quad Cities 2	June 1995	Pall	Polyaramid	Fold-Over	1.4	2	60	302	21	2600	0.41
Quad Cities 2	January 1996	Memtec	Polypropylene	Upright	4	2.5	60	302	60	2600	0.14
Susquehanna 1	DESIGN	Memtec	Polypropylene	Upright	4	2.5	50	507	55	4833	0.17
Susquehanna 2	DESIGN	Memtec	Polypropylene	Upright	4	2.5	50	507	55	4833	0.17

There are currently two basic types of pleat configuration for pleated filter septa being used in full scale applications. One termed a “fold-over” pleat design as shown in Figures 1-1, and the other termed an “upright” pleat shown in Figures 1-2. For BWR condensate filter applications, only Pall has utilized the “fold-over” configuration; Graver and Memtec have employed only the “upright” configuration. In at least one full-scale trial, Pall has supplied “upright” pleat design septa.

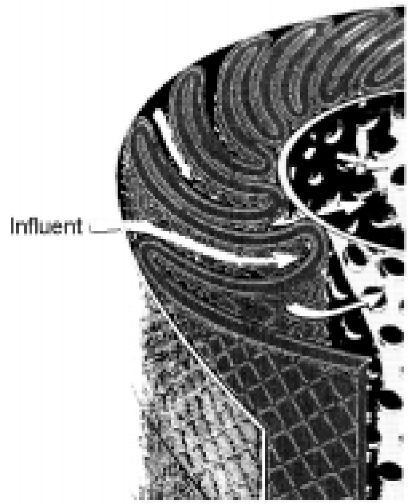

Figure 1-1 "Fold-Over" Pleat Configuration

Figure 1-2 "Upright" Pleat Configuration

Drainage and/or support layers are used on both sides of the pleated filter media. The layers support the filter media and facilitate flow between adjacent pleats on both the influent and effluent sides. The physical properties of the filter media may dictate the type of drainage and/or support layers that may be used.

In both configuration types, the pleated filter media is contained within a cylinder defined by an open molded or woven wire cloth outer surface, often called “the cage.”

In the "fold-over" pleat design, a woven wire mesh capable of retaining precoat material has been incorporated into the cage for septa used with precoats. The outer coverings for the Graver and Memtec "upright" pleat configuration septa are generally molded plastic cages with rectangular openings. Septa are available in various lengths, generally in nominal 10 inch increments. Graver and Memtec have used nominal 2.5 inch diameter septa for BWR condensate applications; Pall has used both 2 and 2.5 inch nominal diameter septa.

Influent enters each septum radially from the outside cylinder wall. The influent flows through the filter media to an inner core. The filtrate flows from the cores through tubesheet passageways into the effluent plenum. Tubesheets may be located at either the top or bottom of the filter vessel. Pleated filter septa have been retrofitted to both top and bottom tubesheet vessels.

Pleated filter septa have demonstrated excellent iron removal capabilities, and initial run lengths longer than achievable with precoated cylindrical non-pleated filter septa heretofore used for condensate polishing. These significant benefits presumably result from the lower particle retention rating filter media used in the pleated filter septa and their greater filtration surface area. However, there has been variability in useful lives (declining run lengths) for septa in full-scale applications.

Although originally intended for non-precoat use, the pleated filter septa are being used in precoat and non-precoat full-scale applications. Non-precoat use is limited to stations where the condensate filters are followed by deep bed condensate demineralizers. At these stations, the pleated filters not only provide low feedwater iron concentrations, they also offer the potential of allowing the demineralizers to operate for a full fuel cycle without resin cleaning operations. At plants without deep bed condensate demineralizers, the pleated filter septa retrofitted to existing condensate filter/demineralizers (CF/D) must be operated to limit ingress of soluble solids to the reactor.

2

REVIEW OF FILTRATION FUNDAMENTALS

Introduction

There are numerous literature sources on the theory and practical aspects of filtration. Five of these sources provided the basis for this review (5-9). A Glossary of Filtration Terms, developed from a listing in a Nuclepore Corporation booklet (10), is provided in Appendix A.

Filtration is defined as the separation of a fluid/solids mixture by passing the fluid through a porous barrier which retains all or most of the solid particles in the mixture. Depth and Surface filtration are generally considered as the two basic mechanisms of the process. Depth filtration occurs when solid particles are trapped within the pores or body of the filter media. Surface or cake filtration involves the formation of a filter cake of increasing thickness on the surface of the filter media. The cake may be either rigid or compressible.

In both the Depth and Surface mechanisms, the filtration volumetric rate is a function of the differential pressure across the filter and the flow resistance imposed by the filter media and the filter cake. In both cases, the flow resistance changes as filtration proceeds. However, the causes and rates of flow resistance change differ for the two mechanisms. In many filtration applications both mechanisms may be encountered, one may be predominant in early stages and the other in later stages.

With Surface filtration, the cake represents the majority of the system pressure drop, and the pressure drop increases as solids accumulate on the filter media surface. The rate of pressure drop increase is a function of the available filtration area and the influent suspended solids properties and concentration. In Surface filtration, when the cake is incompressible the specific cake resistance is proportional to the cake thickness and independent of pressure drop and of location within the cake. However, filter cakes often encountered in industry consist of loose assemblies of very small particles which are compressible and seek minimum packed volumes as pressure drop across the cake increases.

In depth filtration, the pore openings of the filter media are much larger than the particles to be removed. The particles are trapped by mechanical entrapment (particles bridge within the pores) and/or by surface forces between the particle and filter media surfaces. An example of surface forces is the electrostatic attraction between particles and filtration media of opposite surface charges. Positive and negative surface charge filter media and filter aids are commercially available. The enhanced filtration capability of ion exchange resins is generally attributed to the positive and negative charges of anion and cation resins respectively.

Although in Depth filtration the entrapped particles reduce the effective diameter of the flow channels, they do not completely block the channels. The rate of flow resistance increase is a function of available filter media pore volume and the influent solids specific volume and gravimetric concentration, and flow rate. The changes in flow resistance during Depth filtration and Surface filtration with a compressible cake are similar in that both involve decreasing void volumes. Since the Reynolds number for flow through porous beds is a function of the beds void fraction, flow may change from laminar to turbulent during the course of a filter cycle. That is, the relationship between pressure drop and flow may change from linear to a power function.

Filter aids may be used as precoats or body feeds to achieve or simulate Depth filtration. As precoats, the materials are applied to the filter media surface before the start of filtration. When used as body feed, the materials are injected into the influent during all or part of the filtration cycle. Powdered ion exchange resins have been used most frequently as precoats as opposed to body feeds in condensate filtration applications. In these applications they serve to remove soluble and insoluble solids.

Theory

Flow of water through a porous layer may be represented by *Darcy's equation*:

(1) $$Q = KA\ \Delta h/x$$

where Q = volumetric flow rate, m^3/sec,

K = constant = hydraulic conductivity, m/sec,

A = area, m^2,

Δh = hydraulic head = $\Delta z + \Delta p/(\rho g)$, m,

p = pressure, $kg/(m.\ sec^2)$ or Newton/ m^2 ,

ρ= density of liquid, kg/m^3, and

x = thickness, m,

Δz = change in elevation = 0.

The hydraulic conductivity, K, depends on the fluid properties and on the pore structure of the media, and is temperature dependent. Thus,

(2) $K = k\,\rho g/\mu$,

where k = intrinsic permeability of the media, m^2,

g = acceleration due to gravity, m/sec^2, and

μ = viscosity of liquid, kg/m-sec.

In differential form, Darcy's equation is:

(3) $Q/A = u = -k/\mu\, dp/dx$,

where u = superficial velocity normal to the filter media surface, m/sec

The minus sign in Equation 3 results from the fact that the pressure differential is negative. For incompressible cakes, the permeability may be determined by measuring flow rates at several pressure drops and plotting Q/A vs. Δp. The slope of the line equals the fluid conductivity K, from which permeability may be calculated.

Because the hydraulic resistances of the cake and of the filter media change with time, the variable rate of filtration may be expressed as:

(4) $u = (1/A)\, dV/dt$,

where t = time of filtration, sec and

V = volume of filtrate, m^3.

Assuming laminar flow through the filter channels, the basic differential equation of filtration is:

(5) $u = (1/A)\, dV/dt = \Delta p/[\mu(R_c + R_f)]$,

where Δp = pressure drop, $Newton/m^2$,

R_c = filter cake resistance, 1/m, and

R_f = initial filter resistance, 1/m.

The resistance of the filter media, R_f, may be assumed to be a constant. In reality, blinding of the filter media will increase resistance, but in practice the resistance of the media will be significantly lower than that of the inlet and outlet piping and fittings.

Assuming uniformity and an incompressible cake, the resistance of the filter cake is proportional to its thickness, which is related to the filtrate volume and solids loading:

(6) $h_c = (V/A)(C_0)$

where C_0 = (volume of solids)/(volume of filtrate).

The cake resistance may therefore be represented as:

(7) $R_c = r_0 C_0 V/A$,

where r_0 = specific volumetric cake resistance, m^{-2}.

Substituting equation 7 into equation 5, we get:

(8) $u = (1/A)\,dV/dt = \Delta p/[\mu(r_0 V C_0/A + R_f)]$.

For <u>compressible cakes</u>, the specific cake resistance is defined by:

(9) $r_0 = \alpha\ (\Delta p)^s$,

where α = specific cake resistance at $\Delta p = 0$, = 1/k, m^{-2} and

s = cake compressibility coefficient.

The cake compressibility coefficient, s, is 0 for incompressible cakes (e.g., sand) and 1 for gelatinous hydroxides. For most solids, s falls between 0.2 and 0.8.

During <u>constant-rate filtration</u>, the pressure increases with the increase in cake thickness. Equation 8 may be integrated:

(10) $\Delta p = \mu r_0 C_0 V^2/(A^2 t) + \mu R_f V/(At)$.

An interesting perspective on the effect of a compressible cake on the relationship between flow rate and p may be gained by examining equation 10 for the case where μR_f (initial filter resistance) is very small compared to the filter cake resistance. That is,

(11) $\Delta p = \mu r_0 C_0 V^2/(A^2 t)$.

By substituting the expression for r_0 from equation 9 in the above and rearranging one obtains:

(12) $(\Delta p)^{(1-s)} = \mu \, \alpha C_0 (V/(At))(V/A)$

Therefore, at s = 0.5

(13) $\Delta p \propto (V/(At))^2$, a relationship identical to that for turbulent flow.

There are several mechanisms by which depth filtration occurs within filter media pores. In the mechanism known as direct sieving, the particles being removed completely plug the entrances to the pore of the filter media and the rate of plugging is constant with time. This mechanism is rarely encountered. Standard blocking occurs when particles partially block the pores, resulting in a gradual reduction in pore size. This mechanism is the one most frequently encountered. Depth filtration with standard blocking of the filter media usually occurs prior to cake formation.

The following equation describes constant-rate Depth filtration with standard blocking:

(14) $Ct = (1/\Delta p_{in})^{1/2} - (1/\Delta p)^{1/2}$ where $C = [C_0/(\pi \, l_p)](WB'/N_p)^{1/2}$

and $B' = \pi/(8\mu l_p)$,

l_p = average pore length, m,

Δp_{in} = pressure drop at start of filtration, kg/sec^2-m

W = filtration rate, m^3/sec, and

N_p = number of pores.

The filtration time corresponding to total pore blockage may be estimated from:

(15) $t = (1/C)\,(1/\Delta p_{in})^{1/2}$.

Applying Theory To Condensate Filtration

Constant-rate filtration is usually employed in condensate filtration. Individual vessel effluent valves are used to control flow, and in many instances to equally distribute the flow among parallel vessels.

In all filtration mechanisms Δp and its rate of change are functions of the filter media characteristics, properties of the fluid, and concentration and nature of the suspended solids. Therefore, it is essential that these factors be considered when evaluating relative performance of different filter septa.

The various pleated filter septa used in condensate filtration differ in many ways. There are differences in materials of construction, pleat configuration and spacing, filtration area, particle retention rating, and bubble point (minimum pressure at which air can displace liquid from the capillary pores of filter media). In addition to being an indication of particle retention rating, bubble point is an inherent property of the filter media that may effect the performance of the filtration system beyond particle retention. Wetted high bubble point filter media will impede the flow of air through the media. This characteristic may have significant effects on the displacement of air from the filter vessel during filling or on the removal of water from septa cores during draining.

For a fixed filter septum length, the septum with the higher available filtration area will have the higher initial solids holding capacity and lower Δp at a given solids loading. The large surface areas provided by pleated filter septa reduce the thickness of the cake and velocity through the cake, thereby minimizing the rate of pressure drop increase.

In condensate filtration, Depth filtration with standard pore blocking is likely encountered at the start of filtration cycles during cake formation. The amplitude and rate of Δp increase during this stage will depend on liquid and solids properties, the number of pores, the sizes of pore entrances, and the volume of the pores.

Surface filtration occurs in condensate filtration from the inception of filter cake formation. The cakes formed, and possibly the filter media, are compressible. Therefore, it is essential that cake compressibility be considered when setting terminal Δp limits, and when assessing relative Δp rise rates for different filter septa.

In some condensate filtration applications, the flow through compressed cakes is temporarily decreased to allow the cake to expand and thus lower its specific resistance to flow. When the flow rate is returned to its former value, the lower resistance continues for a short period of time, thereby extending the filtration cycle time to reach a specified terminal ΔP. A potential disadvantage of this practice is cake cracking which may have adverse effects on effluent quality and filter media plugging.

Relationships of Δp rise rates to flow rates and solids loading depend on the initial flow resistance and solids holding capacity of the filter media. In condensate filtration, the pleated filter septa must be reusable for multiple filtration cycles, with intervening cleaning, for their use to be economically viable. During each cycle solids are entrapped on and within the filter media increasing its resistance to flow and decreasing its remaining solids holding capacity. To maximize reuse, i.e., extend useful life, the effectiveness of the intervening cleaning method is of paramount importance.

The removal of entrapped solids from filter septa requires the application of forces that are higher than the force holding the solids within the filter septa. Holding forces are a function of filter media characteristics and septa construction, and the maximum Δp during the filtration cycle. In the fluid backwash methods used in condensate filtration, the removal force is provided by the frictional drag of the backwash fluid flowing around the solids, and varies directly with the velocity of the backwash fluid. Backwash velocities are determined by driving and resisting forces. Driving force is the backwash delivery pressure minus friction loss in delivery piping. Resisting forces are those imposed by the filter septa, septa attachments, vessel nozzles and backwash exit piping.

From the foregoing, it is clear that filter septa, backwash method, vessel and piping must be perceived as a single multi component system. That is, the performance of any system component depends on the other components.

Backwash Methods

Cleaning methods must be compatible with the filter vessel design and filter septa construction. There are two alternative vessel designs used in condensate filtration; top or bottom tubesheet designs. The two designs dictate different approaches to backwashing.

The backwash methods used with full-scale applications of pleated filter septa have been either steady state or non-steady state. Steady state backwash methods have been used only with bottom tubesheet filter vessels. Non-steady state methods have been used with top and bottom tubesheet vessels. Both types of backwash methods employ multiple backwash steps during a backwash cycle.

In the steady state method, simultaneous and nearly constant reverse flows of air and water are forced through the filter septa. The reverse flow rates are in the range of 0.09 to 0.44 gpm of water and 0.4 to 0.7 SCFM of air per 10 inches of septum length. Backwash cycles have initial slow backwashing steps using the lower water rate and the higher air rate. The slow steps are followed by fast backwash steps using the lower air rate and the higher water rate.

The Graver MOD III backwash is an example of a steady state method. During the initial drain of liquid from the filter vessel the reverse flows of water and air are 0.22 gpm and 0.65 SCFM per 10 inches of septum length respectively. Following the initial drain, reverse flows of 0.44 gpm of water and 0.65 SCFM of air per 10 inches of septum are used while the liquid level slowly rises in the filter vessel. When the liquid level reaches the top of the filter septa, the final drain is started with the reverse flows of water and air continued.

The non-steady state backwash method used on many bottom tubesheet filter vessels was introduced by Graver Water as the Air Surge method about twenty years ago. Benefits claimed for the non-steady state Air Surge method were improved septa cleaning and lower liquid waste volumes. The method is in use at many power plants, including nuclear power plants. In the Air Surge method water is displaced from the bottom plenum and through the filter septa by high pressure air from an air storage tank. Before each air surge delivery the filter chamber above the tubesheet is totally or partially liquid free. The maximum liquid velocity is determined by the starting air pressure and volume in the storage tank, the resistance of the air delivery piping, and the flow resistance of the passages through the tubesheet. The volume of liquid delivered per surge is approximately equal to the volume in the effluent plenum between the tubesheet and the bottom of tubes extending downward from each tubesheet hole.

Non-steady state backwash methods for top tubesheet vessels, including those used at nuclear power plants, also have been used for many years. The common feature of these methods is the means by which water is forced from the effluent plenum above the tubesheet and through the filter septa. The backwash sequence starts with a partial draining of liquid from the chamber above the tubesheet to a predetermined level; the chamber below the tubesheet remains liquid-filled. Air is introduced to the upper chamber to pressurize the vessel contents. The flow of liquid from the top chamber is initiated and achieved by a rapid opening of the drain valve in the drain line from the lower chamber. The maximum backwash liquid velocity achievable is determined by the starting pressure and volume of air in the upper chamber, the resistance to flow of the drain valve and line, the speed of drain valve opening, and the flow resistance of the passages through the tubesheet; the limiting resistance usually is that through the drain valve and line. The volume of liquid delivered through the filter septa per surge is equal to the liquid in the partially drained upper chamber before the surge. The liquid waste from each surge is equal to the volume of liquid from the partially drained upper chamber plus the full volume of the lower chamber.

In a non-steady state backwash method invented by the author (11) for top tubesheet vessels the lower chamber is liquid-free prior to the delivery of backwash water surges. The claimed advantages of this method are higher maximum backwash velocities and lower liquid waste volumes.

3

PILOT PLANT TESTS

Hope Creek Test Stand

Construction, use and results from the Hope Creek Test have been extensively reported (12-16). The test stand uses a Hope Creek Nuclear Generating Station condensate side stream, thus all filters are exposed to actual, rather than simulated, BWR insoluble solids. Each filter vessel contains a single filter septum or module.

All of the vessels for Fiber Matrix Filter (FMF) septa testing, except for the vessel used with Graver septa, were designed to simulate a top tubesheet design. However, the simulation was not exact. The top effluent plenum used in full-scale top tubesheet vessels was omitted; septa open ends were connected directly to the effluent/backwash pipe. This variation had little or no effect during filtration flows but, did effect simulations of backwash methods (14).

Filtration flux rates (gpm/ft^2) shown in Table 1-1, and varied run termination criteria and backwashed methods used during the testing of each filter device were set by mutual agreement with the supplier of each device. All devices were installed with the suppliers' guidance or instructions.

In a 1993 EPRI report (16) excellent iron removal was reported for both the Hollow Fiber Filter (HFF) and the FMF devices. The HFF devices had consistently achieved 99.5% or greater iron. It was noted that the HFF devices achieved these results over more than 500 days of operating at temperatures at 90^o to 135^{o}F. Successful operation at these temperatures resolved the concern that the HFF devices which are in wide use in Japan at lower temperatures may not have been suitable for the higher condensate temperatures frequently encountered in the United States.

Three of the four FMF devices (Filters E, F, H and I in Table 1-1) included in the report achieved iron removal of 95% or greater. The exception was Filter E which also demonstrated rapidly declining run lengths. Of the four filters, Filter E had the highest particle retention rating (5 µm) and was the only filter septum without a pleated filter media configuration. Filter E was replaced by Filter H from the same supplier.

By 1994 a number of filter devices had been eliminated from the testing program for various reasons, and run times for the remaining devices were sufficient to allow a preliminary assessment of test data to be presented at an EPRI Workshop (13). In addition to Filter E, Filter C had been eliminated from the test program because of rapidly decreasing run lengths. Filter D remained in the program with good performance but, was not included in the assessment because its commercial availability was not likely. Filter J was a recent addition to the program with insufficient data to assess.

The 1994 assessment encompassed Filters A, B, F, H and I. By this time all of the filter devices had accumulated more than one year of operating time, with the HFF devices having the longer times. In the HFF category, Filter A had 2.5 years and Filter B 2.2 years of operating time. The operating times for the FMF devices were 1.2, 1.2 and 1.6 years for Filters F, I and H respectively. The filters were assessed on the basis of iron removal and projected useful lives.

Iron removal by both HFF devices was greater than 99% throughout the testing period. Filter H maintained iron removal at 98% or greater for the first 1.4 years of its operating time. Iron removal by Filter F dropped below 98% after about 1 year of operation, Filter I after about 0.8 years. Sudden rises in effluent iron from Filters F and I were attributed to mechanical failures.

The criteria for useful life assessments of each filter were ability to maintain iron removal of 99% in the case of HFF devices and 98% for FMF devices, and 7 day run lengths with a 20 ppb insoluble iron influent while operating at the flux rate (gpm/ft^2) and to the terminating Δp values used during the test. The HFF devices Filters A and B were each operated at a low and high flux rate. A preliminary cost comparison of the filter devices being tested indicated that the cost of HFF devices would be an impediment to their use in BWR condensate systems in the United States. The higher flux rate operations were adopted in the later stages Filters A and B testing to obtain an early indication of the practicality of reducing the number of HFF modules required. Modules designed specifically for higher flux rates were tested later in the program.

Estimates of run length decline with continued use were based on the concept of increasing initial Δp and the rate of Δp rise both contributing to declining run lengths, as shown in Figure 3-1. Simple linear regressions were performed on the tabulations of data for both of these parameters to obtain their rates of change as a function of filter runs completed. Therefore, from starting values of initial Δp and the rate of Δp rise it was possible to estimate run lengths for successive filter runs.

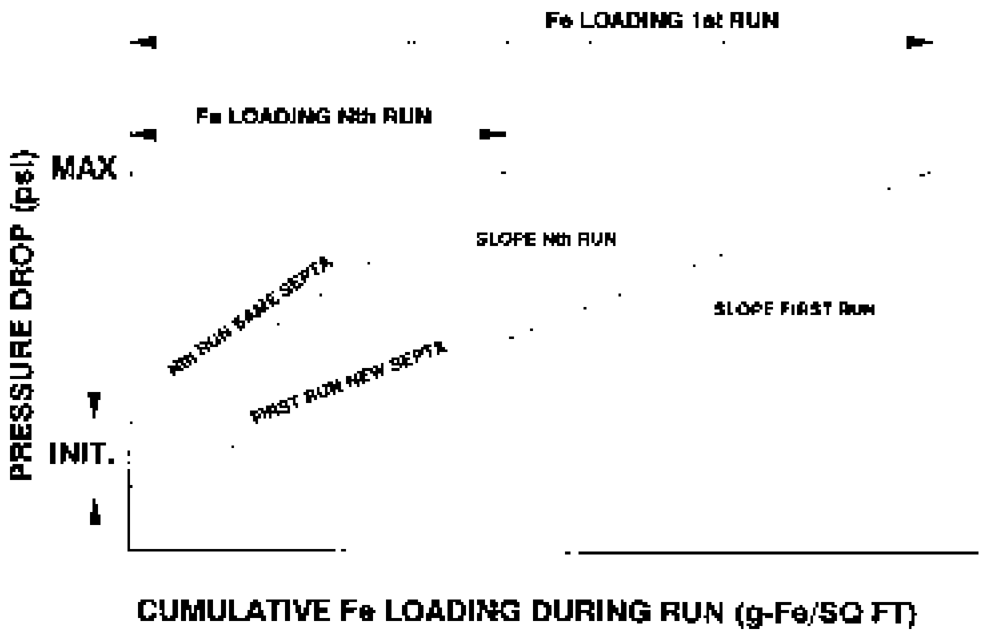

Figure 3-1 Influence of Initial dP and dP Rise Rate On Run Lengths

During the 572 days of Filter B operation at the original lower flux rate neither the initial Δp, the rate of Δp rise nor iron leakage increased indicating an infinite life based on the data available. Based on the 237 days at the higher flux, declining run lengths were projected to limit its useful life to about 1.5 years. Filter B was always operated with a thin iron oxide precoat, the only filter in the test program so operated.

Based on the performance of Filter A during its 758 days of operation at the lower flux rate its projected useful life was about 3.6 years to the minimum run length of 7 days. At the higher flux rate its projected useful life was about 2 years, again as limited by the minimum run length criterion.

The projected useful lives of Filters F and I were limited by < 98% iron removal to 1 and 0.8 years respectively. Projected useful lives based on the minimum run length criterion were 1.6 years for Filter F and 1 year for Filter I.

By 1996 filters in operation on the test skid were Filters M, N, O, R, S, and T. Filters M and N had replaced Filters B and A respectively, and were filters specifically designed for higher operating fluxes than the filters replaced. The particle retention rating of Filter M is 0.2μm as compared to 0.1μm for Filter B which it replaced. Likewise, the particle retention rating of Filter N is 0.1 to 0.2μm as opposed to 0.1μm for Filter A which it replaced. The same filter media material was used for Filters A and N, polyethylene, supplied by Toshiba. Organo changed the filter media material from polyethylene in Filter B to polysulfone for Filter M.

Filter O is a ceramic membrane filter. The filter is being tested for potential use as a high temperature heater drain filter, rather than as a condensate filter (15).

Filters R uses a porous pleated membrane filter media. Filters S and T use pleated fiber matrix filter media. These three filters are representative of filter septa currently being offered and used for BWR condensate filtration applications.

Run performance data for Filters M and N are given in Table 3-1. The total operating times for Filters M and N are 711 and 534 days respectively. As was the case with Filter B supplied by Organo, Filter M was intended to be used with a thin overlay of iron oxide. Run 1 through 8 did use these type precoats. However, thereafter the precoats were not used due to material unavailability. Iron removal by Filters M and N remained > 99.5%, as was the case with Filters B and A.

Table 3-1
Hope Creek Test Stand - Hollow Fiber Filters M and N Hydraulic Performance

Filter M (Japan Organo)						
Run No.	Run Length (days)	Avg Flow (gpm)	Initial dP (1) (psi)	Final dP (1) (psi)	Slope dP/day (psi/day)	Remarks
1	19	2.68	6.97	10.29	0.175	Crud Burst & Rx S/D
2	100	3.13	7.21	12.36	0.052	
3	38	3.06	8.67	10.70	0.053	Low Final dP
4	38	2.95	8.74	10.85	0.056	Low Final dP
5	59	3.17	9.07	12.76	0.063	
6	61	3.16	9.30	13.82	0.074	
7	36	3.01	10.01	14.20	0.116	Rx S/D
8	85	3.17	9.21	14.40	0.061	
9	9	2.68	10.96	12.60	0.182	No TOL & Rx S/D
10	63	3.19	9.23	13.25	0.064	No TOL

Table 3-1
Hope Creek Test Stand - Hollow Fiber Filters M and N Hydraulic Performance

11	54	2.92	10.85	12.15	0.024	No TOL
12	56	2.99	9.25	14.25	0.089	No TOL
13	42	3.16	10.72	14.53	0.091	No TOL
14	51	3.14	12.82	15.85	0.059	No TOL
Filter N (Toshiba)						
Run No.	Run Length (days)	Avg Flow (gpm)	Initial dP (1) (psi)	Final dP (1) (psi)	Slope dP/day (psi/day)	Remarks
1	34	8.15	4.65	5.46	0.024	
2	66	8.78	5.08	7.10	0.031	
3	60	8.76	6.00	7.76	0.029	
4	62	8.65	6.38	9.22	0.046	
5	60	8.78	7.15	9.52	0.040	
6	7	6.72	8.66	14.70	0.863	23.2 psi after Crud Burst
7	63	8.65	10.01	11.93	0.030	
8	58	8.07	10.76	16.16	0.093	
9	62	8.81	10.38	16.64	0.101	
10	28	8.88	11.56	14.37	0.100	
11	34	8.71	11.34	13.09	0.051	

NOTES

1. Normalized for temperature and flow.
2. Rx S/D = Reactor Shutdown
3. TOL = Thin Overlays

The behavior of Filter M's initial ΔP and ΔP rise/day (Slope) can be seen in Figure 3-2. The Initial ΔP and ΔP rise/day gyrations when the thin iron oxide precoats were not used are obvious. Discounting data affected by crud bursts, Initial ΔP increased from about 7 psi to a stable value of about 9 psi, and the ΔP rise/day rate increased from about 0.05 to 0.06 psi/day. Considering that the filter had about 1.2 years of operating time through Run 8 and nearly 2 years through Run 14, a useful life of about 4 years appears to be a reasonable estimate when operated at the test conditions (20 - 30 ppb influent iron at 0.21 gpm/ft^2) and with the thin iron oxide precoats.

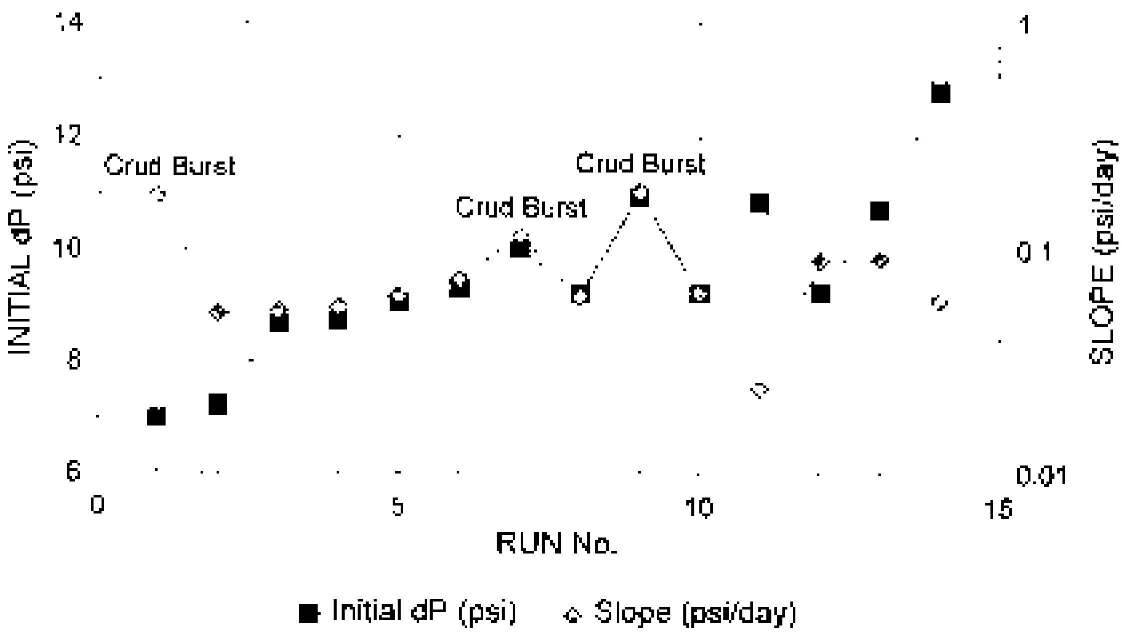

Figure 3-2 Hope Creek Test Stand - HFF "M"

Figure 3-3 shows the behavior of Initial ΔP and ΔP rise/day for Filter N. The steady rise in the Initial ΔP is the most disturbing observation on the behavior of this filter. From Run 1 to Run 8 the Initial ΔP increase from 4.6 to 10.8 psi, i.e., nearly 0.8 psi/run. The rate of increase after Run 8 was less but still significant at 0.2 psi/run. The total operating time of this filter through Run 11 was 1.5 years. If a maximum final ΔP of 15 psi is tolerable, an estimated useful life of about 3 years appears achievable for operations at the test conditions.

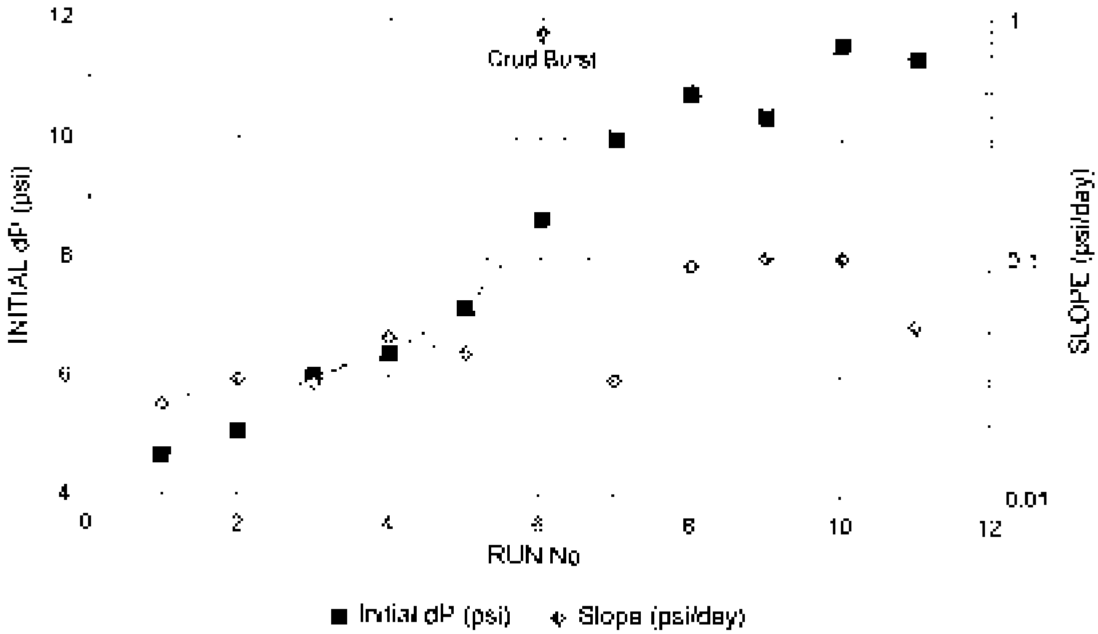

Figure 3-3 Hope Creek Test Stand - HFF "N"

Table 3-2 lists run performance data for Filters R, S and T. This data covers less than 5 months of operating time for each filter, thus projections of long term performance are not possible. The first runs of all filters were operated at lower flows and terminated at lower pressures than in subsequent runs. All filters achieved > 99% iron removal.

Table 3-2
Hope Creek Test Stand - Fiber Matrix Filters R, S and T Hydraulic Performance

Filter R (Graver)					
Run No.	Run Length (days)	Avg Flow (gpm)	Initial dP (2) (psi)	Final dP (2) (psi)	Avg dP/day (psi/day)
1	23	8.51	0.67	4.68	0.174
2	58	12.02	1.11	9.40	0.143
3	29	12.07	2.09	9.10	0.242
4 (1)	11	9.16	1.15	3.62	0.225
Filter S (Pall)					
Run No.	Run Length (days)	Avg Flow (gpm)	Initial dP (2) (psi)	Final dP (2) (psi)	Avg dP/day (psi/day)
1	23	7.51	0.43	4.31	0.169
2	52	11.58	1.49	6.23	0.091
3	34	10.15	1.43	6.83	0.159
4 (1)	12	11.46	1.29	3.20	0.159
Filter T (Memtec)					
Run No.	Run Length (days)	Avg Flow (gpm)	Initial dP (2) (psi)	Final dP (2) (psi)	Avg dP/day (psi/day)
1	12	7.42	0.02	1.50	0.123
2	65	10.05	0.75	4.00	0.050
3	29	10.15	0.90	3.98	0.106
4 (1)	11	9.65	0.61	3.51	0.264

NOTES

1. Run in progress.
2. Normalized for temperature and flow.

Figures 3-4, 3-5 and 3-6 are plots of normalized ΔP vs. Run Days for Filters R, S and T respectively. The numbers at the ends of the plots are run numbers. For all three filters the second runs showed the best performance, not only in run lengths but, more importantly in the average rate of ΔP rise/day.

Normalization consists of adjusting measured ΔP values to base conditions to compensate for variations in flow rate and temperature during a filtration cycle. The base conditions are normally the design values. For the Hope Creek test data (16), the base temperature was 110°F and the base flow was the target value peculiar to each filter device.

The relationship used for ΔP normalization is:

$$\Delta P \propto (\text{Flow Rate})^{n1} \times (\text{Viscosity})^{n2}$$

where,

$n1 = 1$ to 2

$n2 = 0$ to 1

For the Hope Creek Test data (16), the appropriate value for n1 and n2 were determined to be 1.2 and 1.0 respectively. The adjusted ΔP values do not include piping, and vessel entrance and exit losses.

The performance of Filter R shown on Figure 3-4 demonstrates repeatability with exception of Run 3. The third runs of all filters occurred during the same time period and all experienced unusually high average rates of ΔP rise/day. Note that the average flow of Filter R during Runs 1 and 4 was about 25% less than in Runs 2 and 3.

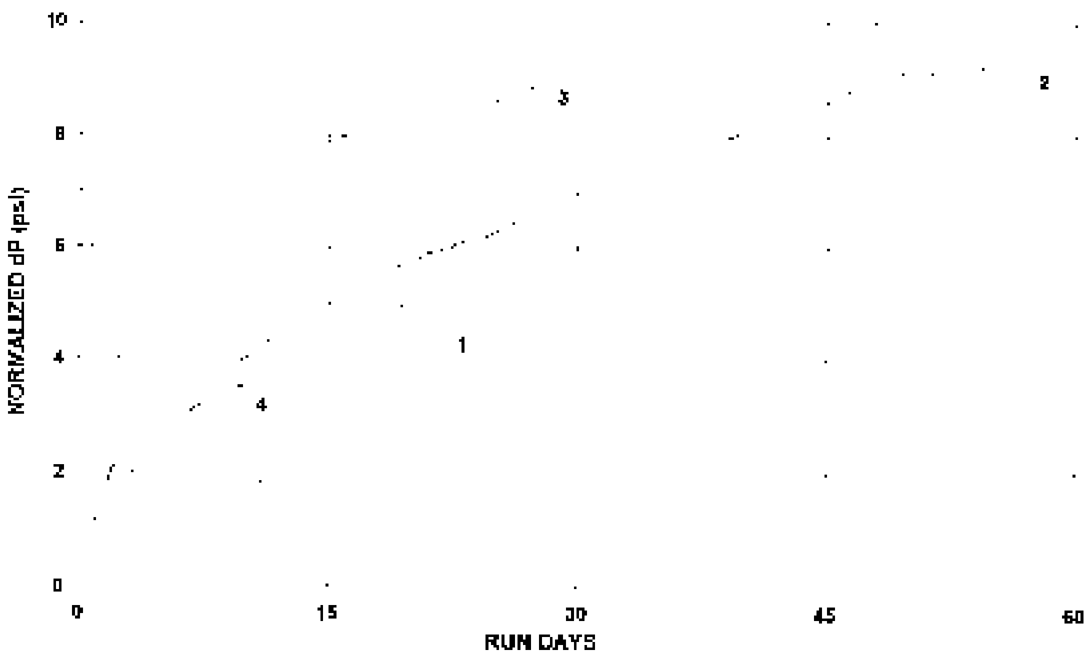

Figure 3-4 Hope Creek Test Stand - FMF "R" For Four Runs

The comparison of Runs 1 and 4 shown on Figure 3-5 for Filter S indicates no deterioration of performance over the albeit short test period to date. In this regards, note the average flow for Run 1 was about 7.5 gpm whereas the average flow during Run 4 was about 11.5 gpm.

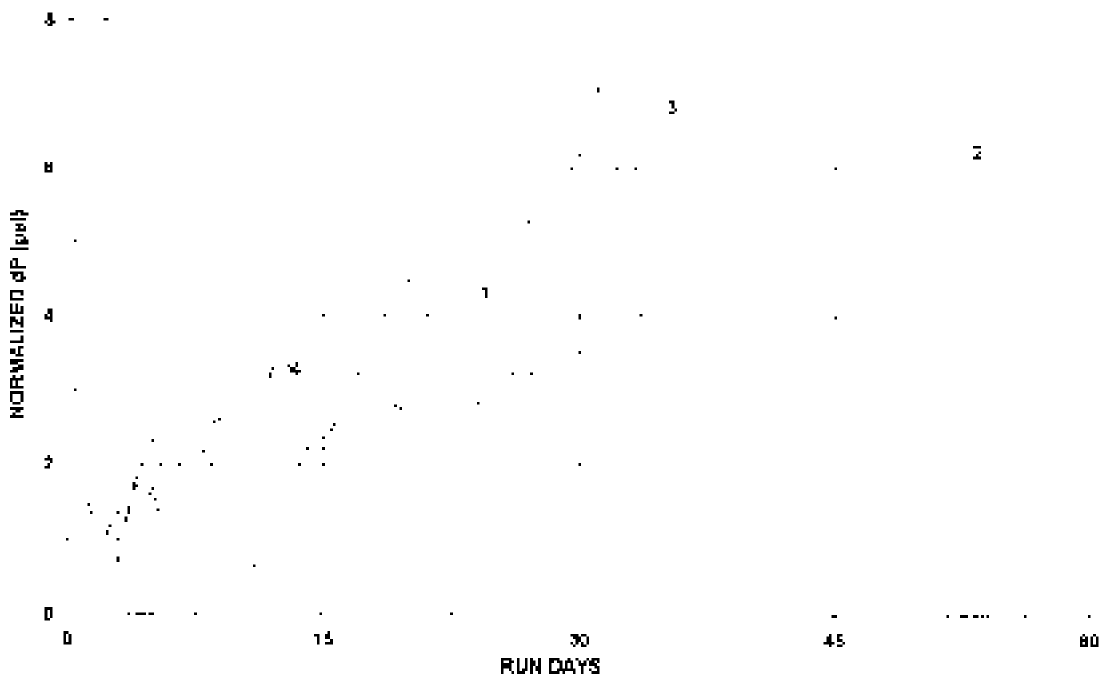

Figure 3-5 Hope Creek Test Stand - FMF "S" For Four Runs

The run to run performance of Filter T, as depicted on Figure 3-6 differs from that of the other filters. While the performance of Run 4 was superior to Run 3 for Filters R and S, for Filter T the performance during Run 4 was inferior to that of Run 3. This anomaly is probably due to a change in the backwash method following Run 2. The change was made in an attempt to simulate a surge backwash method starting with an empty filter chamber. As explained earlier, the “top tubesheet vessels” on the test skid have neither a top tubesheet nor a top effluent plenum from which backwash water is normally delivered. In addition the vessel system did not include automatic valves. Therefore, the backwash simulation required rapid operation of several manual valves to capture and deliver a specified volume of backwash water. With hindsight, the skid operator believes the three manual valves could not be operated rapidly enough. As a consequence it is probable that water drained away from the septum core and became mixed with air when the air delivery valve was opened before the surge could be initiated by opening the vessel vent and drain valves. The combined effect of two-phase flow and greater distance for the backwash water to travel would result in backwash water volume and velocity much lower than intended.

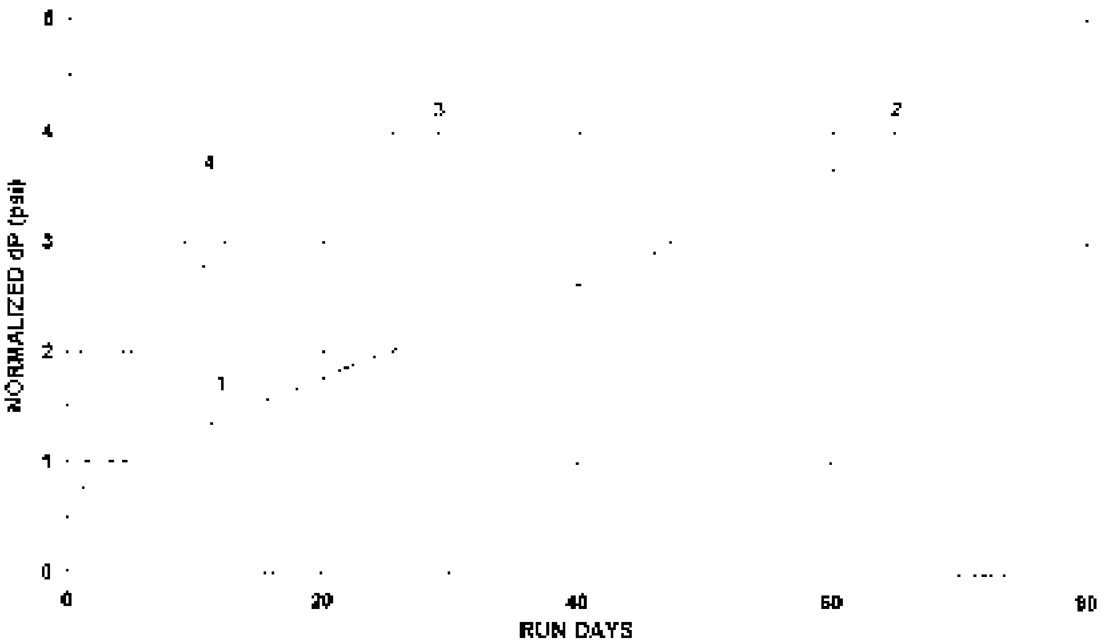

Figure 3-6 Hope Creek Test Stand - FMF "T" For Four Runs

When comparing performance of Filters R, S and T, the important parameter of flow per unit length of septum should be considered. Flow per unit area is not an appropriate parameter for evaluating pleated filter septa. The filtration areas available in septa from different suppliers are not necessarily effective in terms of run length and useful life.

Since many pleated filter septa are constructed from nominal 10 inch long cartridges, it is convenient to express this parameter as gpm/10 inches of length. The parameter is significant because in full-scale applications the number and length of filter septa with identical outside diameters, albeit with different filtration areas per unit length, are set by the filter vessel size.

The lengths of Filters R, S and T (as shown in Table 1-1) are 50, 40 and 49 inches respectively. Therefore, Filter R at 12 gpm operates at 2.4 gpm/10 inches, or at 1.8 gpm/10 inches with a 9 gpm flow rate. Filter S at 11.5 gpm operates at 2.9 gpm/10 inches, and Filter T at 10 gpm operates at 2 gpm/10 inches. That is, on the basis of flow per unit length the filters were not operated under similar conditions; Filter S operated with the highest flow/unit length. The significance of this parameter of flow per unit length can be demonstrated through its use in comparing the performance of the filters on the basis of Run 2, the longest and most stable for each.

From Table 3-2 the simple ranking on the basis of Average ΔP/day is 0.05 psi/day for Filter T, 0.091 psi/day for Filter S and 0.143 psi/day for Filter R. However, a more meaningful comparison is gained when the filters are compared with throughput and ΔP normalized on the basis of flow per unit length. On this basis one day of operation during Run 2 of Filter R is equivalent to 1.2 days of Filter T (2.4/2), one day for Filter S is equivalent to 1.45 days on Filter T. Normalizing ΔP on the basis of direct linearity with flow results in 1 psi on Filter T being equivalent to 0.83 psi on Filter R and 0.69 psi on Filter S. The ranking of the filters on the basis of ΔP/day normalized to 2 gpm/10 inches is then:

Filter S 0.043 psi/day

Filter T 0.050 psi/day

Filter R 0.099 psi/day

The above comparison is intended solely to demonstrate the significance and importance of comparing results on the basis of flow per unit length of septa. The ranking does not express or imply a ranking of suitability for condensate filtration applications. In such applications, septa useful life is more important than the ΔP rise rate over a single early run. There are insufficient data from the testing to date for projections of useful lives.

Ion Exchange Performance

Results of ion exchange performance testing performed at a septa supplier's laboratory were reported at a 1996 EPRI Workshop (17). The testing compared the performance of powdered ion exchange resin precoats on upright pleated filter septa to similar precoats applied to a cylindrical yarn wound filter septa. Ion exchange performance tests on fold-over pleated filter septa have not been published.

The results of these tests are shown in Figure 3-7. The superior performance of precoats on the yarn wound filter septa is clearly indicated. The single pleated and a single yarn wound septa were tested sequentially on the same day and in the same bottom tubesheet pilot plant vessel. The three pleated filter septa were tested at a later date in a top tubesheet pilot plant vessel designed to accommodate three filter septa. All of the pleated septa had 2.5 inch nominal outside diameters, 50 inch lengths, 50 ft^2 nominal filtration areas and 4 µm particle retention ratings, and were tested at 10 gpm/septum (0.2 gpm/ft^2). The yarn wound septum had a 2 inch nominal outside diameters, 60 inch length and 2.6 ft^2 nominal filtration area, and was tested at 6.7 gpm (2.6 gpm/ft^2).

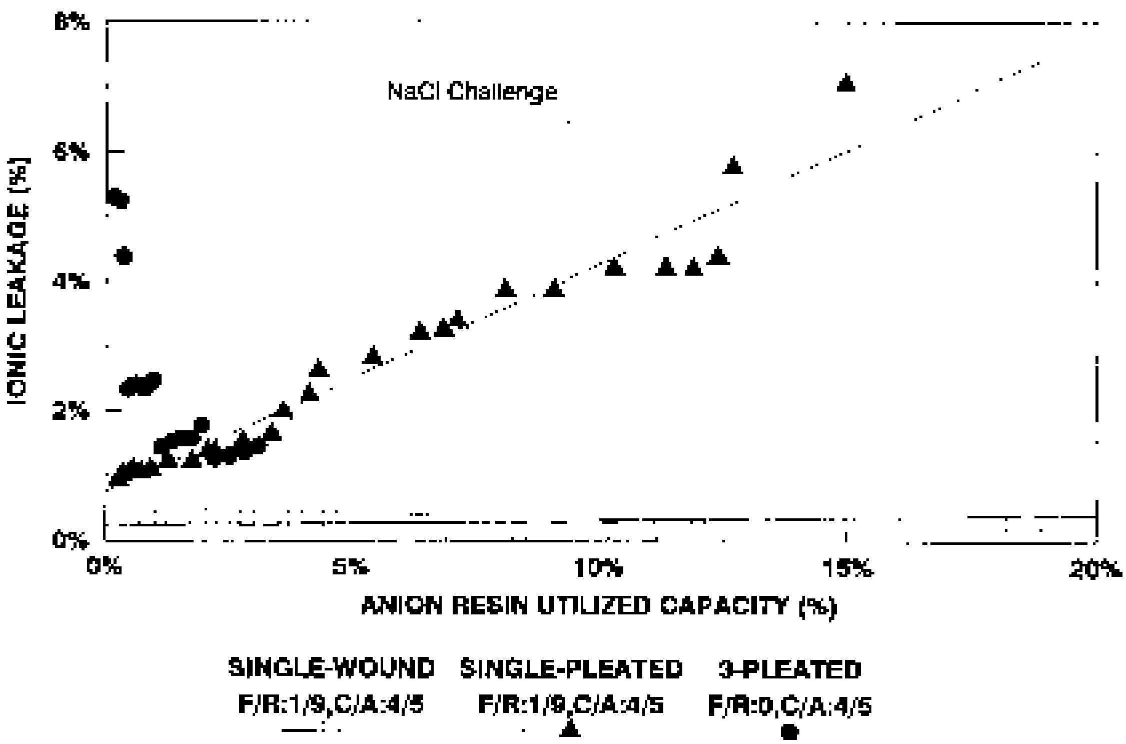

Figure 3-7 Ion Exchange Performance - "Upright" Pleated vs. Cylindrical Septa

The precoat material used on the single yarn wound and pleated septa had a dry weight composition of 10% fiber, 40% cation resin and 50% anion resin. For the test of the three pleated septa the precoat material contained no fiber, its composition was 44% cation resin and 56% anion resin. The septa supplier indicated a preference for fiber free precoats on the bases of precoat uniformity and ease of removal by backwash. In addition, such precoats maximize the available ion exchange capacity.

The precoat dose for the single yarn wound and pleated septa were 0.42 and 0.62 dry lb/septum respectively. For the test of the pleated septa in the three septa pilot plant vessel, a precoat dosage of 0.53 dry lb/septum was used. The septa supplier recommends that precoat dose be limited to the amount that can be contained below the cage that surrounds the pleated filter media.

During the testing of the single yarn wound and pleated septa an effort was made to maintain a constant influent salt concentration by using a constant injection solution concentration. The influent NaCl concentration ranges were 406 to 883 ppb for the yarn wound septa, and 268 to 630 ppb for the pleated septa. Variability in the salt solution injection rates were responsible for the ranges.

During the test of the pleated septa in the three septa pilot plant vessel the injection solution concentration was allowed to vary with periodic replenishments. An influent range of 300 to 1330 ppb NaCl resulted. This is the reason for the stepped appearance of the data (▲) for this test in Figure 3-7.

It is unfortunate that due to time limitations the testing of the pleated septa were not completed beyond a 15 % anion resin capacity utilization. Testing to at least 30% utilization, preferably to 50%, is required to determine quantitatively the full implications of increasing ionic leakage from precoats on pleated filter septa. In view of the findings, full verifiable ion exchange performance testing of all types of pleated filter septa currently offered as precoatable should be undertaken and published as soon as possible.

Ionic leakage from precoats on pleated filter septa is pertinent only to plants without deep bed demineralizers following their condensate filters. Fourteen BWR systems fall within this category. Eleven of the fourteen use cooling towers on the water to their condensers.

For the fourteen plants, the consequences of ionic leakage through condensate filter/demineralizers are dependent upon a number of factors, including:

condenser cooling water concentration and composition;

condenser tube integrity history and current status;

maximum allowable reactor water concentrations (sulfate, chloride, silica);

maximum RWCU rate;

maximum cooling water ingress rate at which full power operation should be feasible;

minimum practical run length (usually limited by radwaste processing); and

types and maximum allowable dosages of precoat materials.

4

FULL-SCALE APPLICATIONS

Browns Ferry Nuclear Plant (precoat septa)

One of nine filter/demineralizer vessels of Unit 2 has been fitted with 302 upright pleated filter septa, each with a nominal outside diameter of 2.5 inches and 60 inch length. The pleated septa replaced yarn wound septa of similar dimensions.

The three runs completed with pleated septa are summarized on Table 4-1. A fourth run is in progress. All resin precoats with a cation/anion dry weight ratio of 4/5 are being applied to the pleated septa. The precoat doses of 96 and 60 dry pounds are equivalent to 0.32 and 0.20 dry pounds/septum, significantly less than the 0.5 to 0.6 dry pounds/septum used in the pilot plant ion exchange performance tests discussed previously. Approximately 0.5 dry pounds/septum are used on the yarn wound septa in the remaining 8 filter/demineralizer vessels. No changes in reactor water chemistry have been noted since placing the pleated septa in service. However, the effect on reactor water chemistry of ionic leakage, if any, from one of nine vessels would not be detectable at Browns Ferry.

Table 4-1
Browns Ferry Unit 2 Condensate System - Precoated Pleated Filter Septa Performance

Vessel	Run No.	Start Date	Run Length (days)	Average Flow (gpm)	Initial dP (1) (psi)	Final dP (1) (psi)	Average dP/day (psi/day)	Precoat Dose (dry pounds)	Precoat Material
Memtec Polypropylene 2 Micron Rating Pleated Septa									
B	1	5/15/96	26	3200	3.6	8.1	0.173	96	PD-11
B	2	06/19/96	43	3200	3.9	8.0	0.096	60	PD-11
B	3	08/02/96	49	3100	3.7	8.0	0.088	60	PD-11

NOTES
1. Normalized to 3200 gpm; dP = k* (flow)^1.6 (estimated for use with measured values that include vessel entrance and exit losses).

Over the first three runs Initial ΔP and run lengths have remained stable. There are insufficient runs to forecast future trends for either parameter.

Effluent insoluble iron values are plotted on Figure 4-1 for the three completed runs and the start of the fourth. The effluent iron concentrations are plotted against the dates of iron transport monitor disk removal. Each disk was used for 2 to 3 days of sampling. Generally there were two 2-day samples followed by a 3-days sample which spanned a weekend. Effluent irons from the vessels using yarn wound cylindrical filter septa at Browns Ferry are in the range of 1 to 2 ppb.

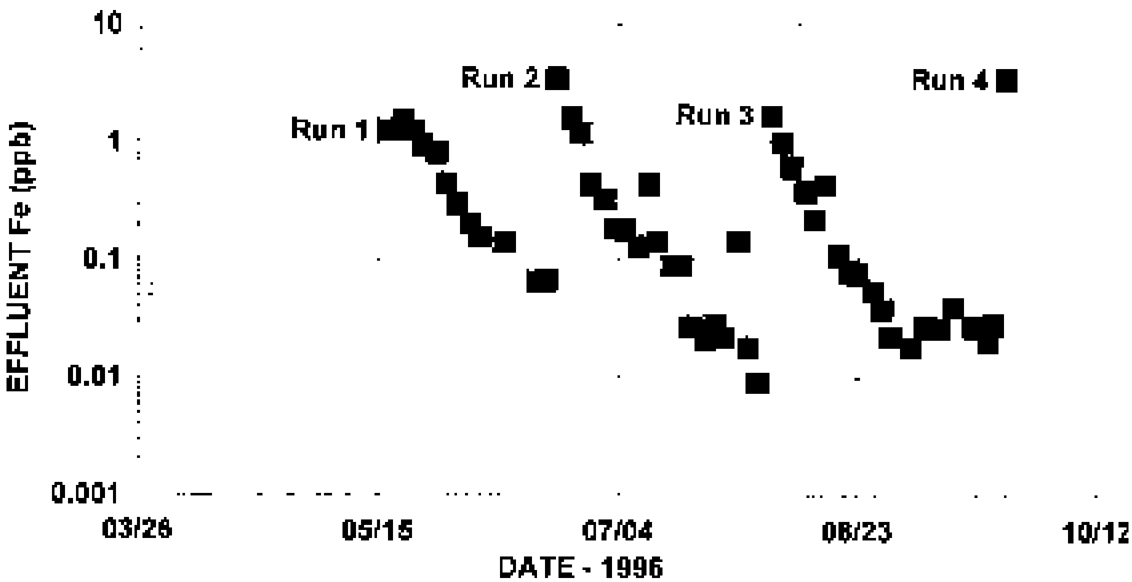

Figure 4-1 Browns Ferry Unit 2 - Effluent Fe With Precoated 2 μm Pleated Filter Septa

Maintaining initial iron values of 1 ppb or greater for 4 consecutive runs starts may be an indication of the effectiveness of septa cleaning at Browns Ferry. The Graver Air Surge backwash method with eight surges per backwash is employed. However, an increasing rate of effluent iron decline is also evident. An effluent iron value of 0.1 ppb was achieved after about 30 days in Run 1, whereas only about 18 and 15 day were required in Runs 2 and 3 respectively.

Although the initial performance of precoated pleated septa at Browns Ferry is quite promising, there are far too few runs and operating days (118) to allow a forecast of septa useful lives. In addition, the significance of ion exchange performance with pleated septa at Browns Ferry remains an open issue until at least a majority of a unit's filters are using pleated filter septa.

Brunswick Nuclear Project (non-precoat septa)

There have been several reports at EPRI Workshops on condensate filters and feedwater iron at the Brunswick Nuclear Project (18, 19). In the 1994 report (18) it was announced that one of four condensate filter demineralizers would be converted to the use of non-precoated pleated filter septa. At that time, a total annual saving of $630,000 was projected if non-precoat filter septa were used in the four filters of each unit. The full use of pleated septa was to depend on an evaluation of their performance in a filter vessel trial scheduled to start in 1994.

Results with pleated septa in all filters of both units were presented (19) in 1996. By May, 1995 all filters of both Brunswick units were equipped with pleated filter septa. Pleated filter septa were first used in Filter D of Unit 1 with operation starting in August 1994. These original septa are still in service. The septa installed later in other vessels are slightly different due to design improvements introduced by the septa supplier.

Table 4-2 provides statistics for Filter D of Unit 1 and Filters A and C of Unit 2. Average flows of 4800 to 5000 gpm result from normally using 3 rather than 4 filters on-line. As noted earlier, the septa in Filter D of Unit 1 were the first installed and slightly different than those in the other filter vessels. For a time there was a tendency for operators to favor the use of the vessels with the newer septa. The exponent for flow, 1.29, used in the relationship to normalize initial dP values is an estimate based on initial ΔP and flow measurements for the first 10 consecutive runs on Filter A of Unit 2.

Table 4-2
Brunswick Units 2 & 3 Condensate Systems - Non-Precoated Pleated Filter Septa Performance

Run No.	Start Date	End Date	Run Length (Days)	Initial		Final		Average Flow (gpm)	Normalized Initial dP (2) psi)
				dP (psi)	Flow (gpm)	dP (psi)	Flow gpm)		
UNIT 1 - Condensate Filter D									
1	8/15/94	9/16/94	32	1	1500	11	5200	4600	4.60
2	09/17/94	10/30/94	44	8	4500	12	4800	4800	8.93
3	11/01/94	11/25/94	24	9	4750	8	3600	4400	9.37
4	11/26/94	1/7/95	42	5.5	3700	8	3650	3800	7.90
5	1/8/95	1/29/95	17	6	4000	12.5	4500	4800	7.80
6	2/8/95	02/19/95	12	11	4900	9	3700	4850	11.00
7	03/03/95	03/25/95	23	12	5100	12	4900	4900	11.40
8	5/21/95	6/11/95	22	3.5	2500	10	4800	4450	8.34
9	7/5/95	10/26/95	102	9.5	4900	12.5	4900	4630	9.50
10	10/28/95	11/13/95	16	10	4800	13	4800	4825	10.27
11	12/13/95	1/31/96	29	8.5	4900	14	4900	4800	8.50
12	2/12/96	3/16/96	34	7.5	3800	14	4900	4850	10.41
13	03/29/96	4/11/96	12	11.9	4700	13.2	4800	4800	12.56
14	5/1/96	5/25/96	25	9	4700	14.5	5000	4850	9.50
15	7/10/96	8/7/96	27	11	4800	12.5	4800	3950	11.30
16 (1)	8/13/96	9/4/96	23	10	5000	13.3	4800	4700	9.74

Table 4-2
Brunswick Units 2 & 3 Condensate Systems - Non-Precoated Pleated Filter Septa Performance

Total Days =			**484**						
UNIT 2 - Condensate Filter A									
1	12/21/94	1/25/95	36	7.5	4900	11	4900	4550	7.50
2	2/8/95	3/1/95	23	8	5000	11	5000	4950	7.79
3	3/17/95	4/12/95	27	7	4900	12	5000	5000	7.00
4	4/27/95	8/13/95	101	7.5	5000	11	4800	4850	7.31
5	8/14/95	8/31/95	18	8	4900	11	4900	4600	8.00
6	9/1/95	1/6/96	127	8	4900	10	3400	4250	8.00
7	1/11/96	2/2/96	23	5	3400	7	3200	3300	8.01
8	3/9/96	03/26/96	18	7	2800	13.5	4900	3025	14.41
9	04/10/96	04/28/96	18	11	5000	9	3500	4350	10.72
10	05/10/96	05/25/96	16	12.5	4900	12.5	4800	4900	12.50
11	5/28/96	7/9/96	43	9.5	5000	14.5	5000	4900	9.26
12	7/18/96	8/14/96	23	6	2500	14	5000	4600	14.29
13 (1)	8/31/96	9/4/96	5	10.5	5000	11.4	5000	5000	10.23
Total Days =			**478**						
UNIT 2 - Condensate Filter C									
1	1/26/95	3/16/95	42	6	5000	11.5	5000	5000	5.85
2	4/3/95	6/1/95	52	7	5200	10.5	5000	5050	6.48
3	7/11/95	2/2/96	190	8.5	4800	8	3200	4250	8.73

Table 4-2
Brunswick Units 2 & 3 Condensate Systems - Non-Precoated Pleated Filter Septa Performance

4	3/11/96	5/9/96	54	1	1600	12	5100	4450	4.24
5	5/11/96	6/17/96	38	7	4900	11.5	4900	4950	7.00
6	7/10/96	8/30/96	50	7.5	5200	11	5000	4500	6.95
Total Days =			**426**						
NOTES: (1) Run in progress (2) Normalized to 4900 gpm, with dP = k*(Flow)^1.29									

During the last Unit 1 outage all of its condensate filters were left dry, which with hindsight utility personnel feel was not wise. Filters were kept wet during the last Unit 2 outage.

Filters of both units have experienced backwash system problems. The backwash system in use is the Graver Mod III method which uses simultaneous steady-state air and water backwash flows. At times the air flow has drifted significantly below the required design value. Currently Filter A of Unit 2 is experiencing backwash and effluent control valve problems which will be addressed at the first opportunity. Station personnel perceive that septa run length performance has always improved after such system problems have been resolved.

As shown in Figure 4-2 the ΔP rises rather rapidly at the start of the run, and then remains relatively constant. As will be discussed later, this behavior was also observed for the Graver pleated septa in service at Perry, another unit with FWPD. Of the three types of pleated filter septa in full-scale BWR condensate applications, the Graver septa have the lowest particle retention rating and are the only ones classified as a porous pleated membrane filter. These factors suggest the filter media may be encountering standard blocking, a partial blocking of the pores as described in the Review of Filtration Fundamentals of this report. Standard blocking would be followed by cake formation.

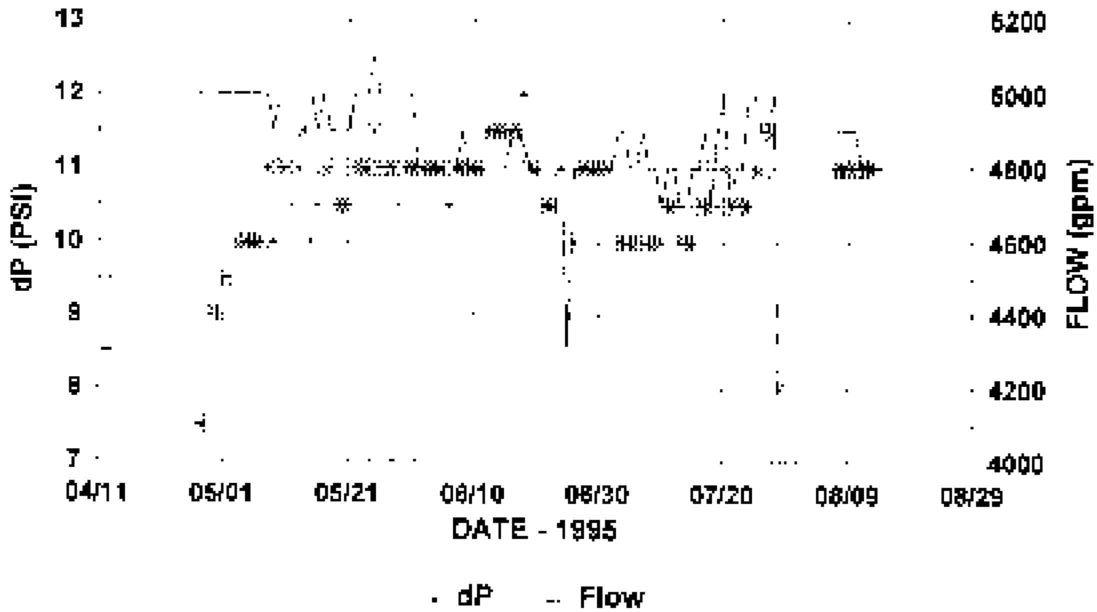

Figure 4-2 Brunswick - Run 4 Filter 2A

Figure 4-3 shows normalized Initial ΔP values at the start of each run for Filter D of Unit 1 and Filters A and C of Unit 2. The backwash system problems, and dry lay up of the Unit 1 filters, noted previously, may explain some of gyrations seen in the data. Nonetheless, an increase in Initial ΔP for all vessels is apparent. Whether or not the Initial ΔP's have stabilized is less apparent.

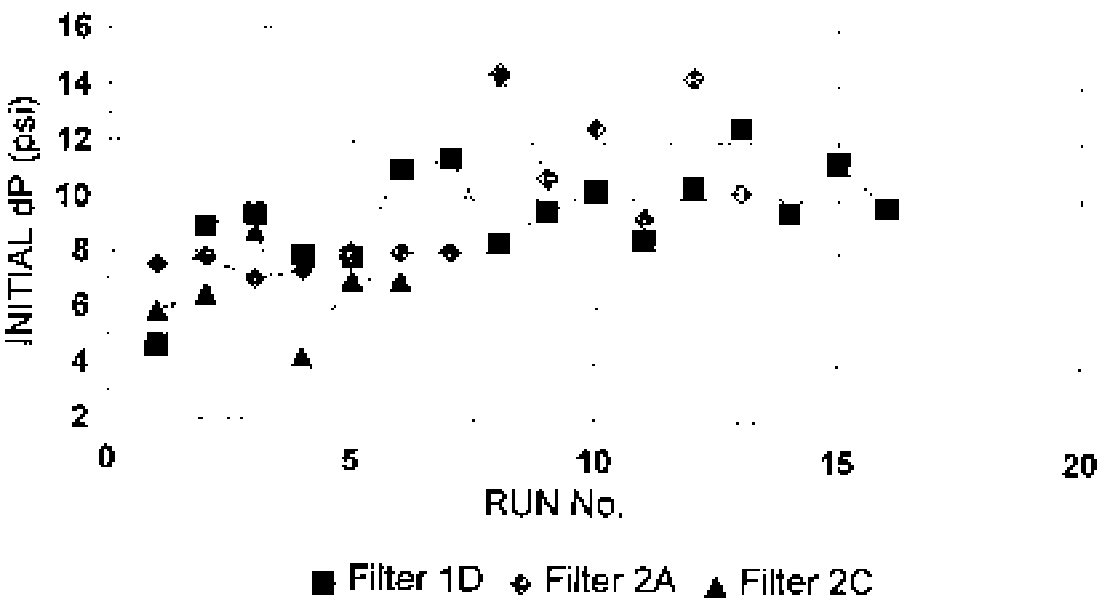

Figure 4-3 Brunswick - Normalized (4900 gpm) Initial dP Behavior

The combination of rapid ΔP rises at the start of runs and increasing Initial ΔP values would portend increased final ΔP limits to maintain run lengths. For plants, such as Brunswick, with existing filter/demineralizer systems originally designed to operate up to 20 to 25 psi this may not be significant. However, for plants adding filters to systems with existing pump head limitations elevated final ΔP limits may be a significant consideration.

Although the pleated septa of Filter D in Unit 1 remain in service after 484 days of cumulative service through September 1996, it is not possible to calculate a projected ultimate useful life for the septa due to the uncertainty of residual effects of the aforementioned dry lay up and system operating difficulties encountered. However, in view of the service time achieved thus far, a speculative useful life of at least 2 years appears achievable if the daily ΔP rise rate remains at about 0.12 psi/day at 4900 gpm and the Initial ΔP increases no more than the current average rate of 0.13 psi/Run. This speculative estimate is based on maintaining run lengths of at least 30 days and a maximum acceptable Initial ΔP of 15 psi.

A caveat on useful life projections, speculative or not, made in this report is appropriate at this point. Such projections are specific to the plant for which they are made. Useful lives depend on plant operating conditions and practices as well as filter septa characteristics. Of the plants with full-scale pleated filter septa applications, only Perry at 10 ppb has an average stable full power Condensate Filter Inlet Concentration (CFI) iron concentration close to the 10-12 ppb reported for Brunswick; the remaining plants have higher concentrations.

Clinton Power Station (non-precoat septa)

In a 1993 EPRI Workshop report (20) Illinois Power's efforts to reduce feedwater iron, personnel radiation exposure and operating costs were summarized. At this time special iron removal resins were already under trial in condensate demineralizers and planning for the addition of condensate filters was well underway, with a stated goal of achieving < 0.5 ppb feedwater iron and filter septa useful lives of 3 years or better.

By 1995 three identical top tubesheet filter vessels had been installed upstream of existing condensate demineralizers. Each vessel received pleated filter septa from one supplier of the three selected for the initial trials. The numbers of septa/vessel, septa lengths, and the proprietary backwash methods used differed among the vessels, all having being prescribed by each septa supplier.

The results of these initial trials were presented at a 1996 EPRI Workshop (21). Run length performances for pleated septa from all three suppliers were below expectations. All septa achieved effluent irons less than 0.5 ppb. However, a sudden rise in effluent iron (> 8 ppb) from the Graver septa started with the March 1, 1996 sample and continued. Graver attributed the increased iron leakage to loss of seal integrity at the tubesheet attachment due to a design fault that has been corrected.

Figures 4-4, 4-5 and 4-6 are plots of run data for the three Clinton condensate filters, derived from the afore referenced EPRI Workshop report. While reviewing these data it should be recalled that the numbers and lengths of septa varied among the vessels. As already suggested in the section on Hope Creek Test Stand results, an appropriate flow normalizing parameter is flow (gpm) per 10 inches of septa length. The values of this parameter during the trials at Clinton were; 1.8 for the Memtec septa, 1.9 for the Pall septa and 2.1 for the Graver septa.

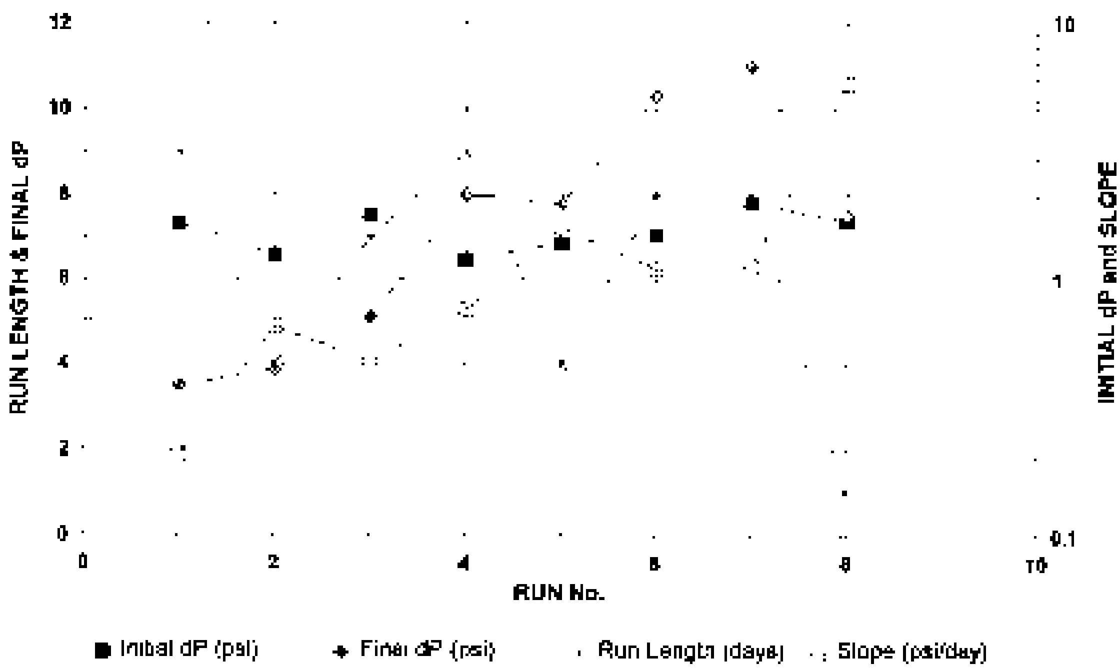

Figure 4-4 Clinton - Graver Septa Performance

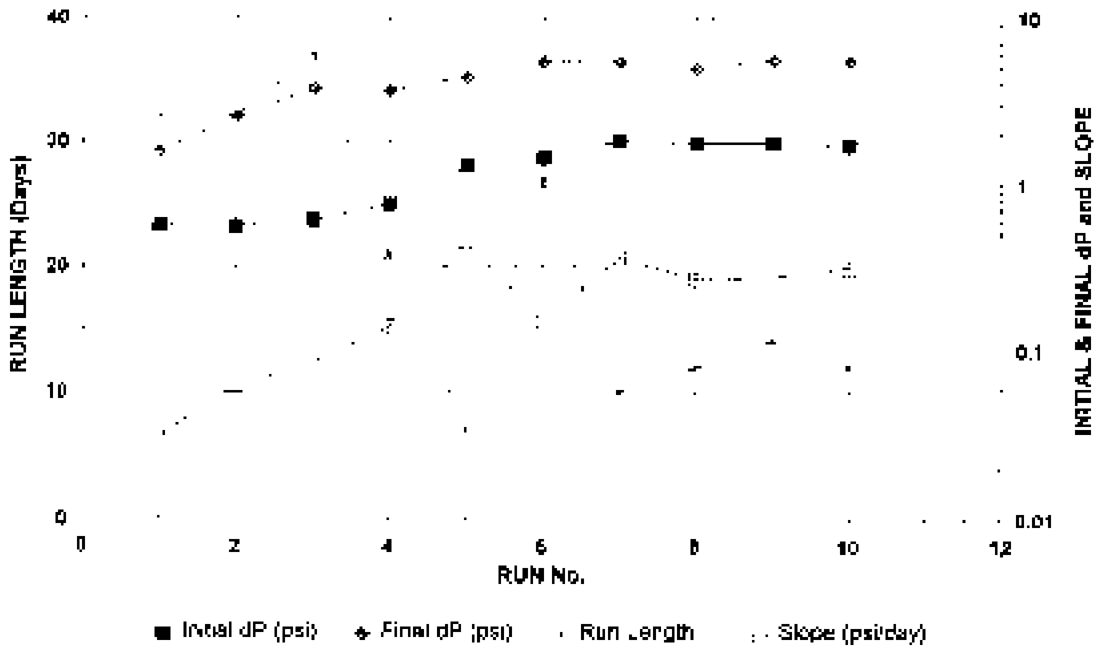

Figure 4-5 Clinton - Memtec Septa Performance

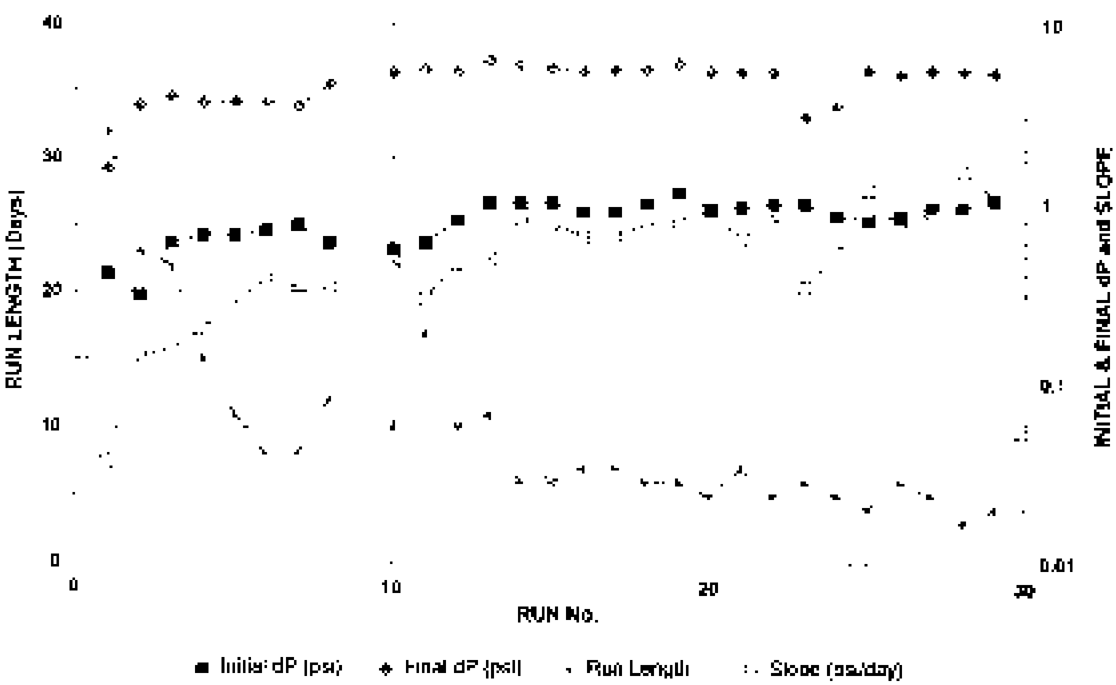

Figure 4-6 Clinton - Pall Septa Performance

In addition to differences in the septa, it appears the final ΔP limits were managed differently among the vessels. With Graver septa final ΔP rose from 3.5 psi on the first run to 11 psi on the final complete run; Run 8 was terminated because of the effluent iron rise. The leveling out of ΔP after an initial rapid rise, as seen at Brunswick, was not apparent in the data from Clinton (21). There are several differences between the Brunswick and Clinton applications that may contribute to the difference in ΔP behavior. Brunswick uses lower particle retention filter media; 0.6 vs. 1.0m. Brunswick septa operate at a lower flow per 10 inches of length; 1.7 vs. 2.1. Brunswick has the lower average flux rate; 0.45 vs. 0.55 gpm/ft^2. In addition to these septa operating condition differences, Clinton has an average CFI iron concentration of 15 ppb and does not have FWPD; Brunswick operates with FWPD, and an average CFI iron of about 11 ppb.

Final ΔP variation was used less aggressively with the Memtec and Pall septa. For the Memtec septa final ΔP ranged from a low value of 1.5 psi on the initial run to maximum of 5.6 psi for the ninth run. The range of final ΔP with the Pall septa was from 1.6 psi for the first run to 6 psi for the nineteenth run.

Initial ΔP values were reasonably stable for all vessels. The smallest variation was with the Pall and Graver septa, 0.75 psi, the variation was 1.25 psi with the Memtec septa. All ΔP measurements at Clinton are across the tubesheets. That is, the measurements do not include the loses across influent and effluent valves and nozzles that are included in measurements on condensate filters at most other power plants.

Despite the relative stability of Initial ΔP for all vessels, run lengths declined for all. A more useful parameter for evaluation is the average ΔP rise rate (psi/day) for each successive run which discounts the effects of Final ΔP increases. These rates are the "Slopes" shown in Figures 4-4, 4-5 and 4-6 which are simply the differences between Initial and Final ΔPs divided by run lengths. By the completion of testing, the Graver and Pall septa slopes had increased to about 1 psi/day, and the Memtec septa were at about 0.3 psi/day.

New septa from the same three suppliers have been installed in the three original filter vessels. The number of septa in each vessel did not change, i.e., the differences among vessels remain. Graver and Memtec lengths were not changed, the new Pall septa have a length of 52 inches rather than the 60 inches for the first installation.

The new Memtec septa use polypropylene rather than polysulfone, and Pall changed from polyaramid to polyolefin. Graver's new septa use the same filter media material as in the first trial set; polyester.

Graver and Pall new septa have greater filtration areas per septum, 25 and 52 ft^2 respectively. Memtec's second trial set has the same filtration area as the first set; 55 ft^2/septum.

Particle retention ratings for the Pall and Memtec second sets of septa for Clinton differ from the first sets. Pall used 1 rather than 1.4 µm, Memtec used 2 rather than 0.5 µm. The 1 µm rating for the second set of Graver septa is the same as the first.

Installation of three additional condensate filter vessels at Clinton is scheduled for 1997; a standard top tubesheet design is being considered. Selection of filter septa has not been determined. Backwash methods different than those used to date at Clinton will likely be used with the new and first three filter vessels.

Limerick Nuclear Generating Station (non-precoat septa)

The condensate filter/demineralizers at Limerick were part of the original plant design. Later, deep bed condensate demineralizers were added downstream of the filters as one of the efforts to reduce feedwater copper. Operation of the condensate filter/demineralizers without precoats became feasible with the addition of the deep beds.

Graver Water supplied the 8 bottom tubesheet filter vessels for each of the two units at Limerick. As originally designed each vessel contained 420 yarn wound septa (2 inch O.D. by 70 inches long) with 3 inch center-center spacing. The Graver Mod III backwash method was used with the yarn wound septa.

A decision to replace the yarn wound septa with pleated filter was made on the basis of reducing operating costs and feedwater insoluble iron concentrations. The GE/Pall Alliance was the selected supplier. The retrofit included replacement of the original backwash with a surge type backwash designed and supplied by the Alliance.

Two hundred and forty (240) pleated septa per vessel with 2.5 inch nominal diameters and 70 inch lengths replaced the original 420 yarn wound septa per vessel. The septa selected used polyaramid filter media and were identical in most respects to Filter H as tested on the Hope Creek Test Stand. Filter H had a larger nominal O.D. (2.75 inches) because of different outside cage construction, however the number, configuration and dimensions of its pleats were the same as those installed in the full-scale application at Limerick.

A presentation at the 1995 EPRI Condensate Polishing Workshop (14) compared the useful life projections made on the basis of Filter H's performance on the Hope Creek Test Stand to the performance being achieved with essentially identical polyaramid septa at Limerick. It was obvious by the time of presentation that the septa at Limerick would not achieve the useful life of about 4 years projected from Filter H performance with adjustments for lower influent insoluble solids and flux rates at Limerick. The discrepancy between projected and indicated performance at Limerick was attributed to significant differences between the Hope Creek Test Stand and Limerick backwash methods. Surge type backwash methods were used at the Hope Creek Test Stand and at Limerick. However, the estimated maximum backwash surge flow at Hope Creek was about 5 gpm/ft^2 as opposed to about 1.3 gpm/ft^2 at Limerick. In addition, the filter media at Hope Creek was exposed to a total backwash flow of 0.12 gal/ft^2 by the 3 surges used, whereas the 2 surges used at Limerick passed a total of 0.02 gal/ft^2 of backwash water through the filter media.

As a result of the short runs at Limerick several different types of septa were given full-vessel trials and backwash method modifications were devised. The current polyolefin filter septa installation at Limerick evolved from these efforts.

Table 4-3 contains run statistics for the use of Unit 1 - Filter A, the first vessel to operate with the polyolefin septa. The first use of polyolefin filter septa in Unit 2 started in June 1996. A backwash method devised during the trials with the polyaramid septa is being used with the current polyolefin septa. Six rather than the original 2 surges per backwash are being used. The first three are delivered during the vessel drain; one with the water level at 3/4 of the septa heights, the second and third at 1/3 and 0 septa heights. The final three surges are with a rising water level with deliveries at 0, 1/3 and 3/4 of septa heights.

Initial dP and flow measurements during the first three runs were used to estimate the exponent for flow, 1.5, in the normalization relationship noted at the end of Table 4-3. Although a crude estimate, it produces a rational progression of Normalized Initial dP values.

Table 4-3
Limerick Unit 1 Condensate System - Non-Precoated Pleated Filter Septa Performance

Run No.	Start Date	Run Length (Days)	Average Flow (gpm)	Initial dP (psi)	Final dP (psi)	Average dP Rise (psi/day)	Normalized Initial dP (1) (psi)
1	12/13/95	35	3400	4	4.5	0.014	4.73
2 (2)	01/20/96	16	3000	3.5	3.5	0.000	4.99
3 (3)	03/07/96	20	3800	5.5	5.5	0.000	5.50
4	03/30/96	30	3800	5.5	6	0.017	5.50
5	04/30/96	31	3800	5.5	6.5	0.032	5.50
6	05/31/96	30	3800	5.5	7	0.050	5.50
7 (3)	07/01/96	30	3800	5.5	7	0.050	5.50
8	08/08/96	28	3800	5.5	7	0.054	5.50
9 (4)	09/07/96	17	3800	5.5			5.50
Total Service Days = 237							

NOTES:

1. Normalized to 3800 gpm with dP = (Flow)^1.5.
2. Run terminated for RFO.
3. Run terminated by plant shutdown.
4. Run in progress.

Currently runs are terminated after 30 days of operation; some runs were terminated earlier by plant shutdowns. Thus far Initial ΔP has been stable. However, there is a trend of increasing Final ΔP values while maintaining the thirty-day run lengths. This is reflected in the increasing Average ΔP Rise rate (psi/day) from run to run.

There are far too few available data for a reliable projection of the useful lives of these septa under the Limerick operating conditions. However, given the 237 days of operation already completed, it can be reasonably speculated that a total operating time of about 2 years with 30 day run lengths is achievable, if Initial ΔP remains stable and the increase in the Average ΔP Rise rate continues at its current value of about 0.005 psi/day per run. Useful lives may be extended, if run lengths less than 30 days are acceptable and/or by increasing the Final ΔP limit. However, it is cautioned that increasing the Final ΔP limit may adversely effect the behavior of Initial ΔP and Average ΔP Rise rate. Whether the supplier's expected life of four years for their polyolefin pleated filter septa (BPF-4), as stated at a recent EPRI Workshop (22), will be realized at Limerick cannot be determined yet.

Peach Bottom (precoat septa)

Both Peach Bottom units have condensate filter/demineralizers without the benefit of downstream demineralizers, and therefore must be operated with precoats containing powdered ion exchange resins. The bottom tubesheet filter/demineralizers were supplied by Graver Water and use Graver's Air Surge backwash method.

At the 1996 EPRI Condensate Polishing and Water Purification In Steam Cycle Workshop a three million dollar condensate polisher improvement program was described (23). A key element of this program was the replacement of yarn wound filter septa with pleated filter septa in most of the condensate filter/demineralizers. Two to three million dollars of annual savings are expected to result from this program.

A large portion of the expected savings have been reported (23) as realized due to longer run lengths with the pleated filter septa using precoat doses lower than used with the yarn wound septa replaced. The yarn wound septa had used 156 dry pounds of precoat material per precoat, whereas about 60 dry pounds per vessel are used with the pleated filter septa.

The earliest use of pleated filter septa at Peach Bottom started in May 1995 in Filters A and B of Unit 3. Septa with a particle retention rating of 2 µm were used in Filter A, 4 µm rated septa in Filter B. Pleated filter septa (10 µm) were installed in five additional vessels of Unit 3 in the Spring of 1996, leaving only three of the ten filter/demineralizers using yarn wound septa. The current strategy at Peach Bottom is to limit the use of pleated filter septa to seven vessels so their low effluent iron concentrations when combined with the 1 to 2 ppb consistently in the effluents from vessels with yarn wound septa will result in a feedwater iron concentration between 0.5 and 1.5 ppb (23).

Table 4-4 shows all of the Unit 3 filters currently using pleated filters with pertinent run statistics for each filter. As noted in the Comments column, Initial ΔP values on Day-1 were not available for a number of runs. In these cases the Average ΔP/Day Rise rates may be understated. Precoat Dose values and types of Precoat Materials used are reported in the table only for runs for which the information was noted on logsheets made available for review. It was generally intended that all filters would use 60 dry pounds of PD-11 (an all powdered ion exchange resin material). The initial runs on Filters A and B used 91H (mixture of fibers and powdered resins) before standardizing on an all powdered resin material. Likewise, Filters A and B used higher precoat doses before standardizing on 60 dry pounds per precoat. The total operating days for Filters A and B, 400 and 422 days respectively, are believed to be the highest achieved thus far for precoated pleated septa in a BWR condensate application.

Table 4-4
Peach Bottom Unit 3 Condensate System - Precoated Pleated Filter Septa Performance

Vessel	Run No.	Septa Rating (Microns)	Start Date	Run Length (days)	Avg Flow (gpm)	Initial dP (1) (psi)	Final dP (1) (psi)	Avg dP/Day (psi/day)	Precoat Dose (dry lbs)	Precoat Material	Comments
A	1	2	5/24/95	23	2400	2.33	5.47	0.14	84	91H	
A	2	2	6/15/95	32	2500	3.28	7.34	0.13	72	PD-11	Initial dP @ day 4
A	3	2	7/18/95	35	2550	2.32	5.50	0.09	72	PD-11	
A	4	2	8/31/96	19	2550	2.91	4.07	0.06	60	PD-11	Run stop for outage
A	5	2	10/16/95	24	2650	2.85	5.00	0.09			Initial dP @ day 2
A	6	2	11/10/95	7	2800	3.22	3.00	-0.03	60	PD-11	Initial dP @ day 3
A	7	2	11/22/95	10	2750	2.61	3.60	0.10	60	PD-11	
A	8	2	12/7/95	36	2750	3.28	6.96	0.10	60	PD-11	
A	9	2	1/16/96	58	2700	3.50	8.74	0.09			
A	10	2	3/14/96	47	2700	0.90	9.02	0.17	60	PD-11	
A	11	2	4/30/96	44	2650	0.55	9.03	0.19	60	PD-11	
A	12	2	6/14/96	65	2700	1.03	8.75	0.12			

Table 4-4
Peach Bottom Unit 3 Condensate System - Precoated Pleated Filter Septa Performance

B	1	4	5/26/95	21	2500	1.75	5.64	0.19	84	91 H	
B	2	4	6/15/95	33	2550	3.50	7.82	0.13	72	PD-11	Initial dP @ day 4
B	3	4	7/19/95	54	2600	3.18	6.56	0.06	72	PD-11	
B	4	4	10/16/95	8	2600	2.66	4.00	0.17			
B	5	4	10/25/95	41	2850	3.00	7.21	0.10			
B	6	4	12/7/95	16	2880	3.40	6.32	0.18	60	PD-11	
B	7	4	12/22/95	19	2900	4.72	6.80	0.11	60	PD-11	Initial dP @ day 4
B	8	4	1/12/96	43	2800	4.35	8.15	0.09			Initial dP @ day 6
B	9	4	2/24/96	54	2850	4.50	9.62	0.09	60	PD-11	Initial dP @ day 3
B	10	4	4/18/96	48	2600	3.40	7.66	0.09	60	PD-11	
B	11	4	6/6/96	23	2500	3.09	6.32	0.14			Final dP @ day 22
B	12	4	6/29/96	35	2650	3.50	8.23	0.14			Initial dP @ day 3
B	13	4	8/2/96	27	2750	3.92	6.90	0.11			Initial dP @ day 3
D	1	10	3/16/96	70	2800	2.61	5.00	0.03			Initial dP @ day 4
D	2	10	5/25/96	25	2800	2.84	4.12	0.05			Initial dP @ day 4
D	3	10	6/19/96	62	2800	3.09	6.80	0.06			
E	1	10	3/8/96	70	2650	2.36	4.35	0.03			Initial dP @ day 4
E	2	10	5/17/96	75	2850	2.00	7.00	0.07	72	PD-11	

Table 4-4
Peach Bottom Unit 3 Condensate System - Precoated Pleated Filter Septa Performance

F	1	10	5/17/96	75	2700	1.50	4.50	0.04			
G	1	10	4/25/96	76	2800	1.94	4.37	0.03			
G	2	10	7/16/96	45	2550	1.16	5.83	0.10			
H	1	10	4/29/96	76	2900	1.00	3.28	0.03			
H	2	10	7/18/96	41	2800	1.03	3.78	0.07			

NOTES

1. Normalized to 2750 gpm; dP=k*(Flow)^1.6. [The 1.6 exponent is an estimate for a value which must be between 1 and 2].

2. Run in progress.

Figures 4-7 and 4-8 provide plots for pertinent hydraulic parameters for the runs of Unit 3 Filters A and B respectively. For both filters there is variability in run lengths, much of it due to variation in the Final ΔP values among the runs. Once again a better indication of hydraulic performance is gained from run to run behavior of the Average psi/day Rise Rate (slope). There is no sustained increase in this parameter for either filter. However, an increase in Initial ΔP values for both filters is evident, the abnormally low values for the last three runs of Filter A notwithstanding. All three low values were measured at flows close to the normalization flow of 2750 gpm; the cause for the obvious anomaly is not known. Use of the low Initial ΔP values in the calculation of Average ΔP/Day for runs 10, 11 and 12 of Filter A probably overstates values of this parameter for those runs.

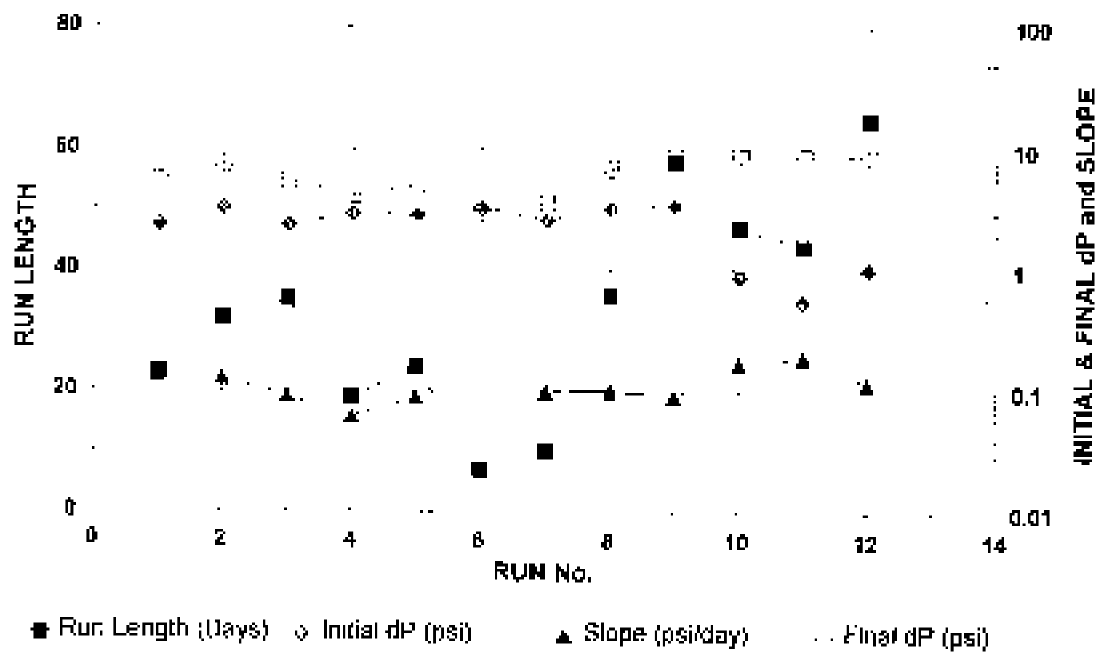

Figure 4-7 Peach Bottom Unit 3 Filter A - Precoated 2 Micron Pleated Septa Hydraulic Performance

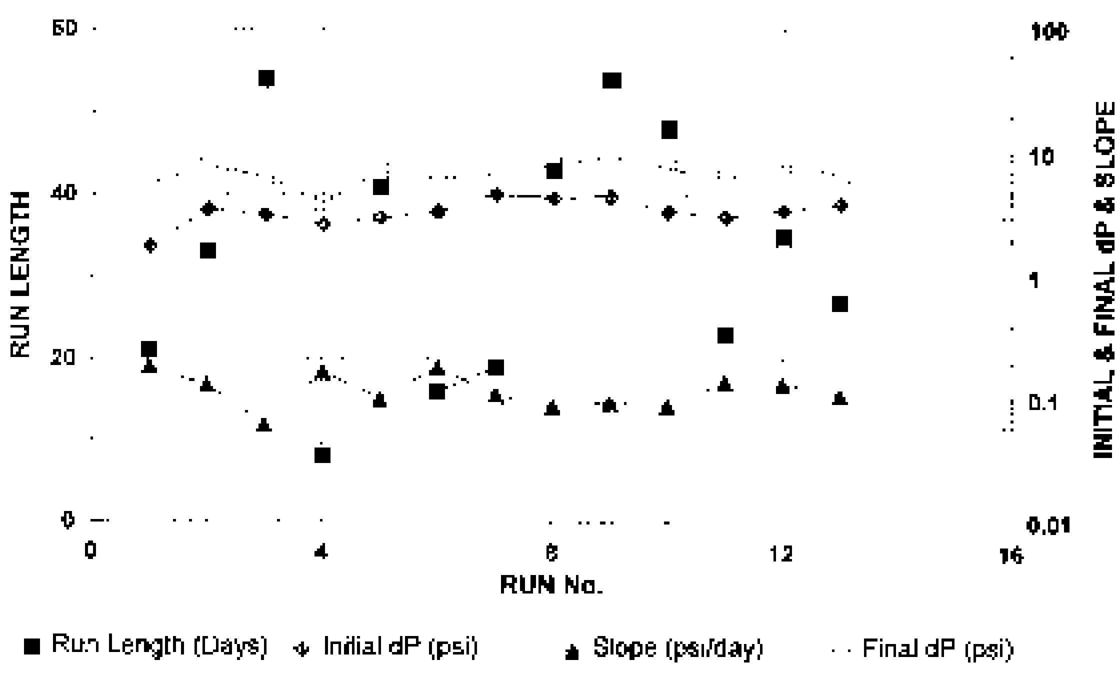

Figure 4-8 Peach Bottom Unit 3 Filter B - Precoated 4 Micron Pleated Septa Hydraulic Performance

Of the five filters of Unit 3 using 10 µm rated pleated filter septa, only Filter D had completed 3 runs. From these runs it appears that Initial ΔP and Average ΔP/Day may be rising towards values similar to those for the 2 and 4 µm rated septa in Filters A and B respectively.

Table 4-5 summarizes the runs of the three Unit 2 condensate filters using pleated filter septa, all of which have 10 µm ratings. In this case only one run had been completed with each filter. Data for runs of Filters D and E in progress indicate an increase in Initial ΔP for both filters.

Table 4-5
Peach Bottom Unit 2 Condensate System - Precoated Pleated Filter Septa Performance

Vessel	Run No.	Septa Rating (Microns)	Start Date	Run Length (days)	Avg Flow (gpm)	Initial dP (1) (psi)	Final dP (1) (psi)	Avg dP/Day (psi/day)	Precoat Dose (dry lbs)	Precoat Material	Comments
D	1	10	5/7/96	85	2300	0.97	5.49	0.05	60	PD-11	
D	2	10	8/12/96	18 (2)	2550	1.40	1.88	0.03			
E	1	10	5/10/96	91	2400	1.55	3.83	0.03			
E	2	10	8/16/96	14 (2)	2550	2.06	2.28	0.02			Initial dP @ day 11
F	1	10	5/16/96	90	2500	1.50	5.00	0.04			

NOTES

1. Normalized to 2500 gpm; dP=k*(Flow)^1.6.
2. Run in progress.

There are too few runs for each of the vessels using 10 µm rated pleated filter septa to even speculate on useful lives for these septa. Although many runs have been completed for the 2 and 4 µm rated septa, a calculated estimate of useful operating life based on Initial ΔP and Average ΔP Rise Rate trends is not possible because reliable measurements of ΔP at run starts were available for too few runs. In the case of Filter A, ΔP measurements at run starts were not available for 3 of the 12 runs and the Initial ΔP values for the last three runs appear to be anomalies, as discussed earlier. Measurements of ΔP at the start of 6 of the 13 runs of Filter B were not available. However, a speculative operating life of about 2 years for the 2 µm rated septa seems reasonable based on a minimum run length of 30 days, a maximum Final ΔP of 10 psi, and an average flow rate of 2750 gpm. Based on the performance during the most recent Filter B runs included in Table 4-4, the 4 µm rated septa may have a slightly shorter life.

The relationship between septa particle retention ratings and effluent iron concentrations is of current interest due to an expected change in BWR guidelines for optimum feedwater iron concentrations (2). The current pleated septa with particle retention ratings of 4 µm or less achieve effluent iron concentrations of 0.1 ppb or less compared to the expected guideline range of 0.5 to 1.5 ppb. A number of strategies are being considered for meeting the expected new feedwater guidelines. Abandoning the use of improved condensate filter septa is not among the options.

The investigation of one option is underway at Peach Bottom. Figures 4-9, 4-10, 4-11 and 4-12 are plots of effluent iron concentrations during multiple successive runs for vessels using 2, 4 and 10 µm rated septa.

The behavior of effluent iron concentrations with 2 µm septa is shown in Figure 4-9. The initial run started with a 5 ppb effluent iron concentration. However, by the tenth day the concentration was below 0.4 ppb. During the second run the effluent concentration was about 0.5 ppb at the sixth day and then rose to a maximum of 0.9 ppb before declining to 0.15 ppb on day 21. The difference in behavior between Runs 1 and 2 may due to a change in precoat material and dose (see Table 4-4). By Run 8 all effluent iron measurements were below 0.1 ppb.

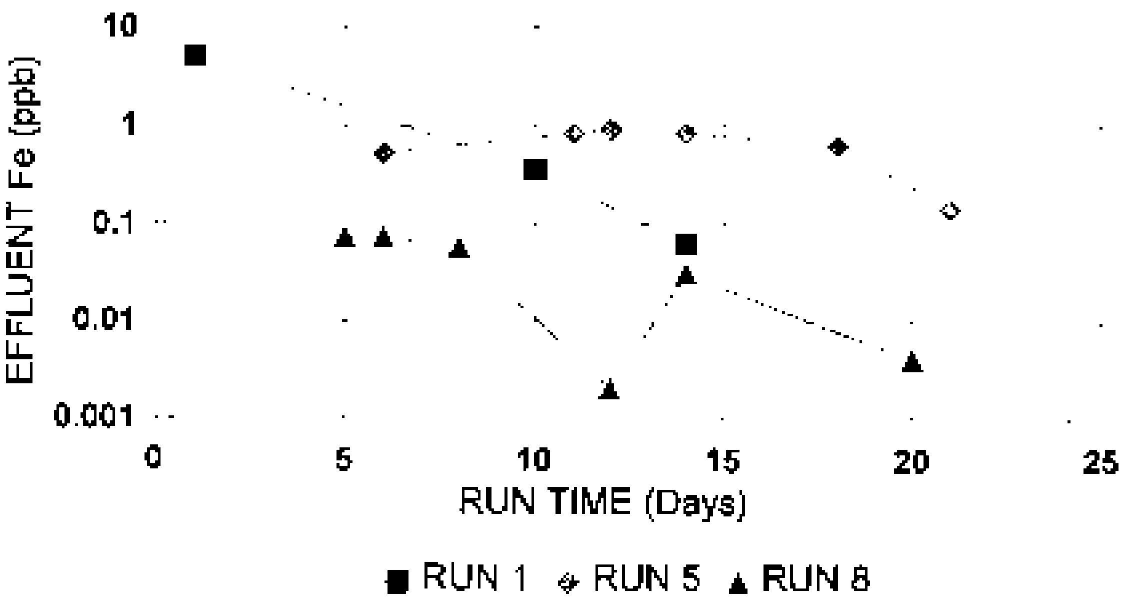

Figure 4-9 Peach Bottom Unit 3 Filter A - Precoated 2 Micron Pleated Septa Effluent Fe

Figure 4-10 shows effluent iron concentration behavior with 4 µm rated septa. At the eighth day of Run 1 the effluent concentration was 3 ppb compared to about 0.4 ppb on the tenth day of Run with the 2 µm rated septa in Filter 3A. However, by Run 8 the 2 and 4 µm rated septa were indistinguishable in terms of effluent iron concentration being consistently below 0.1 ppb.

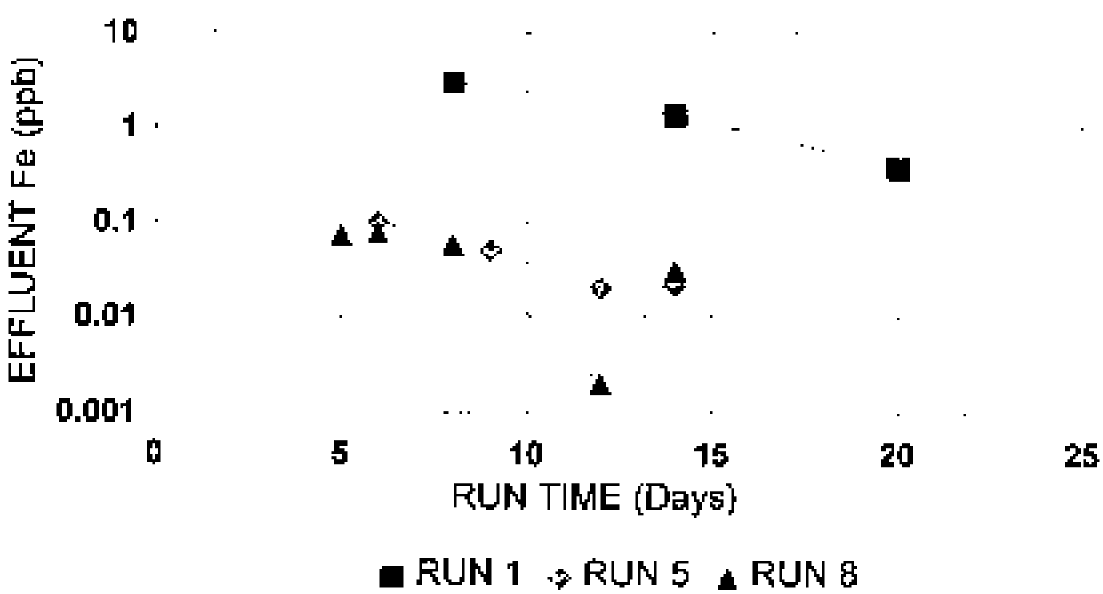

Figure 4-10 Peach Bottom Unit 3 Filter B - Precoated 4 Micron Pleated Septa Effluent Fe

Effluent iron concentration variations during and among runs with the 10 µm rated septa at Peach Bottom may be seen on Figures 4-11 and 4-12. A good amount of reproducibility is evident for the septa in Filters 3D and 3E, with a greater difference between Runs 1 and 2 for the septa in Filter 3E. It remains to be seen if the iron removal characteristics seen in the early runs will continue or if concentrations will decrease as they did with 2 and 4 µm rated septa. It can be noted that all the filter septa with particle retention ratings of 2 to 10 µm eventually achieved effluent iron concentration of 0.1 ppb or less, with the lower rated septa achieving the low concentration sooner.

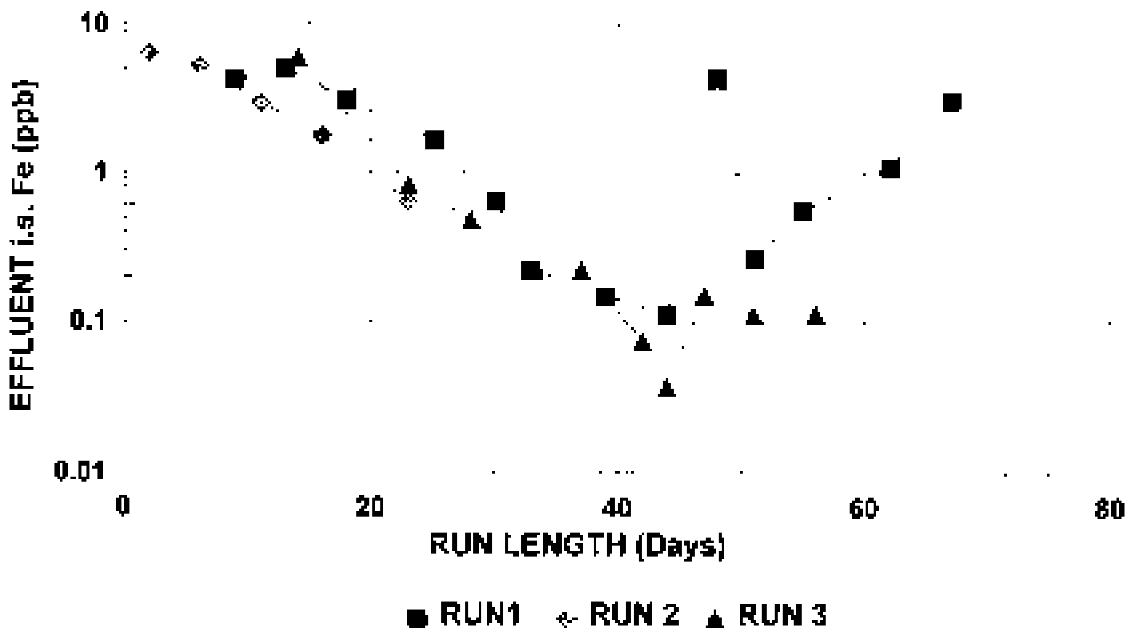

Figure 4-11 Peach Bottom Unit 3 Filter D - Precoated 10 µm Pleated Septa Effluent Fe

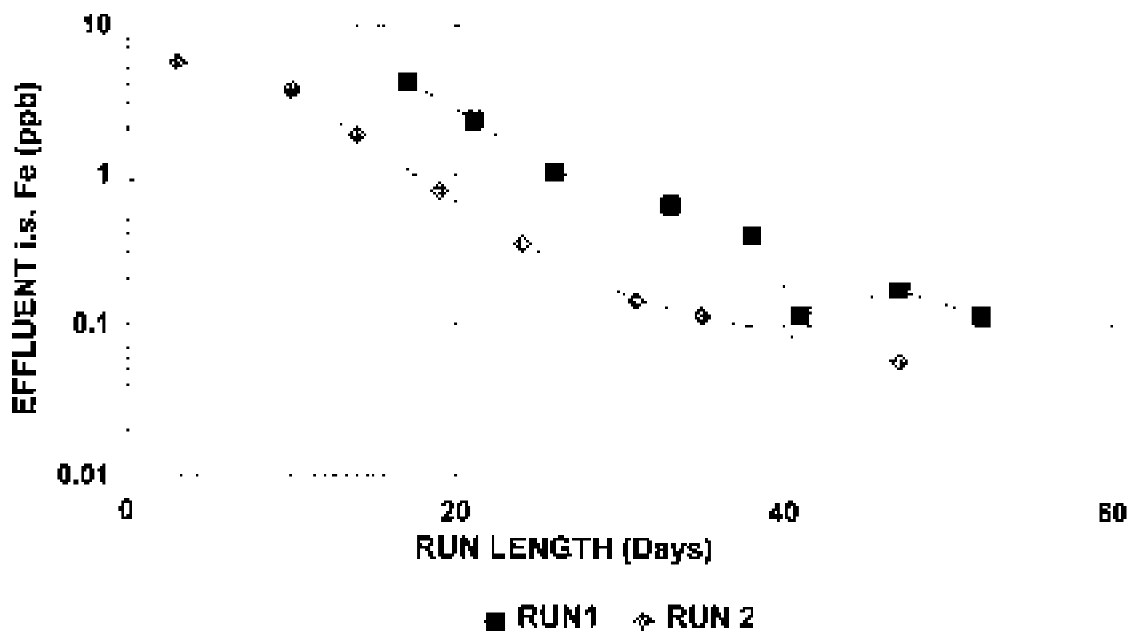

Figure 4-12 Peach Bottom Unit 3 Filter E - Precoated 10 µm Pleated Septa Effluent Fe

Based on the iron removal characteristics of the pleated septa seen thus far, specific operating and installation strategies are being employed at Peach Bottom (23). As already mentioned, pleated septa will be limited to 7 of the ten condensate filters of each unit. The conversion of four additional filter vessels of Unit 2 to pleated filter septa will be done over a sufficiently long time period to minimize the effects on feedwater of the high effluent iron concentrations during the initial use of 10 µm rated septa. Backwashing and return to service of vessels with 10 µm rated septa will be staggered, again to avoid the effects of high initial effluent iron concentrations.

Perry Nuclear Power Plant (non-precoat septa)

Perry operates with the benefits of FWPD and Reheat. The normal condensate flow is 21,000 gpm, equivalent to about 2/3 of the total feedwater flow. At stable full power, the condensate contains an average of 10 ppb insoluble iron prior to passage through the condensate purification system. The purification system as originally designed and now operated contains eight top tubesheet filters followed by deep bed demineralizers. An air bump backwash method is used with the filters.

The rationale for and experience with non-precoat septa were well summarized at the EPRI Workshop on Condensate Polishing and Water Purification In the Steam Cycle (24). The initial attempt to operate the condensate filters without precoats was made in 1991 with Pall Profile cylindrical non-pleated polypropylene septa. After about two months the attempt was terminated when it was apparent that runs were progressively becoming shorter. The first attempt with pleated non-precoat filter septa started in August 1991 using Graver 0.6 µm rated septa. Average run lengths of 30 days and effluent irons < 1 ppb were achieved. However, in July 1995 it was found that the septa's iron removal efficiency had dropped to 65% due to a filter cage joint failure. A second set of Graver pleated septa were placed in service in December 1995, and remain in service. Memtec pleated filter septa first went into service in May of 1995. Currently with 6 of the 8 condensate filters using non-precoat pleated filter septa, feedwater iron is about 0.4 to 0.5 ppb.

Table 4-6 provides run performances statistics for all of the Perry condensate filters currently using pleated filter septa. Runs with the Graver septa have been terminated on the basis of maximum Final ΔP limits recommended by Graver. The Final ΔP limit was increased from 10 psi to 15 psi during consultation with Graver (24), presumably before Run 6. All of the completed runs with Memtec septa were terminated by the start of refueling outages.

Table 4-6
Perry Condensate System - Non-Precoated Pleated Filter Septa Performance

VESSEL	RUN No.	START DATE	RUN LENGTH (days)	AVERAGE FLOW (gpm)	INITIAL dP (1) (psi)	FINAL dP (1) (psi)	AVERAGE dP/DAY (psi/day)
Graver Polyester 0.6 Micron Rating Pleated Septa							
B	1	12/21/95	32	3000	3.1	11.3	0.2563
B	2	1/21/96	5	2700	2.1	9.8	1.5400
B	3	3/18/96	6	2400	2.5	12.5	1.6667
B	4	3/27/96	16	2600	2.5	11.8	0.5813
B	5	4/12/96	3	2900	4.8	11.0	2.0667
B	6	04/17/96	135	3000	4.5	15.0	0.0778
B	7 (2)	9/17/96	7	3000	7.5	9.5	0.2860
Memtec Polypropylene 2 Micron Rating Pleated Septa							
A	1 (3)	11/7/95	69	2950	2	2.3	0.0043

Table 4-6
Perry Condensate System - Non-Precoated Pleated Filter Septa Performance

A	2 (2)	03/18/96	133	3000	1.3	2.3	0.0075
C	1 (3)	06/02/95	220	2900	2.1	4.6	0.0114
C	2 (2)	04/11/96	126	2900	2.3	2.5	0.0016
E	1 (3)	06/03/95	209	2950	2.1	3.5	0.0067
E	2 (2)	04/11/96	103	3000	2.3	3.0	0.0068
F	1 (2)	07/05/96	38	3000	2.1	2.0	-0.0026
Memtec Polypropylene 4 Micron Rating Pleated Septa							
H	1 (3)	05/12/95	239	2800	2.1	2.9	0.0033
H	2 (2)	03/28/96	132	2800	1.7	2.5	0.0061

NOTES

1. Normalized to 3000 gpm; dP = k*(Flow)
2. Run in progress.
3. Run terminated for RFO

With only one completed run per vessel and maximum ΔP Rise Rate of 0.0068 psi/day for the in progress second runs it is impossibly to estimate a definite useful operating life for the Memtec septa. However, given that the septa in Filter C have already achieved more than a year of operating time with a very promising run in progress and that a Final ΔP of 15 psi is acceptable at Perry, a useful life beyond 2 or 3 years appears achievable. In regards to this potentially long useful operating life, it should be noted that the Memtec septa at Perry operate under perhaps the most favorable filtration conditions for plants with full-scale pleated filter applications covered by this report. As reported in Table 1-2 Perry at 10 ppb has the lowest average stable power filter inlet iron concentration, with the next lowest being the 10-12 ppb reported for Brunswick. At an average flow of 2950 gpm per vessel the value for the flow per 10 inches of septum length parameter at Perry is 1.13, the lowest among the plants with full-scale condensate filter applications of pleated filter septa.

From the run statistics summarized in Table 4-6 it is apparent the performances of the Graver and Memtec septa differ. The differences may be at least partially a result of fewer septa per vessel and the operating Final ΔP limits recommended for the Graver septa. The possible significance of the last factor can be seen in the plots of ΔP for Runs 4 and 6 with Graver septa shown on Figure 4-13. Run 4 lasted 16 days and was terminated at 11.8 psi, before the Final ΔP limit was increased from 11 to 15 psi. Run 6, terminated at 15 psi, lasted 135 days. The behaviors of ΔP during the first 16 days of both runs are quite similar. With this perspective its seems the extended run length of Run 6 resulted simply from increasing the Final ΔP limit. It may be recalled that a similar ΔP behavior, a rapid rise followed by a prolonged leveling off, was noted for similar Graver septa operating at Brunswick. As already noted, the CFI iron concentrations are similar at Brunswick and Perry.

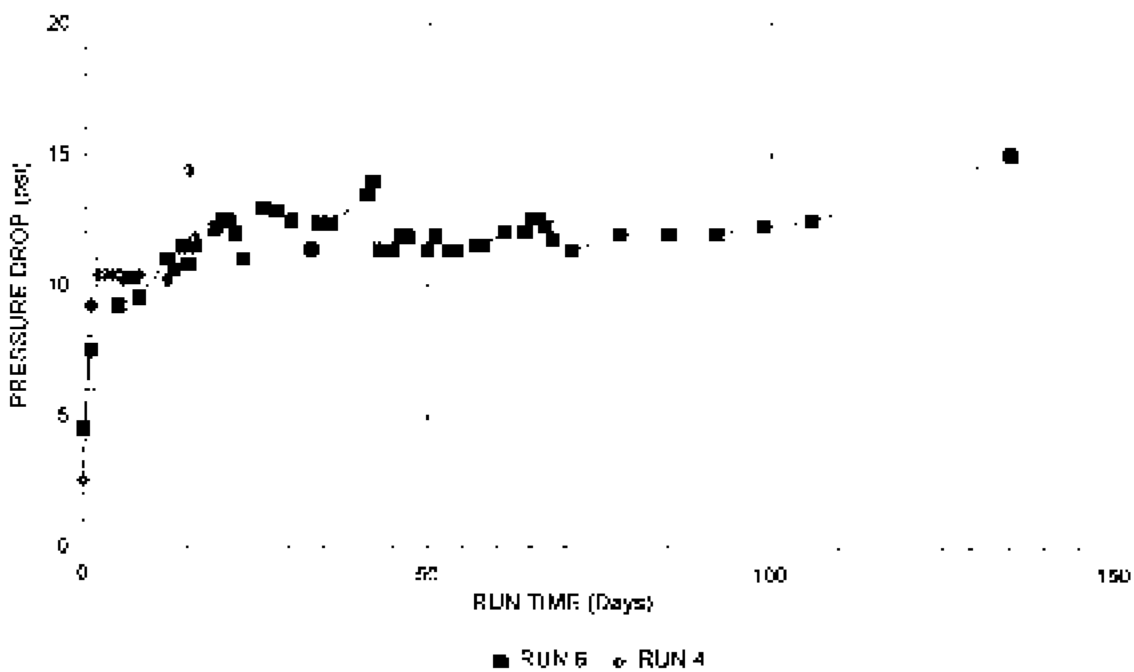

Figure 4-13 Perry Filter B - Graver 0.6 Micron Pleated Septa

It might be speculated that the number of runs with the Graver septa would have been fewer and the average run lengths longer at Perry, if the limiting Final ΔP criterion had been 15 psi from the start of operations. However, the significant increase in Initial ΔP following Run 6 injects a note of caution for such speculation.

Duane Arnold Energy Center (precoat septa)

At Duane Arnold the heater drains are cascaded back to the condenser. However, the plant does have the benefit of Reheat. The average CDI insoluble iron during stable full power operation is 12 to 13 ppb. Five top tubesheet condensate filter/demineralizers are available. Since the plant does not have condensate deep bed demineralizers, the filters must be operated with precoats.

One condensate filter vessel is currently using Pall 2 inch OD polyaramid pleated septa that are 58 inches long with a 1.4 µm particle retention rating. Operations with these septa started in March 1995. With an average flow of 2850 gpm to the vessel containing 336 pleated septa, the flow per 10 inches of septum length is about 1.5.

The precoat dose of a fiber-resin precoat material used with the pleated septa is about 0.09 dry pounds per 10 inches of septum length. This is considerably higher than the dosage of about 0.03 dry pounds per 10 inches of length being used with upright pleated septa at Browns Ferry and Peach Bottom where minimum doses are used to minimize the cost of precoat material procurement and disposal. At Duane Arnold precoats are retained on a woven metal screen which is part of the cylindrical cage which surrounds the pleated filter media. Whereas, at Browns Ferry and Peach Bottom the precoat material is retained by the pleated filter media.

In response to recent inquiries, Duane Arnold personnel stated average run lengths for the pleated septa as being 40 days and longer than those achieved with the 1 inch OD cylindrical septa (744/vessel) being used in the remaining 4 filter vessels. There are plans to install a set of Pall pleated septa in an additional condensate filter vessel. The additional set will use 2.5 inch OD septa and presumably the 1 µm rated polyolefin filter media as currently in use at Limerick.

Hatch Nuclear Plant (precoat septa)

At Plant Hatch heater drains are cascaded to the condenser, however, the plant does have the benefit of Reheat. Condensate filter/demineralizers are used to process the full power condensate flow of approximately 23,000 gpm. The seven condensate bottom tubesheet filters supplied by Graver Water are normally in service during full power operation. During an EPRI sponsored survey of BWR plants, an average stable full power CDI iron concentration of 15 ppb was reported for Plant Hatch.

Since Plant Hatch does not include deep bed condensate demineralizers, the condensate filter septa must be operated with precoats containing ion exchange resins. In January 1995 the 302 yarn wound filter septa in Filter D of Unit 1 were replaced with Pall polyaramid pleated septa with a particle retention rating of 1.4 µm. The pleated septa have a nominal O.D. of 2 inches and are 80 inches long. With an average flow of

3400 gpm/vessel, the flow per 10 inches of septum length is 1.4, the precoated yarn wound septa in the other filters also operate at 1.4 gpm per 10 inches of septum length.

The pleated septa precoat dose is 216 dry pounds per precoat, or 0.09 dry pounds per 10 inches of septum length as also used on the Pall polyaramid pleated septa at Duane Arnold. The precoat material used is P202H, a Graver Water product with an approximate dry weight composition of 33% fiber, 30% cation resin and 37% anion resin.

Average run lengths with the pleated septa as of mid-1996 were about the same as for vessels using wound septa which, as recently as 1995, was reported (25) as about 35 days for Unit 1. However, whereas vessels with yarn wound septa had effluent iron concentrations < 1 ppb, the concentration has been consistently below 0.1 ppb in the effluent from Filter D while using the pleated filter septa.

Monticello Nuclear Generating Plant (precoat septa)

Monticello has neither FWPD nor Reheat. The normal full power condensate flow rate is 13,750 gpm with an average CDI insoluble iron concentration of about 15 ppb. The condensate polishing system consists of five bottom tubesheet filter/demineralizer vessels supplied by Graver Water, all are normally in service during full power operation. In the absence of deep bed condensate demineralizers, all of the condensate filters must be operated with precoats containing ion exchange resins.

Memtec polypropylene pleated filter septa with a 4 μm particle retention rating were installed in one condensate filter vessel with their initial run starting on February 7,1996 and terminating on April 10, 1996 for the start of an outage; run length about 63 days. With an average flow of about 2750 gpm/vessel and 302 sixty inch long septa per vessel, the septa operated at 1.5 gpm/10 inches of septum length. The length based rate at Monticello is lower than at Browns Ferry, and slightly higher than at Peach Bottom and Quad Cities where Memtec precoated pleated septa are also in use.

An all resin precoat was used during the initial run at a dose of about 0.03 dry pounds per 10 inches of septum length. The precoat composition on a dry weight basis was 75% cation resin and 25% anion resin. To reduce initial effluent iron from the septa (about 4 ppb) an all fiber material was body fed at a rate of 0.5 dry pounds/hour.

Since the condenser re-tubing (304 SS), there have been no condenser leaks at Monticello. Installation of Memtec pleated filter septa in two additional condensate filters is planned, using 10 rather than 4 μm rated septa for the additional vessels.

Quad Cities Nuclear Power Station (precoat septa)

At Quad Cities the single vessel trials of pleated filter septa have been at Unit 2. The Quad Cities units have neither FWPD nor Reheat. Normal full power condensate flow is 17,850 gpm with an average CDI insoluble iron concentration of about 14 ppb during stable operations.

There are seven condensate filter/demineralizers for each of the units, and all are normally in service during full power operations. Since deep bed demineralizers are not a part of the condensate polishing systems of either unit, the filters must operate with precoats. The bottom tubesheet filters were supplied by Graver Water and use the Graver Air Surge backwash method.

Each condensate filter vessel contains 302 septa with a triangular pitch center-center spacing of 3.5 inches. As originally supplied and operated the vessels used 2 inch O.D. yarn wound septa with 60 inch lengths.

In June 1995 trials with pleated filter septa were started using 302 Pall 2 inch O.D. by 60 inch long polyaramid precoatable septa with a 1.4 μm particle retention rating. Utility personnel judged the performance to be unsatisfactory and the trial was terminated.

In January of 1996 a second trial of pleated filter started using Memtec polypropylene filter media septa in a single vessel. These septa have a 4 μm particle retention rating, and an O.D. of 2.5 inches and 60 inch lengths. The filter media surface area per septum is about 60 ft^2 compared to about 21 ft^2/septum for the Pall septa used in the first trial. At 2550 gpm/vessel the flow per 10 inches of septum length is about 1.4 gpm for both the Pall and Memtec septa used in the trial.

Precoat doses used with the Pall pleated septa were not reported. However, since precoats on Pall septa are applied to a cylindrical surface as with the yarn wound septa, the standard precoat dose of 0.2 dry pounds/ft^2 for yarn wound septa might be assumed. For the Quad Cities septa this would result in about 0.5 dry pounds/septum or about 0.08 dry pounds per 10 inches of septum length.

The precoat dose used for the two completed runs with the Memtec pleated filter septa was 0.28 dry pounds/septum, or 0.05 dry pounds per 10 inches of septum. With Memtec septa the precoats are retained on the pleated filter media and Memtec personnel have recommended that the precoat dose be limited to what can be accommodated in the volume between the pleated filter media and the underside of the surrounding outer cage. The intention at Quad Cities is to reduce the precoat dose for the Memtec septa to about 0.24 dry pounds/septum. The precoat material used with the Memtec septa at Quad Cities contains no fibers and has a dry weight ratio of cation to anion resins of 4/5.

The two completed runs with Memtec septa were terminated at a Final ΔP equal to the Initial ΔP plus 5 psi. The average run lengths were about 50 to 60 days. In both runs effluent iron concentrations started at 4 to 5 ppb but declined to > 0.1 ppb by the seventh day of operation. Operating time with the Memtec septa has been limited due to plant down time.

Use of Memtec polypropylene pleated filter media septa in one condensate filter of Unit 1 is imminent. Quad Cities personnel are considering the future use of 10 μm rated Memtec pleated septa in an effort to increase effluent iron concentrations.

5

MAJOR ISSUES AND THEIR CURRENT STATUS

Full-Scale Application Service Times

Only pleated filter septa have been used in full-scale BWR condensate applications in the United States for improved iron removal. HFF devices, widely used in Japan to produce low effluent iron, are not used in the United States because they are more expensive than FMF pleated filter septa (16). Cylindrical filter septa have been eliminated from consideration due to run lengths appreciably shorter than those achievable with the pleated septa.

The suppliers of pleated filter septa for BWR condensate applications thus far have been Graver, Memtec and Pall. The earliest and continuing use of Graver pleated septa is at the Brunswick Nuclear Project where the non-precoated filter septa began service in August of 1994. For the Memtec septa, the earliest and continuing uses started in May of 1995 at the Perry Nuclear Power Plant, a non-precoat application, and the Peach Bottom Nuclear Power Station, a precoatable septa application. Pall currently offers two alternative filter media for BWR condensate applications, polyaramid or polyolefin. Polyaramid precoatable septa remain in service at several BWR power stations. The earliest application with continuing use started in January of 1995 at Plant Hatch. The first full-scale and continuing use of Pall's polyolefin non-precoat septa began in December of 1995 at the Limerick Nuclear Generating Station.

Table 5-1 lists the maximum cumulative in-service times through September 23, 1996 for the various types of septa remaining in service. The list includes only plants for which filter run logs were available for the calculation of service times. In the case of precoatable septa, it is conceivable that the Pall pleated polyaramid septa at Plant Hatch and at the Duane Arnold Energy Center may have achieved service times equal to or greater than the 2 and 4 μm rated septa at Peach Bottom.

Table 5-1
Maximum Full-Scale In-Service Times Of Pleated Filter Septa As Of 9/23/96

Plant	Average CDI Fe (ppb)	FWPD	Tubesheet Location	Backwash Method	Nominal Septum O.D. (in)	Flow Per 10" Septum Segment (gpm)	Particle Retention Rating (Microns)	Media Material	Pleat Type	Septa Supplier	Longevity (yrs)
PRECOAT SYSTEMS											
Peach Bottom	15	No	Bottom	Air Surge	2.5	1.36	2	Polypropylene	Upright	Memtec	1.10
Peach Bottom	15	No	Bottom	Air Surge	2.5	1.36	4	Polypropylene	Upright	Memtec	1.16
Peach Bottom	15	No	Bottom	Air Surge	2.5	1.36	10	Polypropylene	Upright	Memtec	0.43
Browns Ferry	17	No	Bottom	Air Surge	2.5	1.74	2	Polypropylene	Upright	Memtec	0.32
NON-PRECOAT SYSTEMS											
Brunswick	11	Yes	Bottom	GRV MOD III	2.5	1.70	0.6	Polyester	Upright	Graver	1.34
Limerick	14	No	Bottom	Air Surge	2.5	2.30	1	Polyolefin	Fold-Over	Pall	0.65
Perry	10	Yes	Top	Air Bump	2.5	1.90	0.6	Polyester	Upright	Graver	0.56
Perry	10	Yes	Top	Air Bump	2.5	1.07	2	Polypropylene	Upright	Memtec	0.95
Perry	10	Yes	Top	Air Bump	2.5	1.07	4	Polypropylene	Upright	Memtec	1.02

The listing in Table 5-1 under Non-Precoat Systems indicates the maximum longevities achieved at the time of this report for septa remaining in service from each of the three suppliers. That is, the maximum in-service experience times are 1.34 years, 1.02 years and 0.65 years for Graver, Memtec and Pall septa, respectively.

Managing Feedwater Iron Concentrations

The iron removal in the full-scale applications of pleated filter septa from all three suppliers generally has been very good. The two known incidents of mechanical failures occurred with Graver septa, a cage joint at Perry and at the septa/tubesheet seal at Clinton. In the absence of mechanical failures all pleated septa have demonstrated the ability to achieve effluent iron concentrations of 0.1 ppb or less. Because of the expected upward revision of BWR guidelines for optimum feedwater iron concentrations to 1 ± 0.5 ppb, the effluent iron concentrations are actually too low.

Memtec pleated septa with 2, 4 and 10 µm ratings have been used with the hope that the higher rated septa would provide higher effluent iron concentrations. After 5 runs or less the effluent concentrations from 2 and 4 µm rated septa were indistinguishable. Precoated 10 µm Memtec septa at Peach Bottom show some early promise of higher average effluent irons. At the time of this report three runs had been completed with a fair degree of reproducibility. Initially effluent iron concentrations were 6 to 7 ppb, declining to 1 ppb in 20-30 days and to 0.1 ppb after about 40 days. This behavior will be useful for feedwater iron concentration management only to the extent that it is sustainable. That is, backwash effectiveness will be important not only for maintaining run lengths but also for sustaining effluent iron concentrations.

Useful Septa Lives

At this point, only speculative estimates of ultimate useful lives of pleated filter septa in full-scale BWR condensate applications are possible. In addition, these speculative values are specific to the operating conditions and practices at each plant for which a speculative estimate could be made. Despite these qualifications, it appears that the useful lives of 3 to 4 years expected by users (20) and suppliers (22) may be achievable under only the most favorable conditions.

Figures 5-1 and 5-2 provide an indication of application challenge severity for current and anticipated full-scale applications, and the current Hope Creek Test Stand pleated septa in terms of Flow Per Ten Inches of Septum Length and Average Full Power CDI Fe Concentrations. These two parameters are strong determinants of run lengths and useful lives. Other important factors are backwash methods and the nature of influent insoluble solids. In these plots, the applications at each station are plotted vertically above or below the station name. The applications shown for Clinton on Figure 5-1 are for the second sets of septa from each supplier, none of which were in operation at the time this report was prepared.

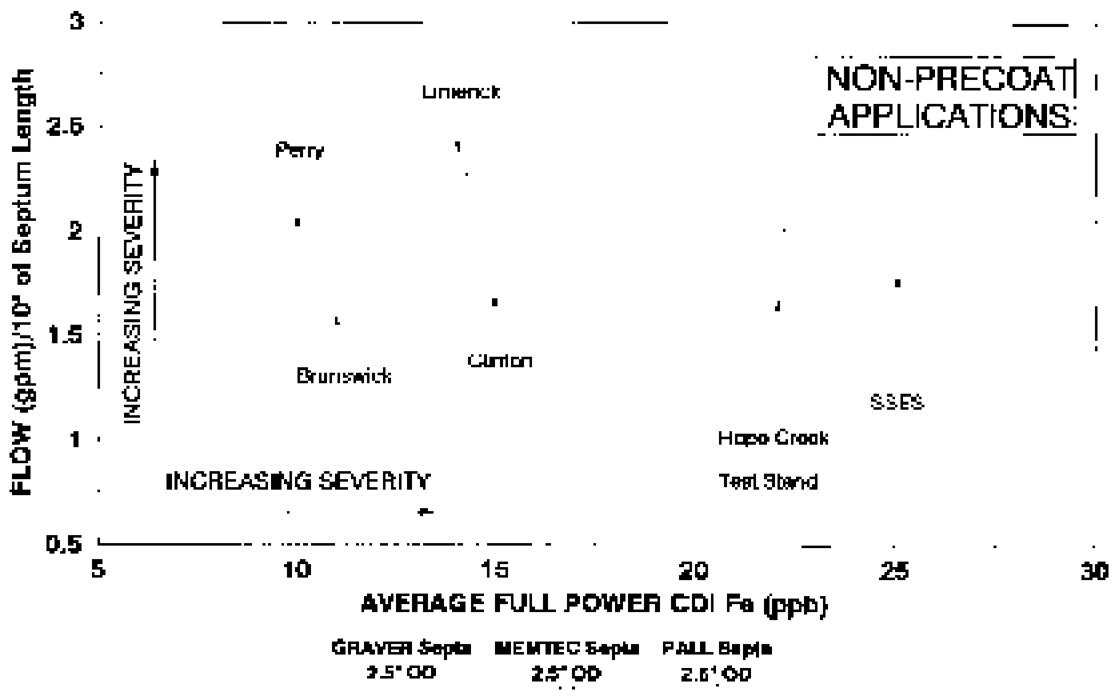

Figure 5-1 Run Length & Useful Life Challenge Severity - Non-Precoated Filter Septa

Since the pleated septa from the three suppliers differ in filter media material, filtration area per unit length and pleat configuration, these plots cannot be used to predict relative performance of septa from different suppliers at the same application. The use of the plots is in comparing the challenge severities among applications of septa from the same supplier. For example, on Figure 5-1 the challenge to be encountered by the second sets of Graver and Memtec septa at Clinton will be more severe than the challenge to the same types of septa at Perry. Top tubesheet vessels and air bump backwashes are used at Perry and Clinton; however, the backwash methods are not necessarily identical at the two stations. The Pall polyolefin pleated filter septa challenge at Limerick is more severe than the challenge to be encountered by the second set of Pall septa at Clinton. At Limerick the Pall septa are in bottom tubesheet vessels using a six surge air surge backwash method. Top tubesheet vessels are used at Clinton; the backwash method that will be used with the second sets of septa has not been determined.

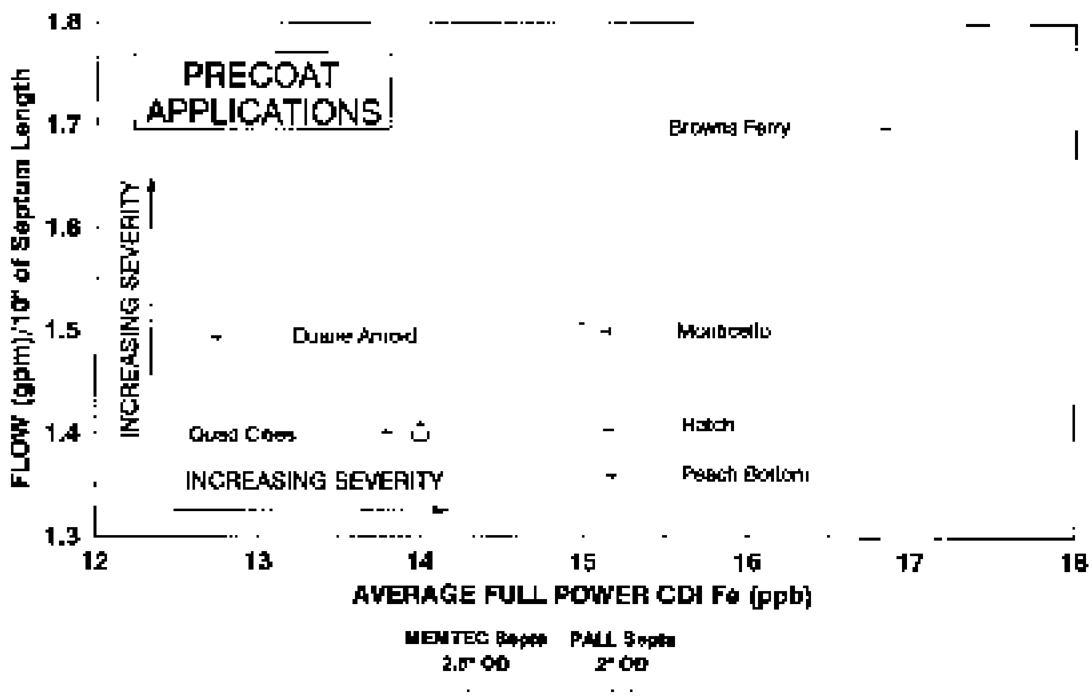

Figure 5-2 Run Length & Useful Life Challenge Severity - Precoated Filter Septa

Of the Non-Precoat applications shown on Figure 5-1, only the Memtec septa at Perry, the Graver septa at Brunswick, and the Pall Septa at Limerick have sufficient service time and evaluated data to allow even speculative estimates of ultimate useful lives. The speculative values as stated in this report with qualifications are: greater than 2 or 3 years for the Memtec septa at Perry; at least 2 years for the Graver septa at Brunswick; and, about 2 years for the Pall polyaramid septa at Limerick.

Of the fourteen BWR plants now operating without condensate filters, seven have average full power CDI iron concentrations of 15 ppb or greater. The performance data for the current septa operating at the Hope Creek Test Stand could not be used for useful life projections because only three runs had been completed with a fourth started for septa from each of the three suppliers. Unfortunately operation of the test stand will be terminated before the end of 1996. Therefore, the first indications of non-precoat pleated filter performance at a domestic BWR plant with CDI iron of 15 ppb or greater will be at Susquehanna Unit 1, forecasted to start in August of 1997.

Figure 5-2 depicts the challenge severity for condensate filtration applications of precoated pleated septa. At all of the plants shown, except for Duane Arnold, the pleated septa are in bottom tubesheet vessels. All of the bottom tubesheet vessels, except for those at Hatch, use the Graver Air Surge backwash method. A steady-state water and air scour method is used at Hatch.

The current full-scale applications of precoated pleated septa bracket the full range of potential additional precoated applications. All of the plants with potential applications would have challenge severity parameters less than those at Browns Ferry. The average run length for the three runs completed at Browns Ferry is about 40 days with all runs terminated at 8 psi. The three runs are too few for even a speculative estimate of ultimate useful life for the septa at Browns Ferry. At Peach Bottom the average run length for 13 runs with Memtec pleated septa is 33 days with Final ΔP varied from 3 psi to 9 psi. The ultimate useful is speculated to be about 2 years while maintaining 30 day run lengths with Final ΔP values at 10 psi or less.

Speculative ultimate useful life estimates for the applications at Duane Arnold, Hatch, Monticello and Quad Cities cannot be made. The trials with 2 inch OD Pall polyaramid precoatable septa at Quad Cities was terminated in less than 6 months due to short run lengths. Pall now offers 2.5 inch OD precoatable septa. Duane Arnold and Hatch have verbally reported average run lengths with Pall septa in the range of 35 to 40 days. Initial runs at Monticello and Quad Cities with Memtec septa were reported to be in the range of 50 to 60 days.

Backwash Methods

For a given influent rate and quality, the primary determinants of run length and filter septa useful lives are the filter septa construction and the backwash method used. That is, the filter septa and the backwash method operate as a system and must be perceived and evaluated as such.

The validity of the system concept for pleated filter septa in BWR applications has been demonstrated. On the Hope Creek Test Stand the run length performance of Filter H (Pall polyaramid) was improved significantly by modifications to the backwash method employed. Later, the failure of filter septa similar to Filter H to perform well at Limerick was attributed (14) to a backwash method much less rigorous than the modified backwash used on the Hope Creek Test Stand. At both Brunswick and Peach Bottom temporary run length declines are suspected to have resulted from temporary backwash system problems. At Clinton, where the first sets of septa from all three suppliers fell short of expectations, filter septa characteristics <u>and</u> backwash methods will be changed.

Steady state backwash methods are used with the full-scale bottom tubesheet applications of pleated septa at Brunswick (non-precoat) and Hatch (precoat). Initial ΔP values have increased at Brunswick; however, runs lengths remain acceptable. Run lengths at Hatch are reported as being about the same as with yarn wound cylindrical filter septa.

Non-steady state bottom tubesheet air surge methods are used with full-scale pleated septa applications at Browns Ferry (precoat), Limerick (non-precoat), Monticello (precoat), Peach Bottom (precoat) and Quad Cities (precoat). Browns Ferry has the most severe challenge of the full-scale precoat applications, and run lengths and Initial ΔP have remained stable, albeit for only three complete runs. Of the non-precoat full-scale applications, Limerick has the highest challenge severity. The Initial ΔP at Limerick through 8 completed runs has increased less than 1 psi. However, whereas the initial run Final ΔP was 4.5 psi after 35 days, the Final ΔP for Run 8 was 7 psi after 28 days. The air surge method used at Limerick differs from the Graver Air Surge method. Among the differences are 6 surges per backwash cycles compared to 8 in the Graver normal sequence.

A direct comparison of steady state and non-steady state backwash methods with bottom tubesheet vessels is not available in the full-scale applications due to variations in operating conditions and septa suppliers. However, it is suspected that the non-steady state methods may provide significant advantages over the steady state methods. Although the service times with the current pleated septa at Browns Ferry and Limerick are short, the performance to date at both stations with high challenge severity does lend support to a preference for non-steady state methods.

The current non-steady state methods used with bottom tubesheets are amenable to improvement. Septa attachment methods with lower flow resistances would increase achievable maximum backwash velocities. Delaying the onset of two phase flow and minimizing its effect would also benefit backwash effectiveness. Increasing air delivery line sizes and/or shortening line lengths, if practical, would improve backwashing. Raising starting air pressures, within the limits of vessel design pressures, would increase backwash velocities. To maintain backwash effectiveness, operation of the backwash system should be carefully and routinely monitored. Valve operating sequence, the opening speed of the quick-opening air valve, and the maximum ΔP across the tubesheet during surges should all be included in a monitoring program.

Non-steady state backwash methods are used at all of full-scale applications of pleated filter septa in top tubesheet filter vessels. The pleated filters at Duane Arnold (precoat) and Perry (non-precoat) were retrofitted to condensate filter systems supplied by Delaval which include the supplier's backwash method. The first sets of pleated septa at Clinton (non-precoat) used proprietary backwash methods prescribed by the three septa suppliers. Although the methods are classified as proprietary, it has been acknowledged that all three were non-steady state.

The application challenge severities are low at Duane Arnold and Perry. At both stations run lengths with pleated septa are significantly longer than with the cylindrical filter septa used previously. Since Pall septa are in use at Duane Arnold, and Graver and Memtec septa are in use at Perry it might be inferred that the Delaval supplied backwash method is satisfactory for use with pleated septa. However, because of the low application challenge severity in both cases it remains problematic whether the backwash is satisfactory for more severe application conditions.

At Clinton the run length performance of the first sets of pleated septa from each of the three suppliers was judged unsatisfactory. Recognizing that the filter septa and backwash method must be considered as a system, a single new backwash method will be employed with the three new filter vessels to be added. The original three vessels will use revised backwash methods as prescribed by the three septa vendors.

Conventional non-steady state backwash methods used with top tubesheet filters may not be sufficient to attain optimum performance and useful lives of pleated filter septa in high challenge severity applications. The poor performance of the initial sets of pleated filter septa at Clinton may be at least partially attributed to ineffective backwashing. In addition, although the Initial ΔP and Average ΔP/Day values for the Memtec septa at Perry have remained stable, the Initial ΔP of Graver septa at Perry have increased significantly. The Graver septa at Perry are challenged more severely than the Memtec septa due to fewer Graver septa per vessel.

These current non-steady state backwash methods are not amenable to improvements. Air pressure increases are limited by filter vessel design pressures. Increasing the number of air bumps per backwash cycle is limited by available liquid waste storage and processing capacity. On existing systems, increasing the size or shortening the length of drain lines to increase backwash velocities may be impractical.

More substantial changes to the backwash methodology, or to the filter septa construction to render them more easily cleanable may be required to obtain optimum performance. The author's method (11) allowing surge deliveries to vessels with liquid-free lower chambers is an example of a substantially different backwash methodology. Modifications to filter septa construction might include but not be limited to filter media material, types of support and drainage layers, particle retention ratings, and number and configuration of pleats. The improved run length performance obtained at Limerick by changing from polyaramid septa to polyolefin septa with more filtration area, a greater number of pleats and different support layers is an example of septa construction modifications making the septa more easily cleaned.

Ion Exchange Performance

The issue of ion exchange performance is only pertinent for users of pleated filter septa that must be precoated because the condensate filters are not followed by deep bed demineralizers. There are fourteen BWR systems for which ion exchange performance is pertinent. Of the fourteen, six are conducting single vessel trials with pleated filter septa, and at Peach Bottom seven of ten condensate filters in Unit 3 and three of ten in Unit 2 are using precoated pleated filter septa.

Ion exchange performance became an issue when pilot plant performance test results from a septa supplier's laboratory became available. The results clearly demonstrated that ionic leakage through precoats on upright pleated septa was appreciably higher than through a precoat on cylindrical yarn wound filter septum. The yarn wound septum is typical of those used in filter/demineralizers prior to the recent use of pleated filter septa in BWR condensate applications.

The issue of ion exchange performance with pleated filter septa is fraught with uncertainties. Ion exchange performance test results are available for only one of the several types of pleated filter septa being offered for applications requiring precoats. Ion exchange performance results available are for the Memtec upright pleated septa on which precoats are applied directly to the pleated filter media. Results are not available for the pleated filter septa offered by Graver and Pall for applications requiring precoats. There are currently no BWR condensate applications of Graver pleated septa using precoats. The most recent Graver offering of a pleated filter septum that may be used with or without precoats, consists of an outer layer of wound yarn on a support cage that surrounds the upright pleated filter media. Currently Pall offers 2 inch and 2.5 inch nominal O.D. polyaramid fold over pleated septa with a surrounding wire mesh forming a cylindrical surface to which the precoats are applied.

The available pilot plant tests were operated only to a 15% utilization of the ion exchange resin's ultimate capacity at which point ionic leakage had increased to 8% with indications that the rate of increase was becoming greater than linear. Of the full-scale applications of precoated pleated filter septa, only the applications at Peach Bottom Units 2 and 3 involve more than 1 vessel of the multiple filter vessel systems. Both Peach Bottom units have titanium condenser tubes and a low incidence of condenser tube leaks. In addition, the Peach Bottom units have the lowest flow per 10 inches of septum length, 1.36. Browns Ferry Unit 2 has the highest at 1.7 gpm per 10 inches of septum length.

Unfortunately the full-scale application experiences thus far do not provide an insight to the impact of ionic leakage. For leakage from precoated pleated septa to have a discernible effect on reactor water quality, close to a majority of the filters in the condensate system must be using pleated filter septa. Only the condensate system at Peach Bottom Unit 3 meets this criteria. However, the Peach Bottom units have a low incidence of condenser leaks.

The available pilot plant data provides a guide only for ionic loading up to 15% of the anion resin's ultimate capacity. To provide practical run lengths under condenser leak conditions at plants with high dissolved solids cooling waters, loading beyond 15% of ultimate capacity may be required.

As stated earlier in the Pilot Plant Tests section under the Ion Exchange Performance heading, the consequence of ionic leakage is plant specific and dependent on a number of factors. Major among these factors are cooling water quality, and tube leak frequency and severity.

Handling Backwash Waste Liquids

Because of the long run lengths expected, and in most cases realized, with pleated filter septa, the iron concentrations in backwash waste liquids are much higher than encountered heretofore with precoated filter demineralizers. Therefore, there is a high probability of shorter radwaste filter run lengths when processing the backwash waste liquids. This problem has already been encountered and plants are seeking solutions (24).

Recommendations On Resolution of Outstanding Issues

Continued and focused monitoring of full-scale applications of pleated filter septa is essential. With the termination of operations at the Hope Creek Test Stand, objective evaluations of full-scale applications offer the only hope of eliminating uncertainty of useful septa lives; the major economic issue after initial capital costs. Full-scale experience will also be the basis of determining whether filter septa particle retention adjustments and/or iron additions will be practical tools for managing feedwater iron concentrations. Continued monitoring of full-scale applications of precoated pleated filter septa, together with additional pilot plant tests, is required to resolve the serious ion exchange performance issue. Monitoring should encompass following means of handling backwash waste liquids with higher iron concentrations due to longer run lengths with pleated filter.

Although all full-scale applications should be monitored, some merit particularly close scrutiny. Among these are the non-precoat applications at Limerick, Clinton and Susquehanna on the basis of their high application challenge severity. The applications of precoatable pleated septa at Browns Ferry and Duane Arnold also deserve close monitoring. Browns Ferry has the highest challenge severity of the current full-scale applications of precoated pleated septa, and Duane Arnold has the only full-scale use of precoated filter septa in a top tubesheet filter vessel. The units at Peach Bottom also warrant close monitoring since they currently have the highest percentage of condensate filters using precoated pleated filter septa. For those plants deserving close scrutiny, details on backwash method operations and precoat operations, where used, and frequent measurements of influent iron concentrations would be of particular value in evaluating and comparing performances.

Quantification of Backwash Velocities and Volumes is required to fully evaluate and compare performance of pleated filter septa at the variety of full-scale application sites.

Although the critical importance of backwash effectiveness to useful lives of reusable filter septa is universally acknowledged, few, if any, measurements have been made to indicate actual backwash velocities achieved with the variety of backwash methods used at full-scale application sites. Lacking such measurements, it is impossible to objectively evaluate the relative performance of different septa when each is backwashed with a different method. Given the economic importance of useful life projections, efforts to quantify backwash velocities should be undertaken.

Means of Improving Existing Backwash Effectiveness and New Backwash Methods should be investigated. Based on currently available data, speculative estimates of useful lives of about 2 years have been stated for the pleated filter septa in condensate filters of 6 BWR systems. Two years is significantly less than the 3 to 4 years frequently anticipated by users and septa suppliers. Only at Perry for filter septa operating under a low application challenge severity was the stated speculative estimated useful life beyond 2 or possibly 3 years.

There are nine BWR units, including both Susquehanna units and the Hope Creek unit, that are operating without condensate filters and which have reported full power average feedwater irons of 2.8 ppb or greater with average CDI irons of 14 ppb or greater. That is, there are nine likely candidates for condensate filter retrofits for which the application severity may be high. It may be noted on Figure 5-1 that flows per 10 inches of filter septum length are higher on systems to which filter vessels were retrofitted (Clinton and Susquehanna) than on systems originally built with condensate filters. The flow rates per septum lengths for the Graver septa at Perry and the Pall septa at Limerick are unnecessarily high. At both stations, significantly larger numbers of pleated filter septa per vessel could have been installed.

Depending on the nature of the potential backwash improvements and new methods, evaluations could be made through pilot plant testing or full-scale trials. If pilot plant tests are used, backwash effectiveness could be judged by achievable backwash velocities, thus avoiding the need to install and operate the system within radiologically controlled areas. Pilot plant systems must be designed to allow convenient and straight forward scale up to full-scale plant conditions.

Additional and more comprehensive Pilot Plant Ion Exchange Performance Tests are required, at least to the extent that performance with all types of the current commercially available precoatable pleated filter are predictable, and optimum precoat materials and dosages are identified. A possible additional benefit of such tests could be the discovery of practical septa construction modifications to enhance ion exchange performance.

6

GUIDE TO USE OF FULL-SCALE OPERATING EXPERIENCE

As indicated on Table 5-1, the maximum service time for pleated filter septa in full-scale BWR condensate applications is less than 18 months. Despite the short service times, it is inevitable that the current and future full-scale operating experience will be an important part of decision making processes concerning the use of pleated filter.

The guide set forth here is based mainly on common sense, and is directed at selecting the most appropriate full scale operating experience for projecting performance for an intended use of pleated filter septa at a specific BWR unit. Because of the current scope of operating experience, many carefully considered judgments will be required in its use. For example, there are no BWR condensate applications of Graver precoated pleated filter septa; the only BWR application of precoated pleated filter septa in a top tubesheet vessel is at Duane Arnold; there are no non-precoat BWR applications of Memtec septa in bottom tubesheet vessels; and, there is no BWR operating experience with non-precoat pleated filter septa at plants with average CDI iron concentrations greater than 15 ppb.

The first step in selecting appropriate full-scale experience is to limit the selection to either non-precoat or precoat applications. Neither specific nor relative performance of different type pleated filter septa are transferable between the two types of application.

The next two factors to consider are the average CDI iron concentrations and the flow per 10 inches of segment length at the full-scale plant from which performance data is available. These two factors can be considered together, and plots similar to Figures 5-1 and 5-2 may be useful in the selection. Of the two parameters defining application challenge severity as shown in Figures 5-1 and 5-2, the flow per 10 inches of septum length should be given more weight. The flow factor effects both the rate of loading per unit length of septum and the ΔP at a given loading. Therefore, one might quantify and define an Application Challenge Severity Index as the product of CDI iron concentration multiplied by some power of the flow per 10 inches of septum length. This quantification can enhance the use of the challenge severity concept for selecting appropriate full-scale operating experiences.

Next, if possible, performance data from vessel configurations, top or bottom tubesheets, that match the user's intended application should be given preference.

Backwash and septum attachment methods are somewhat dictated by vessel configurations. Precoat uniformity is also influenced by vessel configuration.

Backwash methods employed at the various sites from which performance data are available should be the next consideration. Data from plants with backwash methods that can be adapted to the user's intended application are preferred.

Additional factors should be considered when precoated pleated filter septa will be used in the intended application. In these cases performance data source plant sites with cooling water concentrations and compositions most closely approximating conditions at the user's intended application should be given preference. These cooling water factors should be given more weight than the vessel configuration during the process of selecting appropriate performance data sources. Types and dosages of precoat materials used at data source plants should also be considered; their use should be at least feasible in the intended application.

Although not included in the above specific factors for selecting appropriate full-scale operating experiences, the longevity of performance of the pleated septa at the various full-scale sites is important. To even speculate on useful service lives, at least 6 months of service time are required. When the intended application includes low hydraulic head limitations, the available full-scale performance data should be evaluated in relation to the Final ΔP values associated with the run length performance achieved at the data source plant.

7

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A

GLOSSARY OF FILTRATION TERMS

Terms	Description
Absolute Particle	A degree of filtration, usually referring to 100% removal of rigid particulates greater than a stated size.
Retention Rating	Significance depends on determination method.
Absorb	Incorporation of one substances in another.
Adsorb	Attracting and holding a gas, vapor, or liquid on the surface of a solid.
Adsorbent	A solid material which adsorbs, such as clay, carbon, activated alumina, etc.
Amorphous	Non-crystalline, having no determinable form.
Backwash	The reverse flow of air and/or liquid through the filtration media to effect solids removal.
Baffle	A plate protecting filter elements from the velocity of flow entering vessel.
Blind Spots	A place in the filter media where no filtration takes place.
Blinding	Reducing or shutting off of flow due to closing "pores" in the filter media.
Bridging	Accumulated particles arching between adjacent filter septa.
Bubble Point	The minimum pressure at which air can displace a liquid from the capillary pores of filter media. Pore size is inversely proportional to bubble-point. Test liquid and temperature should be specified.
Cake	Solids deposited on the filter media.
Clarity	Clearness of a liquid measured by transmission or

	reflectance of incident light. The opposite of turbidity.
Compressibility	Dimensional change in a filter cake when subjected to compressive force.
Cycle	Filtration interval; length of time filter operates before cleaning.
Delta P (ΔP)	The difference in pressure between two given points.
Depth Filtration	Particulate removal from fluids by entrapment within filter media.
Differential Pressure (dP)	Infinitesimal change in P as used in dP/dt.
Effluent	Fluid exiting a vessel or process system.
Element	Another term for septum.
Filter	Device used to remove insoluble solids.
Filter Media	The material upon which the cake of precoat or suspended solids is formed.
Filtrate	Liquid which has passed through the filter.
Filtration	The process of removing insoluble solids from a fluid.
Filtration Area	The surface through which the fluid flows.
Fines	Particles which are smaller than a specified size.
Hydrophilic	Water wetting.
Hydrophobic	Water rejecting.
Membrane	Filter media with delineated pore sizes, usually < 1 µm, and usually very thin.
Mesh	Number of openings in a lineal inch of wire cloth.
Nominal Particle	A degree of filtration, referring to less than 100% and

Retention Rating	usually more than 95% removal of rigid particulates greater than a stated size. Significance depends on determination method.
Particle Size Distribution	The distribution obtained from a particle count grouped by specific micron sizes; may be stated on basis of eight, volume or number.
Porosity	Voids expressed as percent of total medium or cake volume.
Septa	Plural of septum.
Septum	A structure of filter media mounted on a support.
Surface Filtration	Particulates are stopped and retained on the surface of the filter media.
Suspended Solids	The unsettled insoluble solids in a liquid.
Voids	Volumes within filter media or filter cake not occupied by solids.

B

FILTER SEPTA ATTACHMENT SYSTEMS

Filter septa attachment systems are the means by which filter septa are secured within a filter vessel in a manner that assures that all liquids flowing from the influent chamber to the effluent chamber must pass through the filter media. In addition to these basic and essential requirements, there are additional attributes that are desirable in attachment systems.

One desirable attribute is ease of septa installation and removal. This is particularly important at nuclear power plants due to ALARA considerations. A second valuable attribute is minimum resistance to flow through the tubesheet passageways. Although resistance through the passageways is generally not critical during service cycles, the resistance can limit maximum achievable backwash velocities with non-steady state methods for bottom tubesheet vessels.

Providing axial stiffening of the septa may be another desirable attribute, depending on the application and construction of the septa. When septa are precoated, it is possible for the precoat material to inadvertently form bridges between adjacent septa that exert bending moments on the septa. The displacement of the septa from their vertical axes can result in mechanical failures at the points of attachment to the tubesheet or at the joints between septa segments when septa are composed of multiple segments.

Figures B-1 through B-5 depict various attachment systems. The systems shown in Figures B-1 and B-2 are used with top tubesheet vessels. Attachment systems for bottom tubesheet vessels are shown in Figures B-3 through B-5. All of the figures were extracted from suppliers' non-proprietary sales literature or drawings.

With the attachment method shown in Figure B-1, the septa are installed from above the tubesheet by passing the septa through the tubesheet holes until the larger diameter piece at the top, which includes a captured o-ring on its underside, rests on the top of the tubesheet. After all of the septa are inserted, a clamping plate is secured to the top of the tubesheet with bolts providing a downward force on the septa to hold them in place and to compress the o-rings. Projections from each septum bottom fit into a bottom grid supported by tie-rods attached to the tubesheet. The grid maintains vertical orientation of the septa. This attachment system has been used with pleated filter septa.

Figure B-1 Top Tubesheet - Ferrule/O-Ring

A variation of the system shown in Figure B-1 was used with septa having O.Ds. larger than the tubesheet holes. In this variation, the top member shown in Figure B-1 is a separate piece with a male thread at its end. For installation, the top piece is passed through the tubesheet hole from above. After inserting the top piece, a coupling is threaded onto its end and tightened against the underside of the tubesheet such that the top piece is drawn downward compressing the o-ring beneath the top piece's flare. The septa are then threaded into the other end of the couplings. Note, with this variation a clamping plate is not required.

The attachment system shown in Figure B-2 has also been used with pleated filter septa in top tubesheet vessels and allows the use of septa O.Ds. larger than the tubesheet hole diameters. In this system, the adapter piece on the septum top end cap, with its retained double o-rings, is inserted into the tubesheet from below. The septa are held in the tubesheet holes by adjusting the tie-rods between the tubesheet and the bottom support grid so that the support grid applies an upward force to each septum.

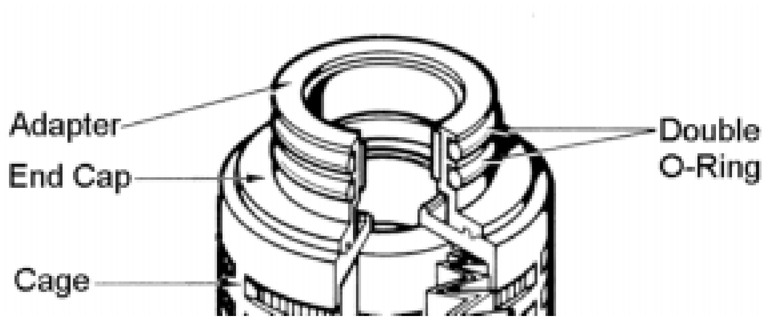

Figure B-2 Top Tubesheet - Double O-Ring Insertion

All of the attachment systems described for use with top tubesheet vessels have the attribute of unobstructed passageways through tubesheets, thus resistance to fluid flow is minimized. However, the attachment systems do not include stiffening rods for the septa.

Graver Chemical's name for the attachment system depicted in Figure B-3 for bottom tubesheet vessels is "Quick Release". However it is often referred to as a "hook and guide rod" system although the bottom hook used at fossil plants has been replaced by a bottom pin in BWR applications. The bottom pin passes through a keyway in the tubesheet fitting adapter which is threaded on to the top of the tubesheet fitting. Tubesheet fittings are straight pipes that pass through the tubesheet with welds at the points of penetration. All power plant bottom tubesheet condensate filter vessels include tubesheet fittings. The pins are attached to the bottom of the guide rods which extend through the septa cores and the spring shown above the septum in Figure B-3. When force is applied to the top of the rod the septum remains stationary, its bottom gasket rests on the tubesheet adapter's sealing edge, and only the guide rod moves down as the top spring compresses. When the pin has passed through the keyway, the guide rod is turned 90° and released. Upon release the rod moves upward, due to the spring action, until the pin engages a concave depression on the underside of the keyway. When the pin is secured in the depression the top spring is still partially compressed and forces the septum's bottom gasket against the sealing edge of the tubesheet adapter. The keyway and pin are obstructions to the passage of fluids between the top and bottom chambers of the filter vessel. The resistance to fluid flow created by the obstruction limits the maximum backwash velocities achievable with non-steady state backwash methods.

Figure B-3 Bottom Tubesheet - Quick Release

The hexnut extensions at the top of the "Quick Release" guide rods fit through holes in horizontal latice strips assemblies to maintain septa spacing and vertical orientation. The hitch pins on the hexnuts are used when lift plates are used for septa removal, and are inserted after the latice and lift plate(s) are installed over the septa assembly. In this attachment method, the guide rods stiffen the septa assembly to limit bending.

Obstructions in the passageways leading from the septa cores to the effluent chamber are avoided in the attachment systems shown in Figures B-4 and B-5; the former depicts Graver Chemical's Sealfast system and the latter a Sure-Snap coupling system of the Fil-Tech Corporation. Center guide rods are not used in either system, thus septa stiffening is not provided.

Figure B-4 Bottom Tubesheet - Sealfast

Septa used with the Sealfast system have caps, with threaded rod extensions, welded to the cores at the top ends of the septa. Caps to cover the septa tops fit over the threaded rod and are held in place by bolting. The hexnut extensions and hitch pins have the same purposes as with the “Quick Release” method. Threaded nipple are welded to the cores of the septa at their bottom end. A coupling is used to join the septa to the threaded upper ends of the tubesheet fittings. The Sealfast system has been used with non-pleated filter septa. Although there is potential for its use with appropriately designed pleated filter septa, no such applications could be identified at this writing.

The Sure Snap attachment shown in Figure B-5 is a recent innovation offered for use with pleated or non-pleated filter septa. The system has undergone pilot scale testing but, there are no full-scale uses known at this time. Advantages claimed for the device are the unobstructed flow path between the septa core’s and the effluent chamber, fewer parts to handle during septa installation and removal, and simple installation and removal of septa.

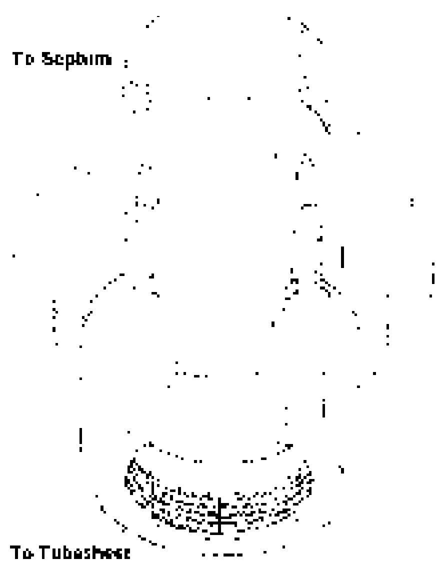

Figure B-5 Bottom Tubesheet - Sure Snap

The device is similar to that used for quick-disconnect hose couplings and has two major segments. The upper segments are threaded onto the filter septa and the second segments threaded on to existing tubesheet fittings. The large diameter piece shown in Figure B-5 is a movable spring loaded collar mounted on the lower segment. When this collar is depressed, ball bearings retained in a horizontal plane of the lower segment are free to move outward from the centerline of the device to allow removal or insertion of the upper segments attached to the septa. When the collar is released the spring moves it upward forcing the ball bearings inward to engage grooves in the tapered ends of the upper segments. The supplier has developed simple tools for the simultaneous depression of the spring loaded collars and insertion or removal of filter septa.

The Graver Chemical pleated filter septa in the Brunswick Nuclear Project condensate filters (bottom tubesheets) are installed with the innovative attachment system shown in Figure B-6. The are no obstructions in the passageways between the septa cores and the effluent chamber with the system, and the system provides septa stiffening.

The cores are attached to the tubesheet fittings, which project upward from the bottom tubesheet, by means of a coupling. Filter septa are slipped over the cores, and their bottoms rest on annular sealing surfaces welded to the core bottoms; above the coupling in Figure B-6. After a septum is placed on the core, the top spring-loaded sealing mechanism is inserted into a keyway at the top of the core and turned 90° to lock it in place. The bottom spring plate contacts the gasketed septum tops, and moves upward as the mechanism is inserted. Sealing at the top and bottom gaskets of the septum results from compressive forces exerted by the spring.

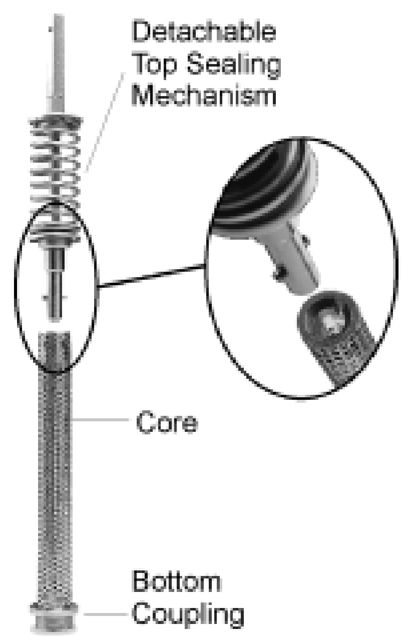

Figure B-6 New Quick Release Fitting

C

PATENTS RELEVANT TO FILTRATION

Table C-1
United States Patents Relevant to Filtration

Patent Number	Date	Assignee	Title
5484528	16-Jan-96	Japan Organo	Filtration Equipment for Hollow Fiber Module
5468397	21-Nov-95	Memtec	Gas BW of Pleated Filters
5326629	5-Jul-94	Dow	Porous Polymer Fiber Filters
5209852	11-May-93	Japan Organo	Process for Scrubbing Porous Hollow Fiber Membranes in Hollow Fiber Membrane Module
5151191	29-Sep-92	Japan Organo	Filtration Process Using Hollow Fiber Membrane Module
5017241	30-Jul-91	Finetech	Backwash Method and Apparatus
4935143	19-Jun-90	Memtec	Cleaning of Filters
4921610	1-May-90	Memtec	Cleaning of Hollow Fiber Filters
4915833	10-Apr-90	Japan Organo	Column Filter Using Bundles of Long Fibers
4886601	12-Dec-89	Japan Organo	Column Filter Using Bundles of Long Fibers
4462906	31-Jul-84	Japan Organo	Filler for Electromagnetic Filters
4460463	17-Jul-84	Japan Organo	Electromagnetic Filters
4032688	28-Jun-77	Pall	Seamless Tubular Nonwoven Webs and Filters thereof
3573158	30-Mar-71	Pall	Microporous Fibrous Sheets Useful for Filters and Apparatus and Method of Forming the Same