Report No. ACNP-6101

PATHFINDER ATOMIC POWER PLANT

FILTRATION OF ALUMINUM CORROSION PRODUCTS PRODUCED IN HIGH-TEMPERATURE, HIGH-PURITY WATER SYSTEMS

Submitted to

U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
Milwaukee 1, Wisconsin

Ref: AEC Contract No. AT(11-1)-589

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by J. H. Noble and R. L. Davie

U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
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by
ALLIS-CHALMERS MANUFACTURING COMPANY

Under
Agreement dated 2nd Day of May 1957, as Amended
between
Allis-Chalmers Mfg. Co. & Northern States Power Co.
under
AEC Contract No. AT(11-1)-589

May 1, 1961

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FOREWORD

This report is issued as one of a series on research and development in connection with the design of Pathfinder Atomic Power Plant. This particular report describes the test program that was conducted to determine the most suitable filter for the reactor water purification system in Pathfinder.

The Pathfinder Atomic Power Plant will be located at a site near Sioux Falls, South Dakota and is scheduled for operation in June, 1962. Owners and operators of the plant will be Northern States Power Company of Minneapolis, Minnesota. Allis-Chalmers is performing the research, development, and design, and is responsible for plant construction.

The U. S. Atomic Energy Commission, through Contract No. AT(11-1)-589 with Northern States Power Company and Central Utilities Atomic Power Associates (CUAPA), are sponsors of the research and development program.

The plant's reactor is designated the Controlled Recirculation Boiling Reactor with integral nuclear superheater.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the following organizations for their contributions to the test program. The Aluminum Company of America supplied the boehmite that was used in the test program. Hi-Lo Engineering, Commercial Filters Corporation, and the Cuno Engineering Corporation supplied filters for the test program. In addition, Commercial Filters Corporation and Industrial Pump and Filter Corporation tested various filters and filter material; and offered valuable advice on filters and filter systems.

TABLE OF CONTENTS

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ABSTRACT

Filter tests were conducted to determine the most suitable filter for removing large quantities of aluminum corrosion product (boehmite) from reactor water. Filters tested included the following: wire-wound, sintered filter elements, sintered ceramic filter elements, cotton string-wound filter elements, felted-cotton filter elements, cation resin, adsorption resin, diatoma ceous earth precoat filter, and a wood-cellulose precoat filter.

Parameters measured were flow rate, filter-influent and -effluent boehmite concentration, pressure drop, and final filter load. The pressure drop and efficiency of the filters was then correlated with boehmite load.

Boehmite deposits on filters as a non-porous gelatinous cake, which causes a rapidly increasing pressure drop. Tests indicate that the optimum load with filter elements and precoat filters is achieved at a pressure drop of 25 psi. Very little additional load can be obtained by operating to a higher pressure drop.

Of the filters tested, the precoat filter and 40-60 mesh cation resin were the more effective in removing boehmite. The efficiency of the precoat filter was in excess of 99 per cent, and the efficiency of the cation resin was for the most part in excess of 95 per cent. For various reasons, the other filters were eliminated from final consideration.

The test program and available literature indicated that an element type precoat filter using wood cellulose as the precoat media would be most suitable for the proposed application.

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I. INTRODUCTION

Reference design for the Pathfinder Atomic Power Plant includes a blowdown purification system to maintain high-purity reactor water. The flow rate of water to the filtering section of the system may vary from 60 to 250 gpm. The blowdown flow rate during normal reactor operation is 100 gpm.

With an aluminum-clad core, the major suspended impurity in the reactor water is boehmite,[1,2,3]

$$Al_2O_3 \cdot H_2O.$$

A preliminary estimate indicates that in excess of 1800 lb/yr of this relatively insoluble corrosion product would be formed during operation of a Pathfinder aluminum-clad core.

Cotton string-wound cartridge filters are used in the Experimental Boiling Water Reactor and other similar installations to remove ferrous corrosion products. Precoat filters are also used to remove iron and copper corrosion products in systems processing ultra-high purity water. Whether or not operating data and experience regarding these systems was applicable to a system filtering large quantities of boehmite was not known. A thorough search of available literature failed to disclose any significant information on the subject.

Tests were therefore conducted to determine a suitable filter for the Pathfinder reactor water purification system. Appendix A contains definitions of terms used in this report.

Before full-scale filter testing was started, the Allis-Chalmers Research Laboratory conducted preliminary tests to determine the filterability of a finely divided or colloidal aluminum corrosion product. A stable boehmite solution was prepared by the reaction of distilled water with aluminum amalgam at approximately 95 C. This sol, when sufficiently dilute (0.3 ppm) remained dispersed for as long as four months. However, none of the sol particles would pass through a coarse paper such as Whatman No. 31. The tests thus showed that boehmite is filterable.

The effect of various electrolytes on the filterability of boehmite was investigated. Neither hydrofluoric nor phosphoric acid caused any observable amount of coagulation when added to the sol. However, small concentrations, 1-to-3 ppm, of acid caused less of the sol particles to pass through a coarse paper. Greater concentrations of phosphoric acid were no more effective. The turbidity of the sol that contained boehmite was found to be directly proportional to the concentration of boehmite. This linear relationship permitted the determination of sol concentrations to be made rapidly by turbidimetric methods.

2. TEST EQUIPMENT AND GENERAL PROCEDURES

2.1 Test Loop. The filter test loop as originally assembled is shown in Figure 1. The loop consisted basically of the following components:

1) two 36-in dia. tanks
2) a 14-in dia. filter vessel
3) a circulating pump
4) an integrating flow meter (gal)
5) two 60-in Hg manometers
6) two Bourdon pressure gages
7) piping, valves, sample cocks, fittings, etc.

All of the tanks including the filter vessel were fabricated of carbon steel and covered with three coats of protective paint. The two 36-in dia. tanks were used as surge and collection tanks, while the 14-in dia. vessel housed the test filter assembly.

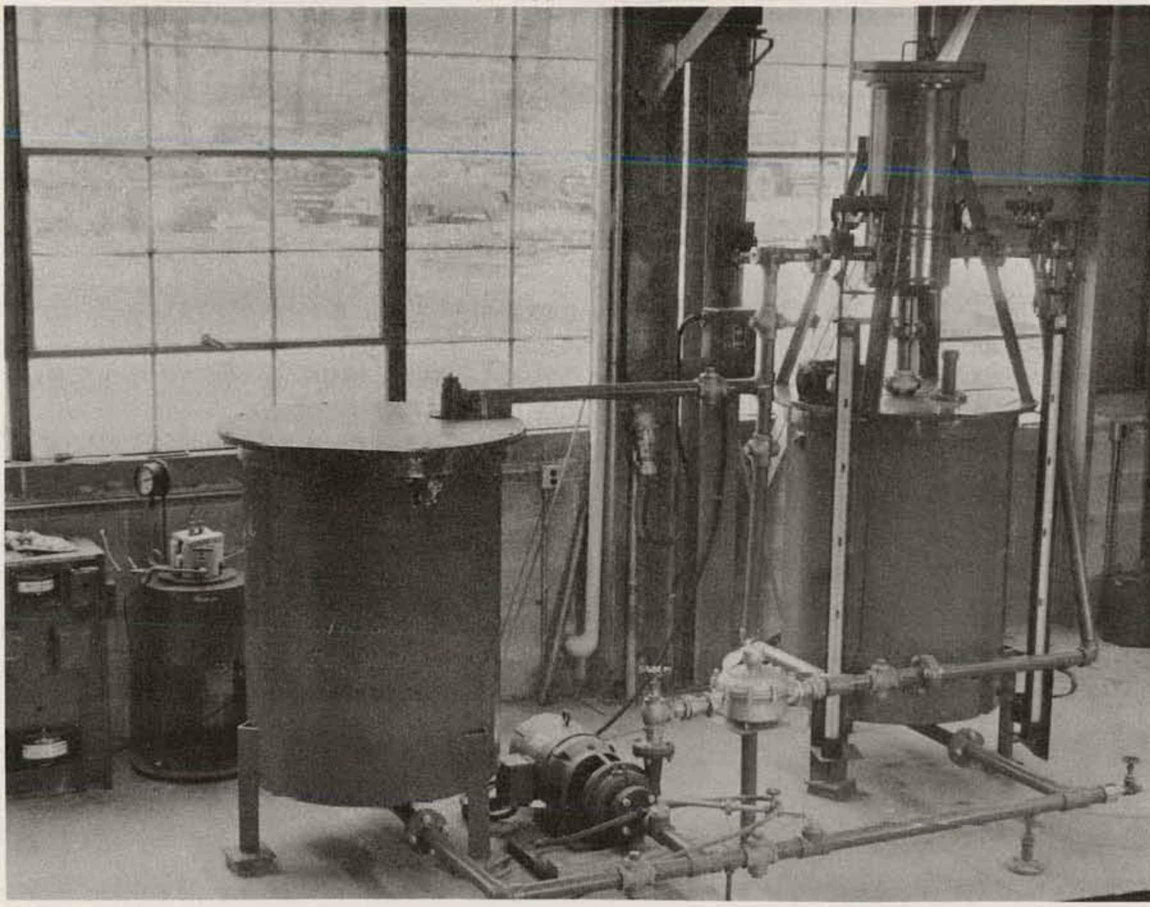

Figure 1. Filter test loop as originally assembled.
(NP Photo 023-29)

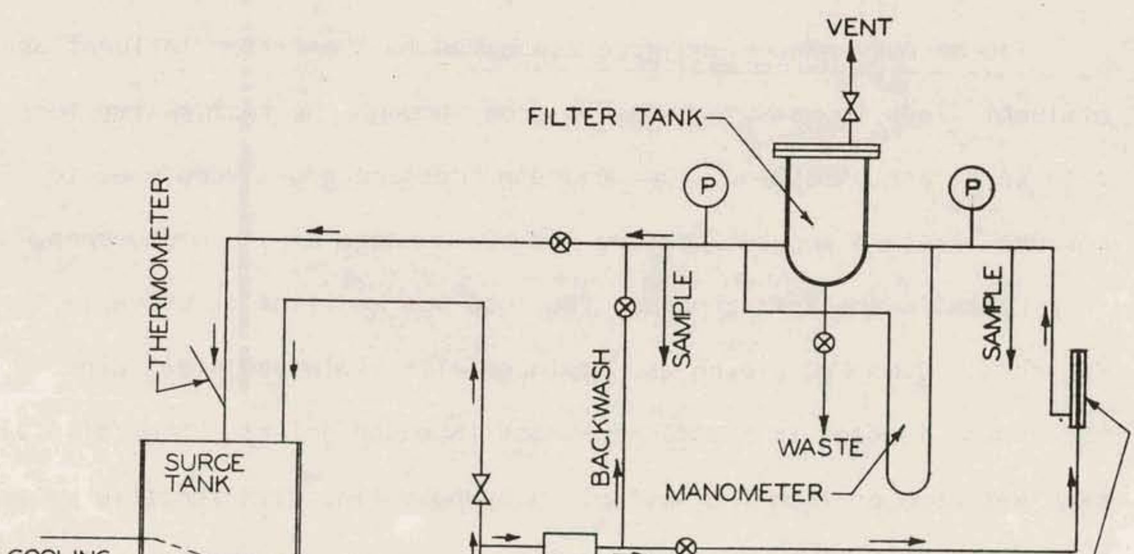

Figure 2. Schematic of filter test loop as modified after initial tests. (AC Dwg. 43-024-446)

An Allis-Chalmers "Electrifugal" pump rated at 80 gpm and 250-ft head was used for circulating water or boehmite slurry through the system. This pump has a brass impeller mounted on a steel shaft and a cast-iron casing. The casing was spray-coated with 304 stainless steel to reduce the quantity of iron corrosion product introduced into the system.

Piping and valves were initially connected so that the circulating pump could take suction from either the surge tank or collection tank, and discharge through any of the three possible flow paths. With these flow paths, the filter could be by-passed, backwashed, or operated normally.

Primary piping consisted of 2-in schedule 80 polyvinylchloride (PVC) pipe and some stainless steel fittings. Brass sampling cocks were installed in the filter influent and effluent lines. All valves and cocks were made of brass. The cocks were designed for grease lubrication, although no grease was used. In the integrating flow meter, all metallic parts in contact with water were made of brass or similar material.

Two mercury manometers were connected to the filter influent and effluent lines to measure pressure drop through the test filter for flow in either direction. Two Bourdon pressure gages were used to measure pressure drops exceeding the 60-in range of the manometers.

Later in the test program, the loop was modified as shown in Figure 2. Some PVC piping was replaced with stainless steel pipe, because of leakage in plastic-to-brass threaded joints. The collection tank was removed from the system. A by-pass line with throttle valve was installed between the pump discharge and surge tank to enable finer control of low flow rates through the test filters. A copper cooling coil was installed in the main surge tank, so that a constant temperature could be maintained during testing. A flow rate meter was installed in the filter inlet line. With this meter, it was possible to accurately measure relatively low flow rates.

2.2 Simulated Corrosion Product. In most tests, finely ground boehmite powder obtained from the Aluminum Company of America was used. A particle size determination was made using first Tyler series sieves and then an Andreasen pipette. The results are as follows:

Particle Size (μ)	100	74	45	25	20	15	10	5	4	3	2	0.6	0.4 (est)
Per Cent Passing	98.8	90.5	80.5	65.5	64.5	48.0	30.5	19.5	18.5	14.0	11.5	2.5	0

2.3 Boehmite Concentration Measurements. A "Hellige" Turbidimeter was used to measure the boehmite concentration in the loop water. In calibrating the turbidimeter, suspensions were made at various concentrations using the boehmite powder. Chemical analysis of each sample was compared to turbidimeter readings to obtain a calibration curve.

2.4 Test Procedure. A general procedure applies to all the testing conducted at Allis-Chalmers. Significant variations in the procedure are described in the applicable sections.

The clean test loop was filled with water. The filter was placed in the adapter in the filter vessel. The pump was then started, and the desired flow rate was established through the filter. Boehmite in 1-gm quantities was dropped into the surge tank. Periodically, samples of water were taken upstream and downstream of the filter vessel, and readings of influent and effluent turbidity were recorded. Normally, influent turbidity was maintained at about 5 ppm. Data such as flow rate, time, pressure drop across filter, and temperature of water were recorded.

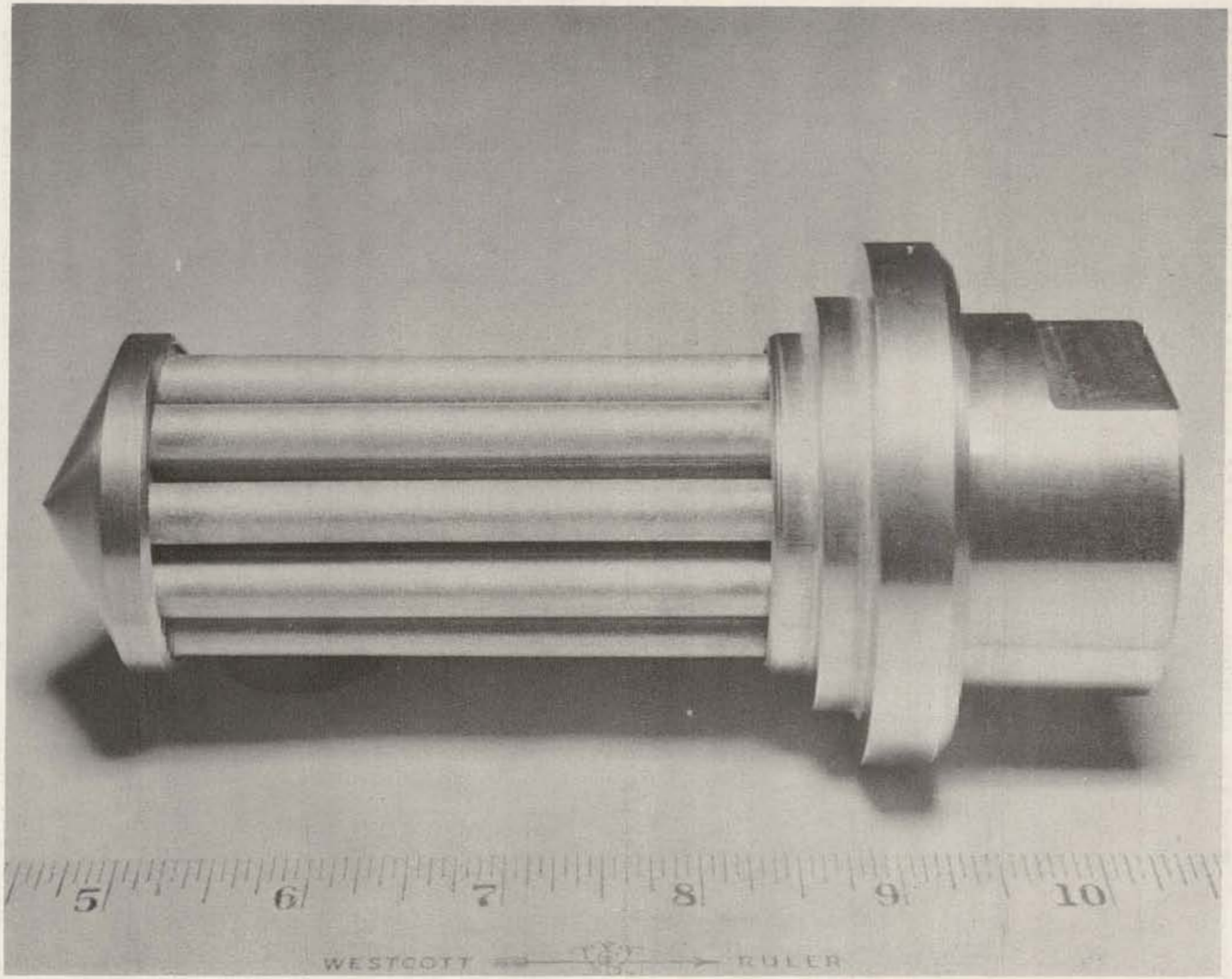

Figure 3. Metallic wound-wire type filter. (HI-LO Engineering and Manufacturing, Inc.) (NP Photo 022-44)

After a cooler was installed, a constant temperature could be maintained. In this manner, the need for pressure-drop and flow-rate corrections was eliminated; and the possibility of any temperature effect on boehmite characteristics was excluded.

3. WIRE-WOUND FILTER CARTRIDGE

The first filter selected for testing in this program was a metallic wound-wire type, obtained from HI-LO Engineering and Manufacturing, Inc. Figure 3 shows a slightly enlarged photograph of the filter. Though normally used in gaseous systems, this filter was selected for testing on the basis of its apparent potential for backwashing. Such a feature would facilitate remote maintenance of the filter system.

The filter consists of twelve stainless steel wire-wound sintered tubes silver-soldered to stainless steel tube sheets. The twelve tubes provide a total surface area of approximately 50 sq. in. This filter is rated by the manufacturer at 10 μ.

3.1 Preliminary Testing. After reducing solids concentrations in the loop to 0.5 ppm, the Hi-LO filter was installed in the vessel and clean-tested. Pressure drop data was recorded for flow rates up to 60 gpm. A set of similar data was then obtained with the filter removed, and with only the adapter remaining in the loop. Results of these tests are indicated on Figure 4. Curve C is obtained by subtracting Curve B from Curve D, and represents approximate pressure drop through the filter only.

With the filter installed and the loop sampling at 32 ppm boehmite, a quick test was initiated to load the filter and attempt a backwash. A low flow rate was established through the filter. Within a few seconds before any data could be recorded, the filter plugged; pressure differential increased to pump shut-off head (110 psig), and flow through the filter ceased. The loop was shutdown, and the filter was carefully removed.

Observation of the filter showed two things of interest. No significant accumulation of boehmite appeared on the element surface. Slight traces of particles were noticed over the entire outside surface of the filter including the top and adapter. There appeared to be no more boehmite on the actual filtering area than on the non-filtering members. Secondly, no traces of boehmite were noticeable inside the filter or filter outlet.

The element was then cleaned by washing with tap water, then distilled water, and finally with high-velocity air.

Another clean-test was made following cleaning of the loop to determine the effectiveness of cleaning the filter. Pressure drop data was recorded with flows up to 60 gpm. The results are plotted as Curve E on Figure 4.

A second attempt to load the filter with an influent concentration of only 2.0 ppm was made. The results of this run were almost identical to the first test. Plugging did not occur quite as fast.

<u>3.2 Final Tests.</u> In view of the difficulties experienced in the initial tests, the final tests were performed using a different procedure. A constant pressure drop across the filter was maintained rather than a constant flow rate. Two tests were performed in this manner. The first and most successful of these tests will be described in detail.

With a boehmite concentration in the loop water of 1.0 ppm, the filter was installed and a clean-run was made. Pressure drop was maintained constant by adjusting the pump discharge valve. At a constant pressure drop of 9.85 psi, a flow-meter reading was recorded very 15 sec

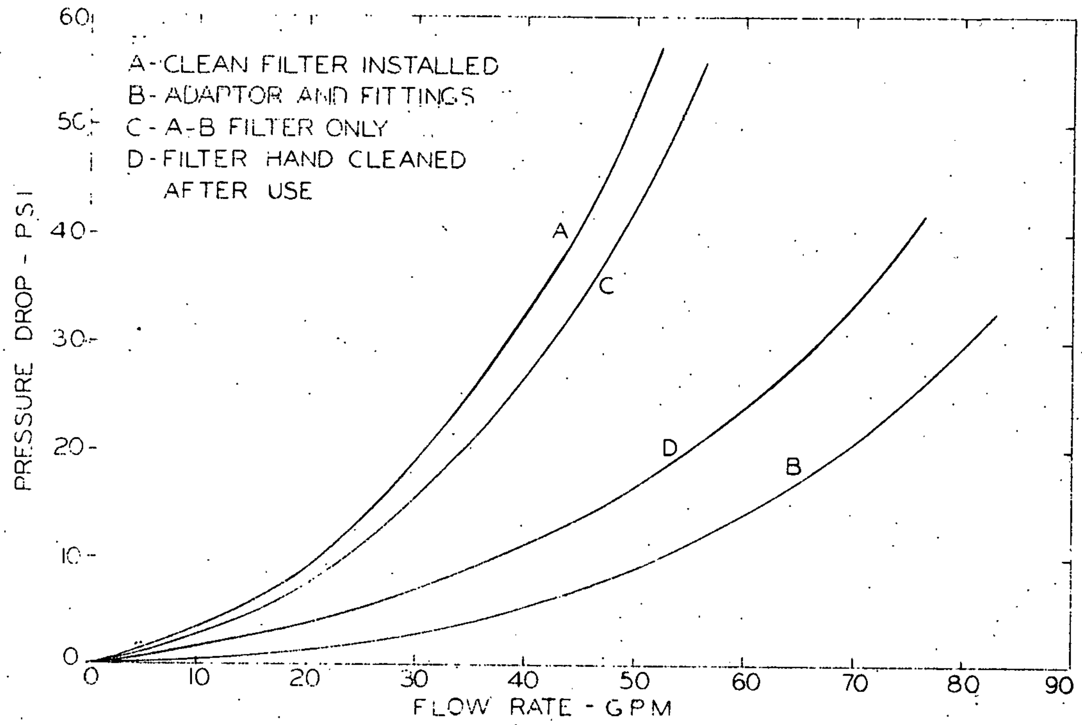

Figure 4d Pressure drop across wire-wound (HI-LO) filter cartridge. (AC Dwg. 43-024-441)

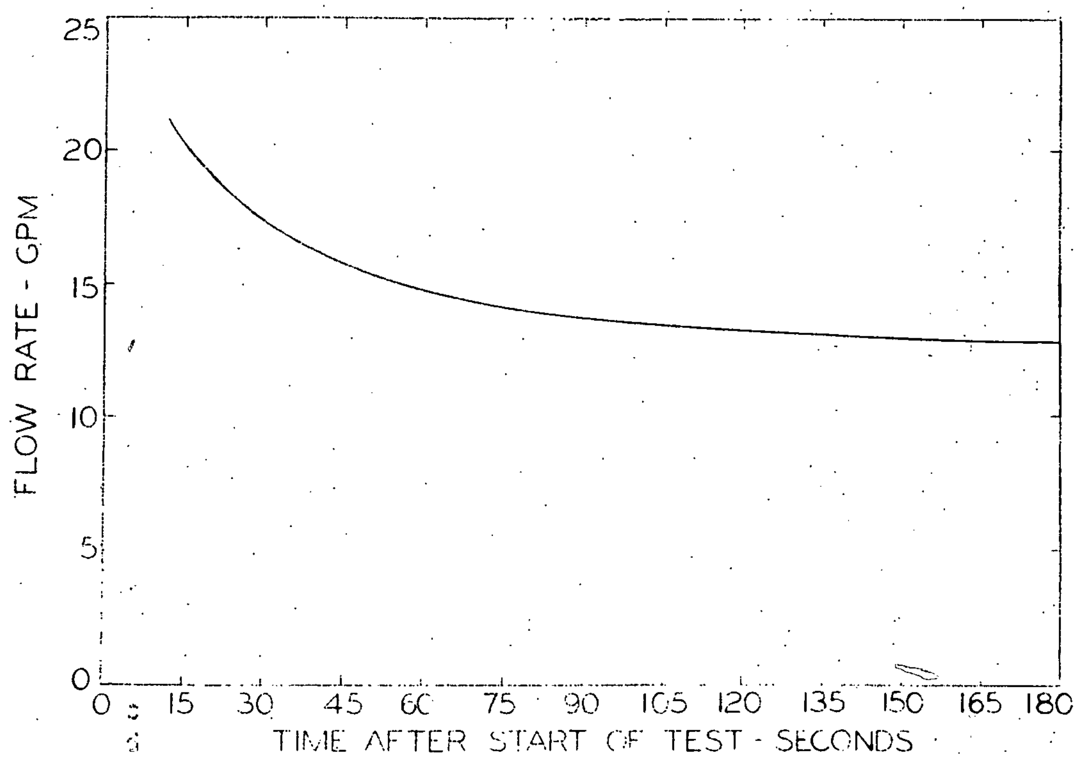

Figure 5. Wire-wound filter cartridge pre-loadup clean-run. Influent concentration of boehmite was less than 1.0 ppm. Pressure drop was maintained constant at 9.85 psi. (AC Dwg. 43-024-431)

for a period of 3 min. Flow rate is plotted as a function of time for the first 3-min period in Figure 5.

The load-up run was performed after the boehmite concentration had been increased to slightly above 2.0 ppm. Flow rate data was again recorded for approximately 3 min (Figure 6). By this time the filter was plugged, and flow rate had dropped close to zero. Because of the limited time available, only one sample of filter influent and effluent was obtained. Both samples indicated 2.0 ppm of boehmite. It was obvious, however, that the filter was removing some of the boehmite.

With the filter removed, the boehmite concentration in the loop was reduced to 1.0 ppm. The filter was then installed and backwashed, at 110 psi for $3\frac{1}{2}$ min.

The test filter was removed again, and the loop cleaned to 0.75 ppm. A final clean-run was made to determine the effectiveness of backwashing. The results of this last run are plotted on Figure 7.

3.3 Summary. Data obtained from the HI-LO tests is not sufficient to enable the performance of this type of filter to be predicted with accuracy should it be used in a large-scale system such as Pathfinder. The filter can be backwashed; but to what degree this can be accomplished over long-term operation is not known.

Operation at lower flow rates would undoubtedly extend operating time. However, considering the rapid plugging, it was thought that any such improvement would not be sufficient to warrant further testing. Testing of the HI-LO filter was therefore terminated.

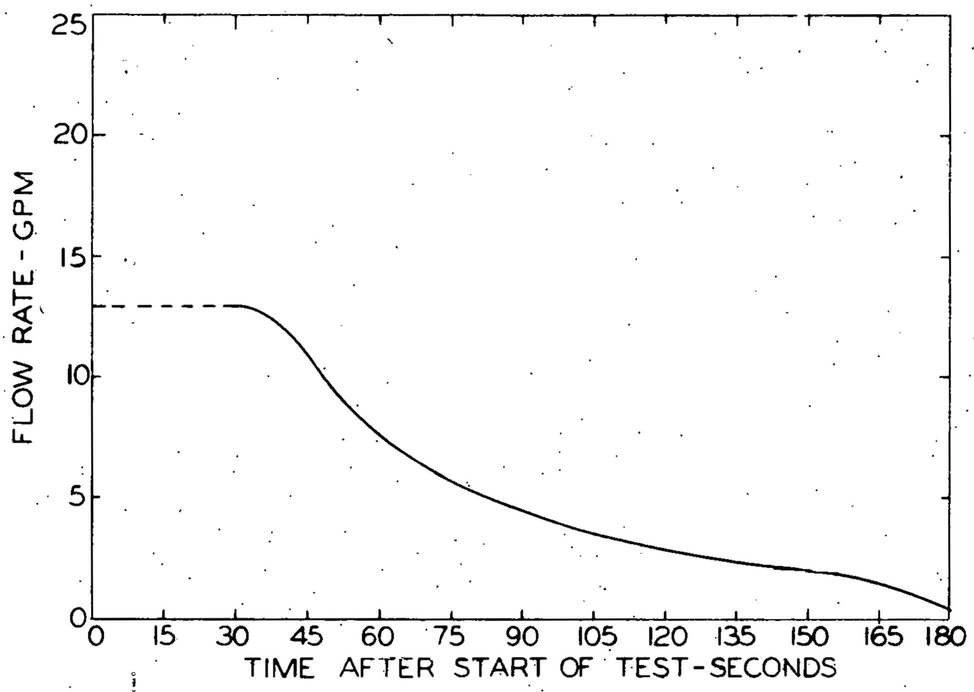

Figure 6. Wire-wound filter cartridge load-up run. Influent concentration of boehmite was greater than 2.0 ppm. Pressure was constant at 9.85 psi. (AC Dwg 43-024-432).

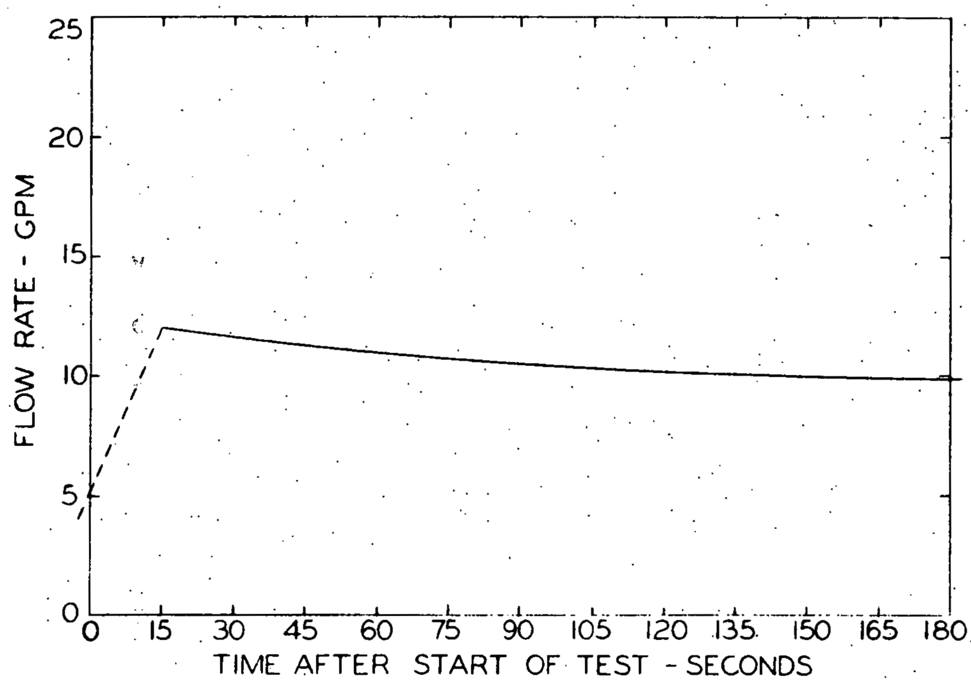

Figure 7. Wire-wound filter cartridge post-loadup run. Influent concentration of boehmite was less than 0.75 ppm. Pressure drop was constant at 9.85 psi. (AC Dwg 43-024-433)

4. SINTERED CERAMIC FILTER ELEMENTS

Commercial Filters Corporation tested a cylindrical ceramic filter element 2.5 in. o.d. x 2 in. i.d. Length varies with the application. The porosity is varied to obtain different filter ratings.

A sample of boehmite was sent to Commercial Filters Corporation. The filters were tested at 1 gpm/sq.ft. to a pressure drop of 25 psi. The following load-up values were obtained.

Filter Rating (μ)	Boehmite Load-up (gm/sq.ft.)
5	2
10	10
25	12

An attempt was made to backwash the filters and return them to service. Backwashing was not successful.

Since such poor results were obtained, another 25-μ element was tried with a diatomaceous earth precoat. Under the same conditions as above a much higher load-up was obtained. Backwashing was completely successful.

4.1 Summary. The results show that a bare sintered ceramic filter would not be suitable for the filtration of any appreciable quantity of boehmite. The rapid plugging and low load-up are undesirable. The work did show that a precoat filter might be suitable for the filtration of boehmite. More will be said of precoat filtration in Section 7.

5. COTTON CARTRIDGE REPLACEABLE FILTERS

Two types of cotton cartridge filters were tested. One is manufactured by the Commercial Filters Corporation and is sold under the Fulflo trademark. The second type is supplied by Cuno Engineering and is called the Micro-Klean filter. Both cartridges are 9½ in. long by 2-3/4 in. dia. and are interchangeable. Two filter cartridges of the same rating were dry-weighed and installed with an adapter in the filter vessel. The filters were dry-weighed after tests to determine final load. The dry-weight was obtained by laboratory balance after driving off moisture from the filter by oven drying at 80°C. The elements were periodically weig hed until no further weight loss was noted.

The method used for correlating and presenting test data for these tests is given in Appendix A.

5.1 Fulflo Cartridges. A Fulflo string-wound filter cartridge is shown in Figure 8. The element consists of cotton string wound tightly around a wire mesh or screen core. Filters of three ratings were tested:

Filter Rating (μ)	Filter Type
5	19 x 20-2CV
10	27R10CV
25	39R10CV

Type 19 x 20-2CV. A short 3-hr test run was made with this filter. The temperature was maintained at 150 to 160 F throughout the test. The initial pressure drop across the filter was about 1.8 psi. At a flow rate of 2 gpm/element for the first 2 hr of testing. Initially, the influent concentration was 10.5 ppm and no additional boehmite was added to the circulating water during the test run. The filter efficiency was about 50 per cent initially, but rapidly decreased to 0 per cent as the test continued.

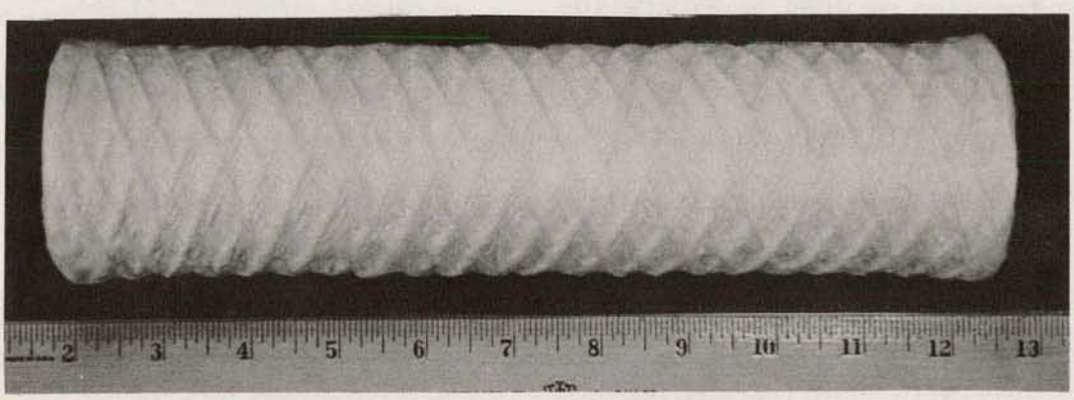

Figure 8. Cotton-string-wound filter cartridge (Fulflo). (NP Photo 035-27)

After 2 hr of testing, the flow rate and pressure drop were doubled to determine if the increases would affect filter efficiency. The flow rate and pressure drop were again doubled after half an hour of testing. No effects on filter efficiency were observed. Data for the test is given in Table I. Results are plotted in Figure 9.

Table I. Test Results with 19 x 10-2CV Filters (2 Elements)

Time	Flow Rate (gpm)	ΔP across Filter (in. Hg)	Turbidity Influent (ppm)	Turbidity Effluent (ppm)
0:00	4	3.7	10.5	4.5
0:30	4	4.05	8.0	5.7
0:55	4	4.15	8.0	7.5
1:20	4	4.05	6.0	7.2
1:50	4	4.25	5.4	5.0
Stop for night				
2:02	7	6.9	6.2	5.5
2:23	7	7.1	5.7	5.7
2:58	15	20.0	5.0	5.0
3:18	15	20.2	5.0	5.0

Type 27R10CV. A test was run with two type 27R10CV elements at a constant flow rate of 2 gpm/element and with the system water temperature varying from 80 to 130 F. Results are given in Table 2. Pressure drop with efficiency are plotted as a function of load in Figure 10. The average influent turbidity during the test was 3 ppm. Initial pressure drop was 4.9 psi.

Filter efficiency decreased initially with increasing load.

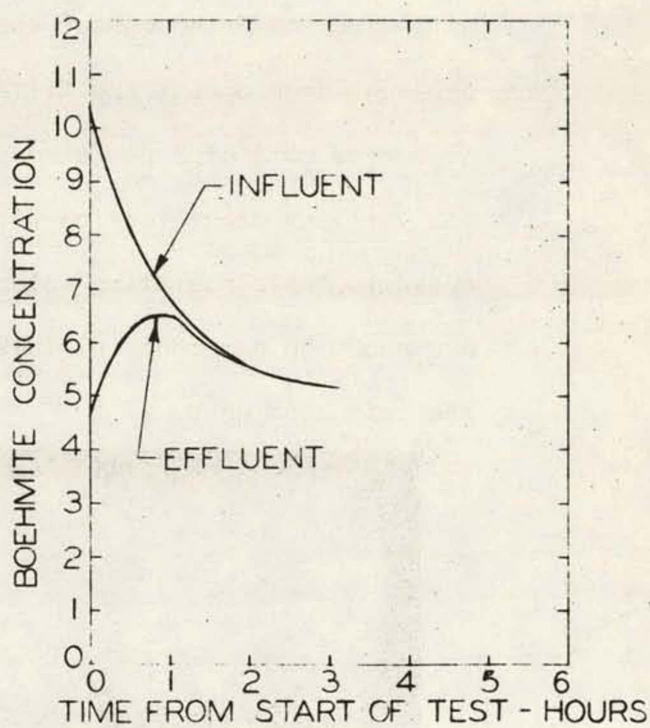

Figure 9. 19 x 10 2CV influent and effluent boehmite concentration. (AC Dwg 43-024-444).

Table 2. Test Data for Type 27R10CV Filter Elements

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity Influent	Turbidity Effluent	Boehmite Added
Hrs	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)	(gm)
0:00	85	3.9	10.5	5.2	1.5	--
0:41	--	3.5	8.7	2.9	1.7	--
1:19	105	4.25	8.6	2.0	1.5	3
2:15	115	4.2	7.7	3.8	2.0	2
2:50	--	4.2	7.7	3.3	2.0	--
3:05	128	4.3	7.5	---	---	1
Stop						
3:05	84	---	---	---	---	--
3:50	90	---	---	3.3	2.5	2
4:35	103	4.0	8.5	3.6	2.5	2
5:15	113	3.9	8.0	3.5	2.7	2
6:05	125	4.3	7.9	3.4	2.5	2
6:29	129	4.0	7.6	4.5	---	--
Stop						
6:29	80	---	---	---	---	--
7:41	92	4.2	10.5	3.5	3.0	4
8:49	---	---	---	4.8	2.3	2
10:09	129	4.0	8.4	2.5	2.0	--
10:14	130	3.4	---	---	---	--
Stop						
10:19	89	---	---	---	---	--
11:47	---	---	---	2.5	2.0	2
12:09	112	4.0	10.1	3.3	---	--
12:32	---	---	---	2.5	1.5	2
13:06	---	---	---	4.5	1.4	--
13:12	129	3.88	10.1	---	---	--
Stop						
13:17	---	---	---	---	---	--
13:55	---	---	---	2.5	1.6	2
14:33	---	---	---	4.0	1.1	2
15:22	128	4.0	29.2	2.6	0.8	--
15:27	130	3.6	30.7	---	---	--
Stop						
15:32	---	---	---	---	---	--
16:12	101	3.9	42.5	1.9	1.2	--
17:12	124	4.2	46.2	0.6	0.5	--
17:32	130	4.0	45.5	0.5	0.3	--

With a load of 6 gm/element, the efficiency began to rise continuously with further increase in load. This latter phase corresponds to the increasing thickness of the surface coat of boehmite.

The pressure drop reached 25 psi by the time a reasonably high efficiency was obtained, and the test was discontinued. The average filter efficiency during the test run was 45 per cent. Test data showed no significant change in filter efficiency when the influent concentration is varied. Pressure drop across the filter remained essentially constant until the filter load reached 50 per cent of capacity. A gradual increase in efficiency was noted until load-up reached 85 per cent of capacity. The pressure drop rose rapidly as load increased from 85 to 100 per cent of capacity.

The boehmite deposited as a thin gelatinous non-porous coating, which accounts for the rapidly increasing pressure drop. The string winding pattern was still very obvious. The boehmite load was 13 to 15 gm/element.

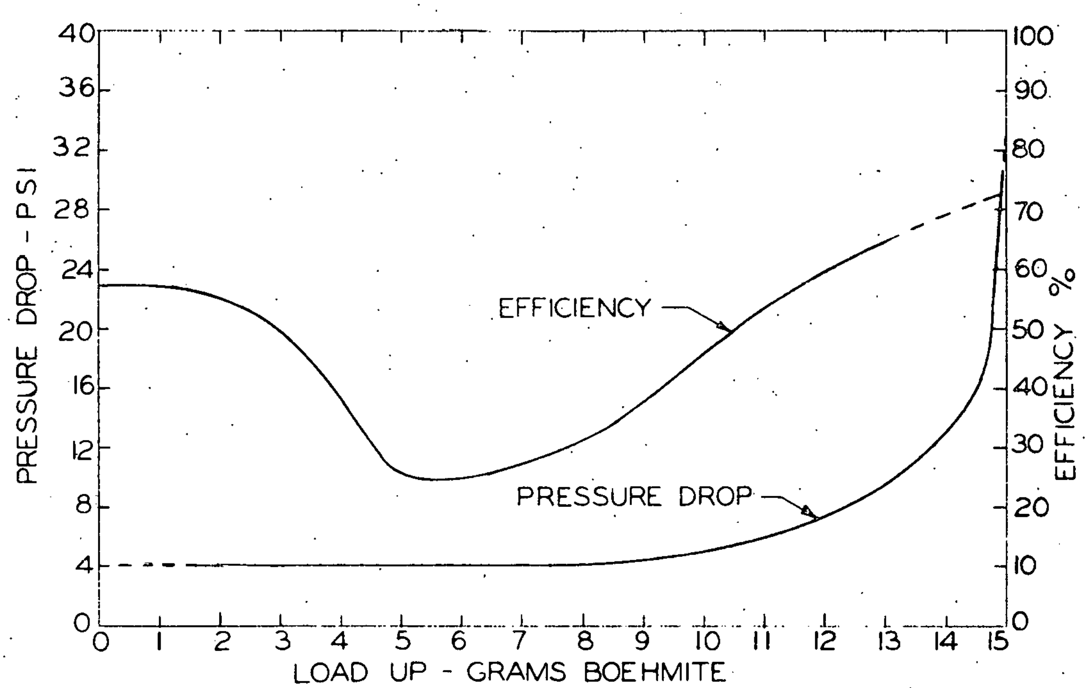

Figure 10. 27R10CV cotton cartridge pressure drop and efficiency as a function of boehmite load. Flow rate during the test was 2 gpm/element. (AC Dwg 43-024-438)

<u>Type 39R10CV Filter.</u> Two 39R10CV elements were tested at a flow rate of 2 gpm/element at temperatures from 80 to 130F. Average influent concentration was maintained at 2 ppm. The average efficiency of the filter was 73 per cent. The maximum load was 15 to 16 gm/element. The initial pressure drop was 9.5 psi. The efficiency and pressure drop for the filters were plotted as a function of load in Figure 11. Detailed results are given in Table 3.

During previous test runs, the test loop was shutdown each evening, and differences in pressure drop and boehmite concentration were noted on startup the next day. In order to determine if these discontinuities in operation had any effect on the final results, a continuous test run was made to maximum pressure drop without shutting down the loop.

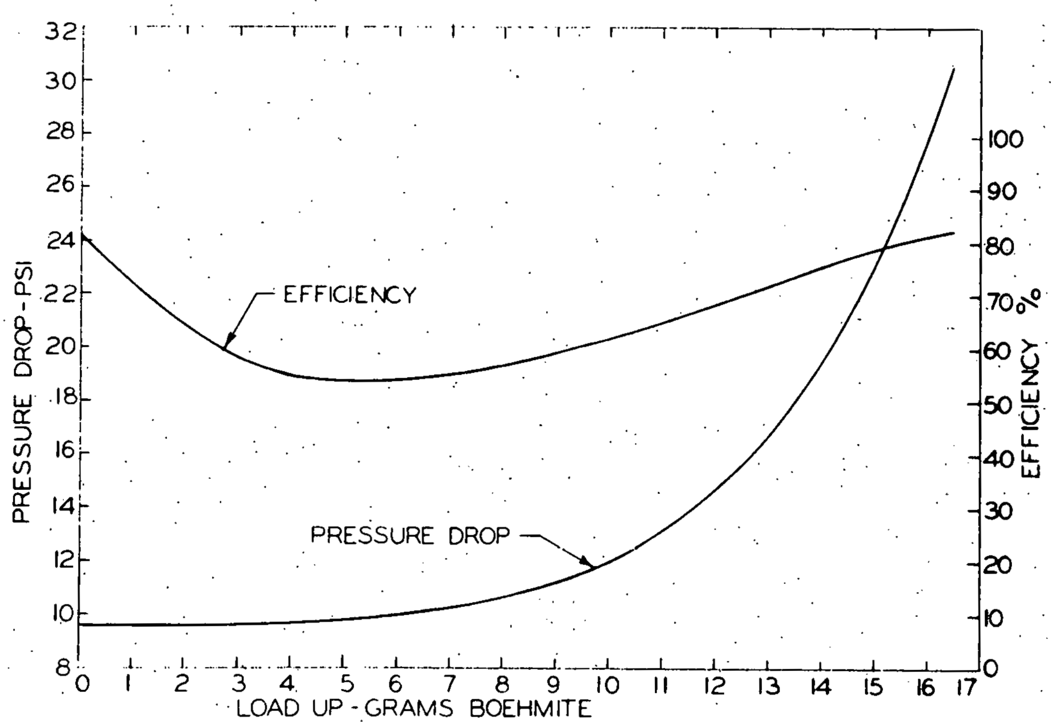

Figure 11. Pressure drop and efficiency of 39R10CV cotton cartridges as a function of boehmite load. Flow rate was maintained at 2 gpm/element. (AC Dwg 43-024-435)

Table 3. Test Data for Type 39R10CV Filter Element

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity		Boehmite Added
				Influent	Effluent	
Hrs	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)	(gm)
0:00	---	---	----	---	---	--
0:25	88	4.4	20.5	---	---	3
0:29	---	---	----	4.0	0.8	--
0:55	97	4.5	19.8	1.9	1.0	2
2:40	122	3.97	16.0	1.9	1.1	--
Stop						
2:45	---	---	----	---	---	2
3:00	82	3.75	24.0	4.5	1.4	3
4:06	101	4.4	23.2	2.1	1.3	2
6:56	128	4.1	18.0	1.7	0.9	--
Stop						
7:01	---	---	----	---	---	--
7:07	---	4.5	27.0	4.0	---	2
7:26	93	4.1	24.0	---	1.1	2
8:21	108	3.9	21.5	2.1	0.9	1
9:36	124	3.97	20.0	2.2	0.8	2
Stop						
9:41	---	---	----	---	---	2
10:11	99	4.65	28.7	2.5	1.3	1
11:06	112	3.8	23.3	2.0	0.9	1
12:21	127	3.8	25.3	1.9	0.6	2
Stop						
12:26	---	---	----	---	---	--
12:51	---	4.0	37.6	3.0	0.4	2
13:56	104	3.8	38.3	2.5	0.5	2
15:51	128	3.26	48.2	0.8	0.3	3
Stop						
15:56	---	---	----	---	---	--
16:08	81	4.52	41.4	2.8	0.7	2
17:10	9	3.56	60.0	1.5	0.5	1

The test was conducted at a temperature of 125 to 131 F at an average flow rate of 2 gpm/element. The effluent concentration was somewhat higher at the beginning of the test than in previous tests, because the loop had not been cleaned before testing.

Test results are given in Table 4. Pressure drop and efficiency are plotted as a function of load in Figure 12. Although the average efficiency of the filters in the test was somewhat lower, results did not differ greatly from previous non-continuous test runs. It was concluded, therefore, that shutdown and startup did not significantly affect tests of cartridge filters.

The third test of 39R10CV filters was made to determine the effect of lower flow rates. A flow of ½ gpm/element was maintained through-

Table 4. Test Data for 39R10CV Filter Elements during Continuous Test Run

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity		Boehmite Added
				Influent	Effluent	
Hrs.	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)	(gm)
0:00	130	---	---	8.5	---	3
0:10	128	3.3	---	10.0	3.2	--
1:40	126	3.6	19.4	2.0	1.5	2
3:45	130	4.2	24.2	2.3	1.2	4
5:35	129	4.7	28.4	2.5	---	1
6:00	131	4.9	23.4	2.0	1.5	3
7:25	131	4.1	21.8	2.0	0.5	4
8:57	130	4.05	24.0	2.0	0.5	3
10:13	130	4.0	29.0	2.0	0.5	4
11:45	131	3.8	44.5	---	---	1
12:15	129	4.0	54.8	---	---	1
12:45	131	3.6	60.5	2.0	0.5	--

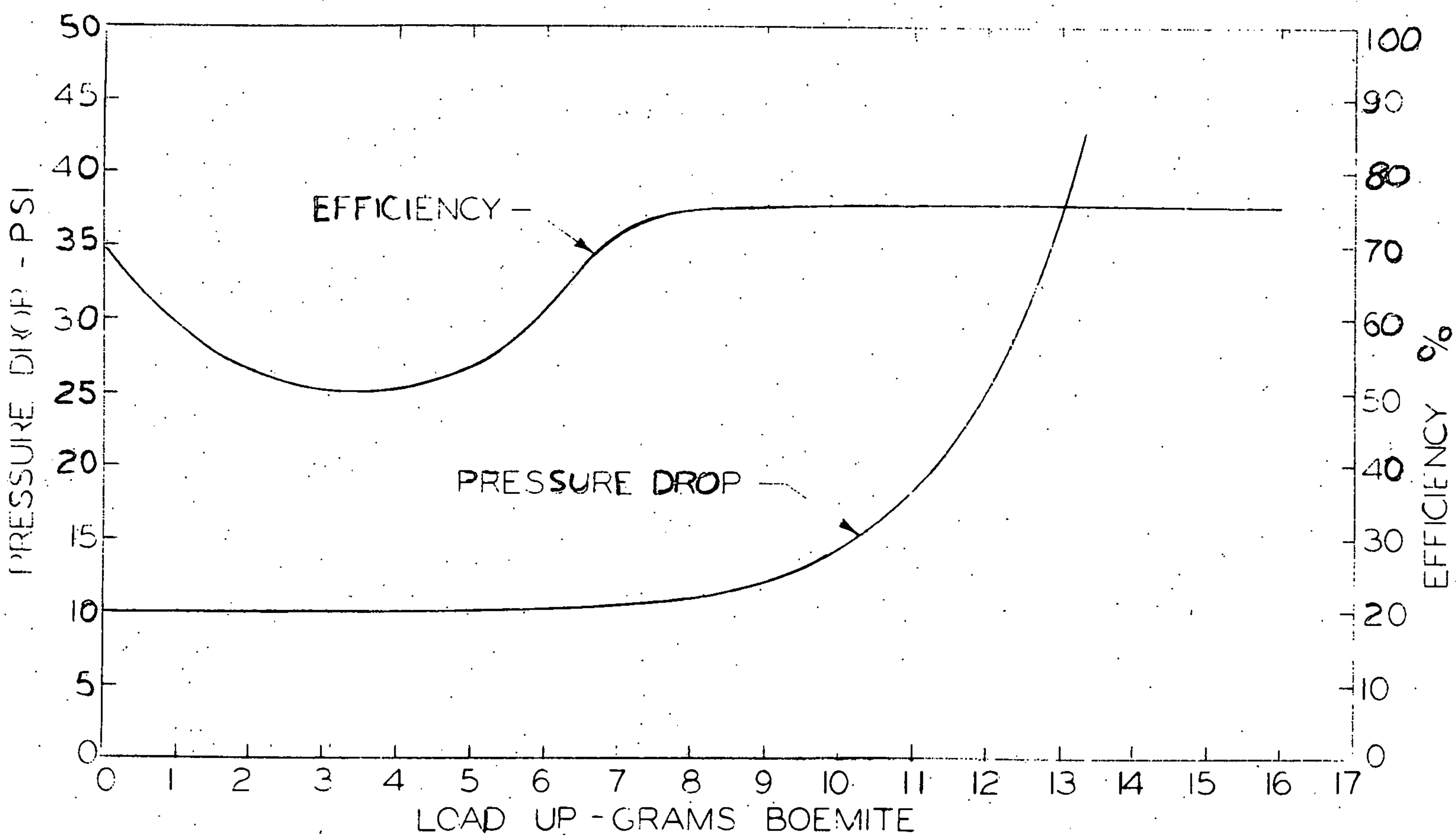

Figure 12. Pressure drop and efficiency of 39R10CV cotton cartridge as a function of load in a continuous test run at a 2gpm/cartridge flow rate. (AC Dwg 43-024-437)

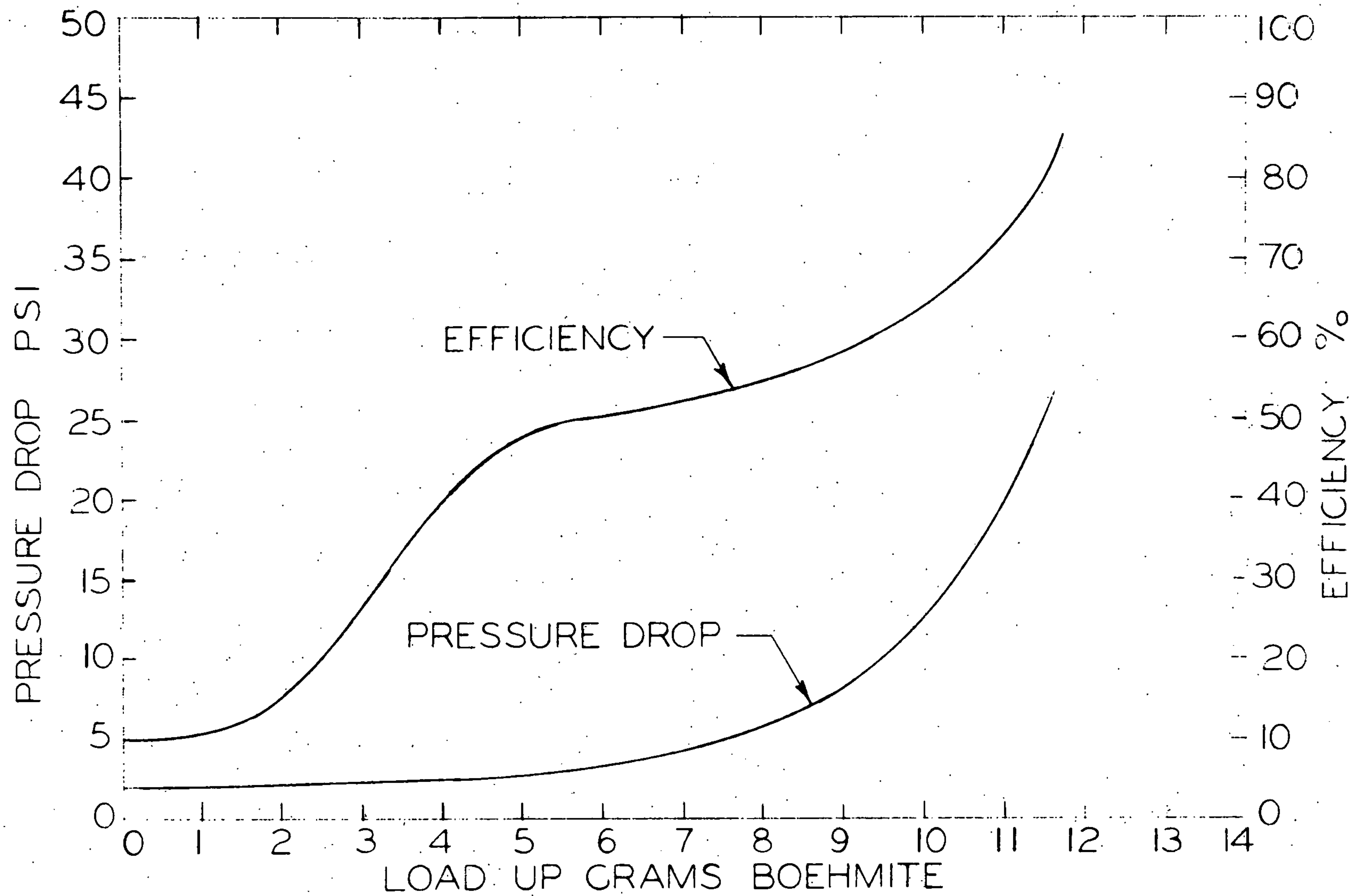

Figure 13. Pressure drop and efficiency of 39R10CV cotton cartridge as a function of load at a ½ gpm/cartridge flow rate. (AC Dwg 43-024-434).

Table 5. Test Data for 39R10CV Filter with Flow Rate of ½ gpm/element

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity Influent	Turbidity Effluent	Boehmite Added
Hrs	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)	(gm)
0:00	122	1	4.0	2.0	0.9	----
2:05	130	1	4.4	3.6	1.6	1
4:35	128	1	4.0	3.0	2.4	1
9:35	116	1	4.5	---	---	1
12:15	130	1	4.3	3.6	---	----
Stop						
12:20	134	1	4.3	--	--	----
13:36	135	1	4.2	3.6	3.3	1
18:26	130	1	4.5	3.5	2.6	2
26:16	129	1	3.7	---	---	----
26:21	---	---	---	---	---	----
Stop						
26:26	---	---	---	---	---	----
26:51	128	1	3.7	4.7	3.8	1
29:41	131	1	3.2	4.0	3.3	2
32:26	128	1	3.1	5.5	5.5	4
40:21	129	1	5.1	---	---	----
40:24	---	---	---	---	---	1
Stop						
40:29	131	---	---	---	---	3
41:39	130	1	3.9	7.3	5.2	3
43:59	131	1	4.4	8.0	6.0	1
47:39	129	1	4.9	8.0	4.5	1
52:39	129	1	6.9	---	---	4
54:39	126	1	8.6	---	---	2
54:40	---	1	---	6.7	3.5	----
Stop						
54:45	---	---	---	---	---	2
56:30	131	1	10.6	7.3	3.1	4
61:55	131	1	24.3	4.5	1.5	1
65:25	132	1	45.3	3.3	1.1	2
66:40	131	1	53.0	3.5	0.7	----
67:25	130	1	56.4	3.5	0.6	----

out the test run. The temperature was maintained at about 130 F. Because load was increasing too slowly, the influent concentration was increased during the latter half of the test.

The efficiency and pressure drop are plotted as a function of load in Figure 13. Detailed data for this test is given in Table 5.

The initial pressure drop of 1.8 psi was, as expected, considerably lower than in tests conducted with a flow rate of 2 gpm/element. The pressure drop increase followed the same pattern as in previous tests, but the average efficiency was considerably lower. The maximum load was 11.5 gm/element, which was also lower than in previous tests.

5.2 Micro-Klean Cartridges. The Micro-Klean cotton filter cartridge is constructed of small cotton fibers felted with a resin binder. The density of the filter is higher toward the center of the cartridge.

A filter rated at 5 μ (Micro-Klean 2278-B2) was selected for testing. The tests were conducted in the same manner as the tests with the cotton string-wound filters.

The pressure drop across a clean filter as a function of flow rate is shown in Figure 14. A reproducible pressure drop for a given flow rate was not obtained, because of difficulties encountered with equipment. However, a general pressure drop pattern was established.

In the first test with boehmite, it was not possible to maintain a 2 gpm/element flow rate. The pump was disassembled and a piece of rubber was found lodged in the impeller. When the test was resumed, the pressure drop across the filters rose to 25 psi in 1/2 hr, and the influent concentration became too high to determine. Restoring the flow through the pump to full capacity could have caused a large quantity of boehmite

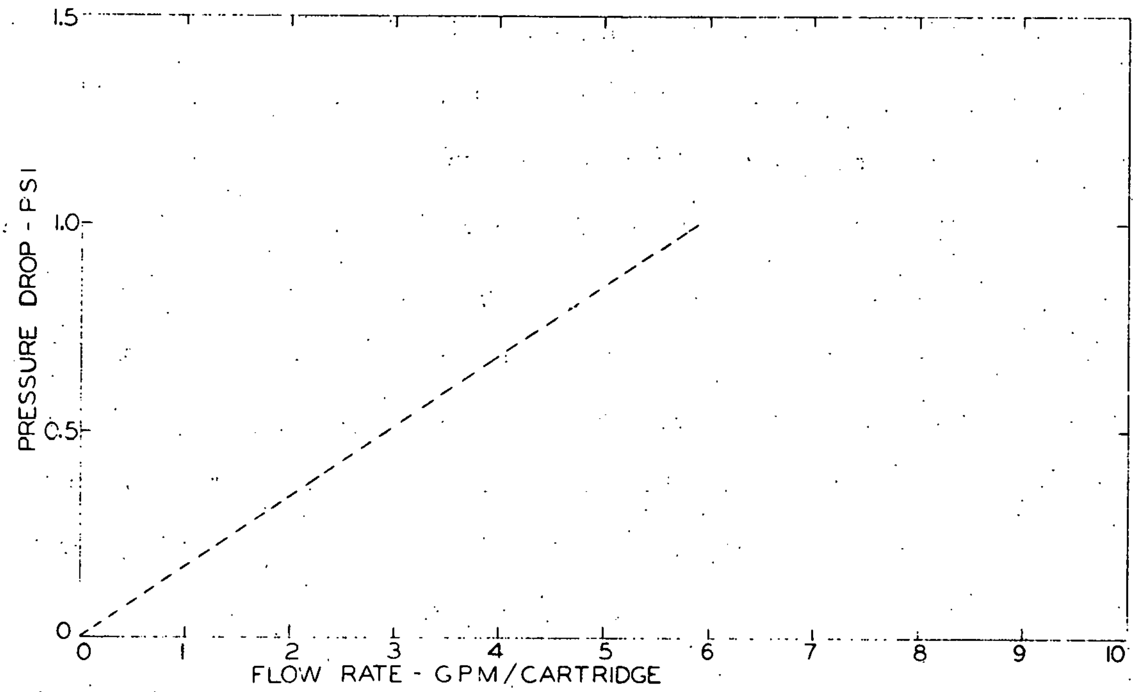

Figure 14. Pressure drop as a function of flow rate for a clean Micro-Klean 2278-B2 filter cartridge. (AC Dwg 43-024-440).

that had settled out to be put back in suspension. Data for the test is given in Table 6.

A 1/16-in coat of boehmite was found on filters after the test. This coat was removed from the filter surface and weighed. The weight of the boehmite within the filters was determined by dry-weighing. The weight of the boehmite coating was 14.3 and 13.9 gm, respectively for the two elements. The total load on the filter was 36.4 and 39.9 gm, respectively.

Data for a second test run is given in Table 7. The test was run during a single day. A pressure drop of 16 psi was reached at the end of the day. The slope of the pressure drop curve of these tests indicates that there would be little additional load-up if the test had continued to a pressure drop of 25 psi.

Some tests were made to determine the feasibility of cleaning the Micro-Klean filters and using them again. The filters used in the second

Table 6. Test Data for Micro-Klean Filter 2278-B2 Cartridge

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity Influent	Turbidity Effluent
Hrs	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)
0	120	2	0.5	2.0	1.25
1:15	121	2	0.6	1.75	1.25
1:30	122	2	0.6	6.5	1.75
1:45	123	2	0.6	6.5	1.75
2:20	126	2	0.6	3.5	1.5
2:45	129	2	0.6	4.75	1.3
3:15	128	2	0.65	4.5	1.5
4:00	128	2	0.65	3.75	1.25
5:25	127	2	0.6	2.25	1.0
6:10	127	2	0.65	2.5	0.5
6:40	126	2	0.65	4.0	0.5
Stop for Night					
6:45	107	2	0.8	4.0	0.5
7:10	111	2	0.8	4.75	0.25
7:55	117	2	0.9	3.5	0.25
8:30	122	2	0.85	2.5	0.0
8:40	122	2	0.85	7.0	0.0
9:15	128	2	0.85	2.0	0.0
9:50	123	2	0.9	2.0	0.0
10:40	127	2	).9	1.5	0.25
11:10	130	2	0.9	2.0	0.0
11:50	131	2	0.9	2.0	0.0
12:20	126	2	0.95	4.0	0.0
Shut Down for Pump repair 2 days					
12:20	Start no readings				
12:50	121		53	20+	0.0
Stop					

Table 7. Test Data for Micro-Klean Filter 2278-B2 Cartridge at Flow Rate of 2 gpm/element.

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity	
				Influent	Effluent
Hrs.	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)
0	95	2	0.4	4	1.0
0:30	128	2	0.4	3.0	2.0
1:05	130	2	0.4	7.0	2.5
2:0	127	2	0.6	4.75	2.5
5:0	127	2	0.5	5.0	2.25
5:35	127	2	0.5	5.75	2.5
Stop					
6:30	119	2	0.5	3.0	2.5
9:05	134	2	0.5	7.0	2.5
12:05	129	2	0.6	3.5	1.5
11:55	130	2	0.75	2.0	0.5
Stop					
12:25	103	2	1.05	6.0	0.5
13:55	114	2	3.9	6.0	0.5
14:55	118	2	8.2	3.0	0.25
15:55	123	2	11.1	5.5	0.25
16:55	122	2	17.6	4.75	0.25
17:25	121	2	19.9	4.0	0.0
18:10	121	2	23.2	3.25	0.0
19:10	121	2	28.0	6.75	0.0
20:15	121	2	31.8	3.25	0.0
20:45	121	2	34.0	2.75	0.0
Stop					

test run were cleaned and replaced in the loop three successive times. After the first of these tests, a portion of the outside surface of the filter was found free of a boehmite coat. The area found free of boehmite coat after the second test was larger. After the third test, almost no boehmite coat was found on the filter. It was concluded, therefore, that cleaning the filter would extend the useful life of the filter somewhat. Data for these tests is given in Tables 8, 9, and 10.

Table 8. Test Data for Micro-Klean Filter after First Cleaning

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity	
				Influent	Effluent
Hrs.	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)
0	118	2	0.35	2.5	0.5
1:30	124	2	1.8	5.5	0.25
2:45	122	2	9.95	2.0	0.25
Stop					
3:45	104	2	11.5	0.25	0.0
4:45	117	2	23.5	3.5	0.0
5:45	118	2	27.5	4.5	0.0
7:0	119	2	32.3	3.5	0.0
8:0	119	2	33.7	2.5	0.0
9:30	119	2	38.8	0.75	0.0
11:30	119	2	47.5	2.5	0.0

Table 9. Test Data for Micro-Klean Filter after Second Cleaning

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity	
				Influent	Effluent
Hrs.	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)
0	90	2	0.75	6.0	0.5
0:45	106	2	0.5	3:25	0.0
1:45	117	2	0.6	4.5	0.0
2:45	120	2	3.0	2.0	0.0
3:45	122	2	12.4	4.75	0.0
4:45	120	2	22.0	4.75	0.0
5:45	121	2	33.9	5.5	0.25
6:45	121	2	44.8	4.5	0.0
7:00	124	2	45.7	5.5	0.0

Table 10. Test Data for Micro-Klean Filter after Third Cleaning

Time	Water Temp.	Flow Rate	ΔP across Filter	Turbidity	
				Influent	Effluent
Hrs.	(F)	(gpm)	(in. Hg)	(ppm)	(ppm)
0	120	2	0.7	8.25	0.0
1	118	2	0.6	4.0	0.25
2	120	2	0.6	4.5	0.0
3	122	2	1.3	4.0	0.25
4	121	2	8.7	2.5	0.0
5	120	2	17.5	5.0	0.0
6	121	2	27.9	5.0	0.0
7	122	2	35.7	4.5	0.0
8	120	2	46.5	5.0	0.0
8:10	120	1	21.5	---	---

5.3 Iron-Boehmite Comparison Test. To obtain additional information for purposes of comparison, both Micro-Klean and Fulflo cartridges were installed in a by-pass on a test loop at Greendale Laboratories. Rust had become quite a problem in this test loop. The filters were used until they could no longer maintain the desired clarity at a pressure drop of 25 psi. Flow rate is not known. Load-up was determined as before. The Micro-Klean 2278-B2 cartridges retained an average of 230 gm of rust. The Fulflo 39R10CV cartridge retained an average of 81 gm. Figure 15 shows a comparison of the filters used with boehmite and with iron corrosion product.

5.4 Summary. A comparison of results obtained with 39R10CV Fulflo filters and the 2278-B2 Micro-Klean filters is made in Figure 16. The graph shows that the pressure drop characteristic for the Micro-Klean filter is significantly more desirable than the pressure drop characteristic for the Fulflo filter when filtering boehmite. The efficiency of the Micro-Klean filter also exhibits a more desirable characteristic than the Fulflo filter in that efficiency steadily increases from the beginning of the test. The loading achieved at a pressure drop of 25 psi for the Fulflo cartridge was 15 to 16 gm/element; for the Micro-Klean filter, the loading was 36 to 40 gm/element.

Tests showed that the 19 x 20-CV and 27R10CV Fulflo cartridges were not efficient in removing boehmite. While these filters may remove the larger boehmite particles, residual fine particles continue to pass through them until a cake builds up.

The results indicated that boehmite forms a gelatinous non-porous filter cake. Very thin coats (approx. 1/16 in.) are sufficient to pro-

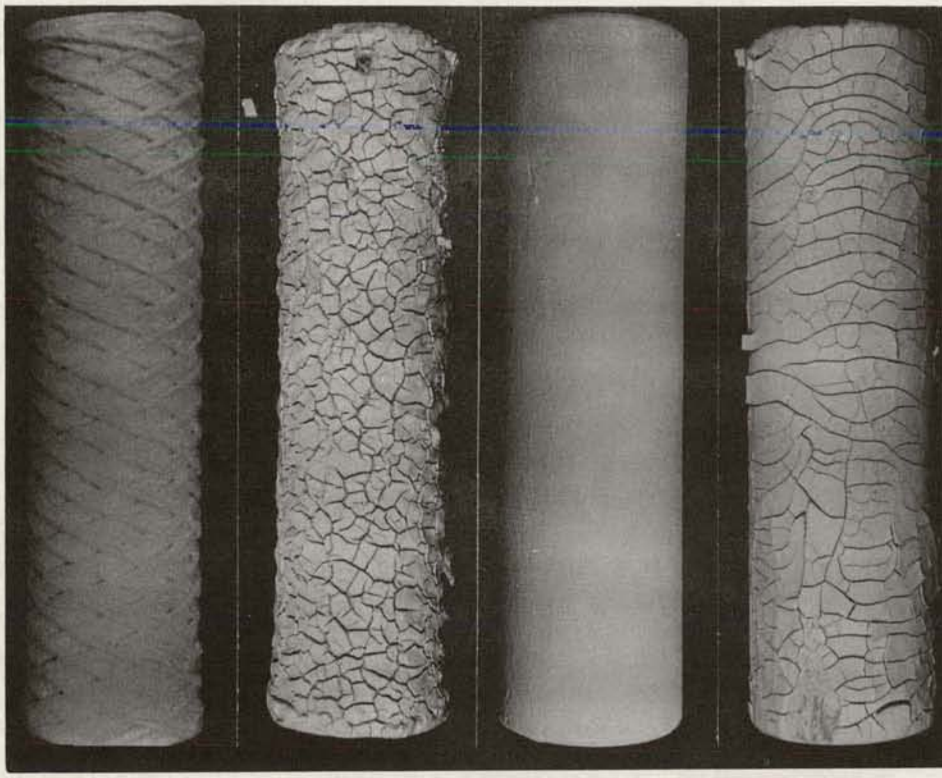

Figure 15. Comparison of filters loaded with iron corrosion product and boehmite. The two filters on the left are Fulflo 39R10CV cartridges loaded with boehmite (left) and iron corrosion product (right). The two filters on the right loaded similarly are Micro-Klean 2278-B2 Filters.

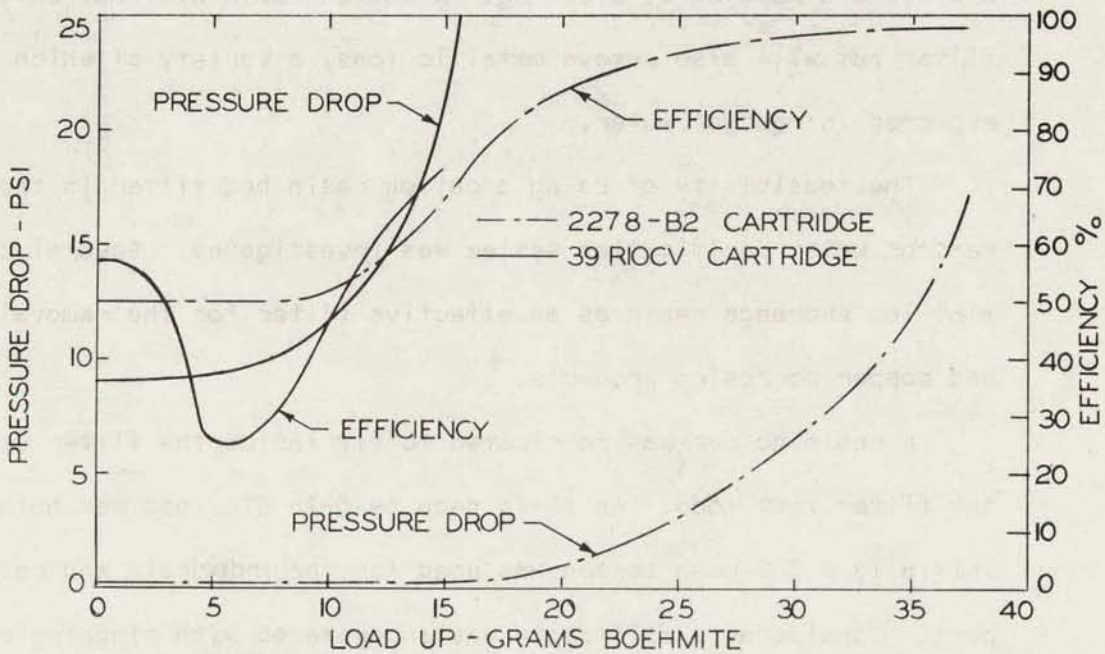

Figure 16. Comparison of performance of the Fulflo 39R10CV and Micro-Klean 2278-B2 Cartridges (AC Dwg 43-024-436)

duce a 25 psi pressure drop. If Figure 16 is reviewed it will be noted that the increase in pressure drop becomes very rapid as the element reaches its load-up point. There seems to be little advantage in using the filters to a higher pressure drop.

A comparison of the results using iron and the results using boehmite indicates that load-up data gained through the use of cotton element filters in an iron or steel system does not necessarily apply to an aluminum system. The filter characteristics of the boehmite indicate that any media used for this corrosion product will require frequent renewing or replacing. With this thought in mind, the selection of a filter that can be backwashed becomes much more desirable.

6. RESIN-BED FILTERS

A resin bed filter is of interest since corrosion products that are collected on the bed can be removed by backwashing. The resin can be installed and removed by sluicing. A cation resin will not only act as a filter but will also remove metallic ions, a variety of which may be expected in reactor water.

The feasibility of using a cation resin bed filter in the Pathfinder reactor water purification system was investigated. Several reports list ion exchange resin as an effective filter for the removal of iron and copper corrosion products.[4]

A resin holder was fabricated to fit inside the filter vessel of the filter test loop. An 18-in deep by 6-in dia. bed was obtained. Initially a 200 mesh screen was used for the underdrain and resin support. Considerable difficulty was encountered with plugging of this screen. A sheet of Neva-Clog was substituted for the screen with partial elimination of the plugging. The Neva-Clog was replaced with a Purolator metal edge disk with 0.005-in spacing, which completely eliminated the problem. A 60-40 mesh screen was fitted to the top of the resin holder to retain the resin during backwashing.

The load was determined by washing a known volume of resin to remove the collected boehmite, diluting the wash water, and determining the concentration turbidimetrically. The maximum load was the load at the breakthrough point, i.e. when a definite increase of boehmite was noted in the filter effluent.

Two types of resin were tested: a cation resin sold under the trademark, Nalcite HCR-W, and an adsorptive resin sold under the trademark, Duolite S-30. The pressure drop for these materials at various flow rates is shown in Figure 17.

6.1 Nalcite HCR-W. 12-40 Mesh Size (Standard) Resin. Three tests of standard Nalcite HCR-W were conducted to determine optimum flow rate, efficiency, and maximum load. The first test was performed at flow rates of 9 to 50 gpm/sq.ft. Data for this test is given in Table 11. The filter was not efficient at these flow rates, and became progressively less efficient as the boehmite load increased. After testing, boehmite was found distributed throughout the bed. Loading of the bed was as follows: 45 gm/cu.ft. in the top 6 in.; 30 gm/cu.ft. in the middle 6 in.; and 15 gm/cu.ft. in the bottom 6 in. Microscopic examination of the resin showed the boehmite attached to the beads.

The second test was conducted at a flow rate of 2.5 to 7.5 gpm/sq.ft. The resin removed the boehmite satisfactorily when the flow was held constant. When the flow rate fluctuated, boehmite was carried through

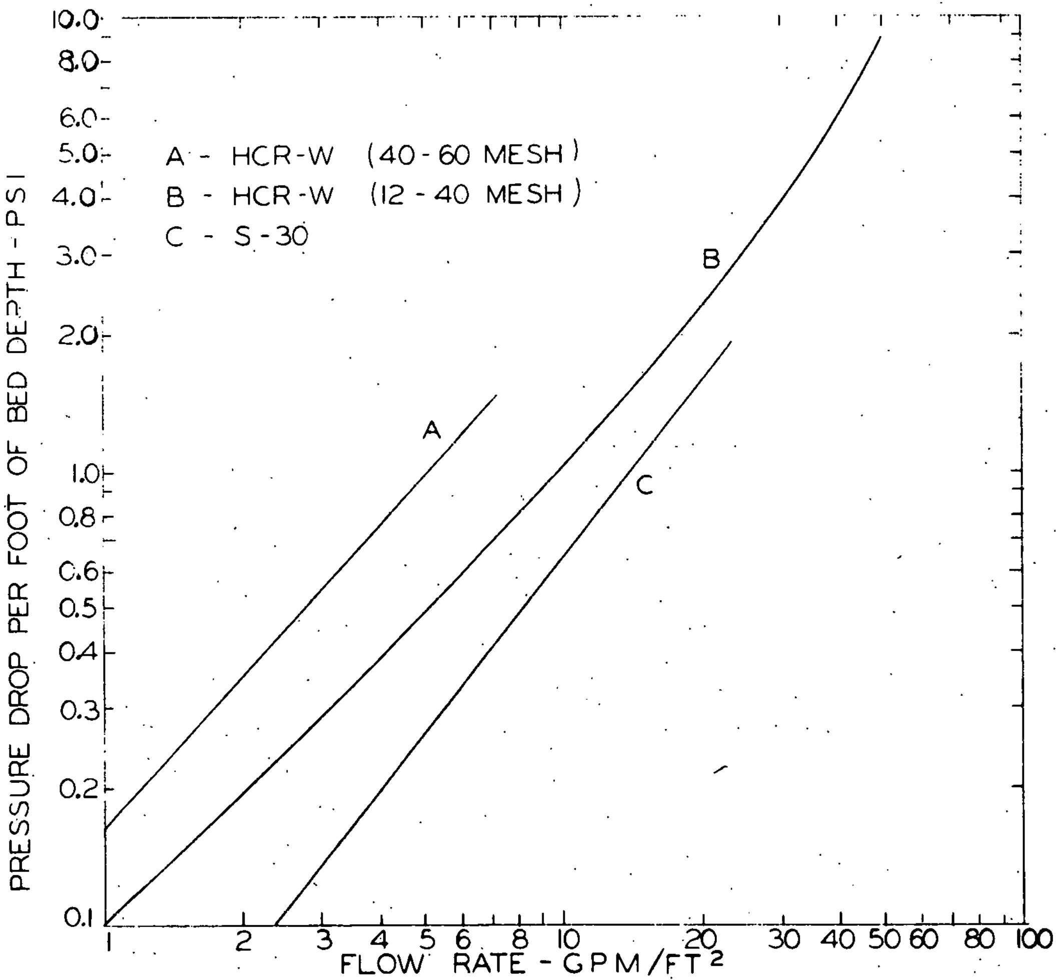

Figure 17. Pressure drop of various resins as a function of flow rate. (AC Dwg 43-024-447)

Table II. Test Data for 12-40 Mesh Nalcite HCR-W at High Flow Rates

Time	Water Temp.	Flow Rate	Turbidity Influent	Turbidity Effluent
hrs	(F)	gpm/sq.ft.	(ppm)	
0	132	45	38	17
0:10	132	45	24	20
0:30	133	50	15.8	12.3
1:35	135	45	9.7	9.7
1:45	135	45	4.7	6.8
4:00	138	30	11.5	7.8
4:15	138	10	16.3	9.8
4:30	139	9	7.7	4.5

Table 12. Test Data for 12-40 Mesh Nalcite HCR-W at a Flow Rate of 5 gpm/sq.ft.

Time	Water Temp.	Flow Rate	Turbidity	
			Influent	Effluent
Hrs	(F)	gpm/sq.ft.	(ppm)	
0:00	100	5	0.75	0.75
0:15	102	5	4.0	0.5
1:00	108	5	6.0	0.75
1:30	114	5	5.25	0.5
Stop				
1:45	85	5	5.0	0.5
2:30	113	5	6.5	0.75
3:30	118	5	5.25	0.25
4:45	115	5	3.75	0.25
6:00	114	5	4.5	0.0
6:45	113	5	5.0	0.0
7:15	113	5	4.75	0.0
8:00	112	5	4.0	0.25
9:00	112	5	3.75	0.0
9:25	111	5	6.0	0.25
10:25	113	5	6.5	0.0

the bed. This became more evident as the amount of boehmite in the bed increased. The test indicated that filtering efficiency decreased significantly when flow was increased above 5 gpm/sq.ft. The efficiency was not improved at flows below 5 gpm/sq.ft.

A third test was conducted at a flow rate of 5 gpm/sq.ft. with an influent boehmite concentration of about 5 ppm. The efficiency of the filter was about 85 per cent or better throughout the test. No increase in pressure drop across the bed was noted. Test data is given in Table 12. The boehmite load as a function of bed depth is shown in Figure 18.

The sensitivity of loaded resin to flow-rate increases indicated the ease with which the boehmite could be removed by washing. This washing was possible without difficulty even after the loaded resin was undisturbed for prolonged periods. Five test runs were therefore made to further evaluate backwashing of this resin.

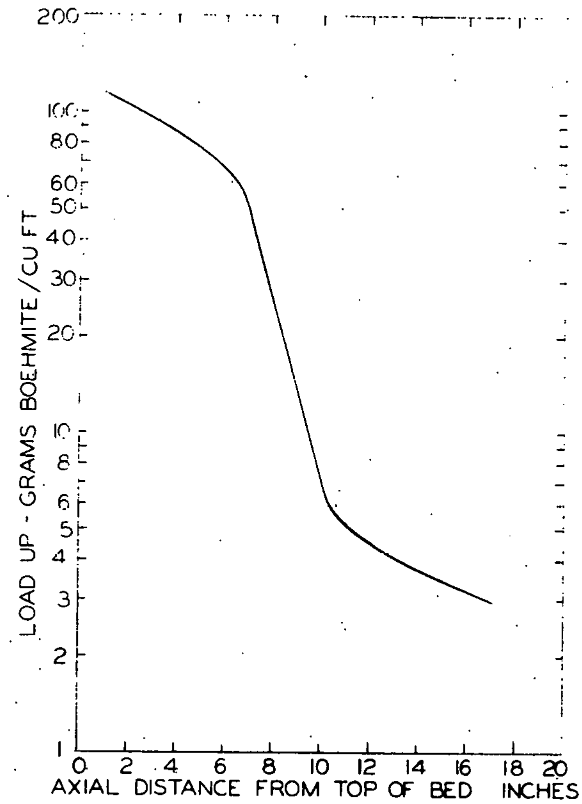

Figure 18. Boehmite load in 12-40 mesh Nalcite HCR-W as a function of bed depth. (AC Dwg 43-024-442)

Backwashing was very successful, but due to the limited space available very little bed expansion was possible. A series of short fast flows upward through the bed effectively removed the boehmite. During these flows the resin was lifed up against the retention screen. When the resin was lifted against the screen, it could have acted as a filter in the reverse direction explaining why satisfactory backwashing could not be accomplished with one continuous flow. Observations indicate that some form of backwash involving a scrubbing action with the resin would give best results.

After backwashing, the resin could be returned to service with the same results as new resin. Figure 19 shows the performance of the resin being returned to service after backwashing. This curve is typical for five runs. The first water removed from the bed is backwashing water, which would account for the high initial concentration. In all cases, maximum performance was reached in five minutes.

<u>40-60 Mesh Sized Nalcite HCR-W.</u> Tests of 40-60 mesh Nalcite HCR-W were conducted to determine if the smaller bead resin would be less sensitive to flow rate changes. At a flow rate of 5 gpm/sq.ft., and an average influent concentration of 4 ppm, the resin was over 95 per cent efficient until break-through. Results are shown in Figure 20. The graph also

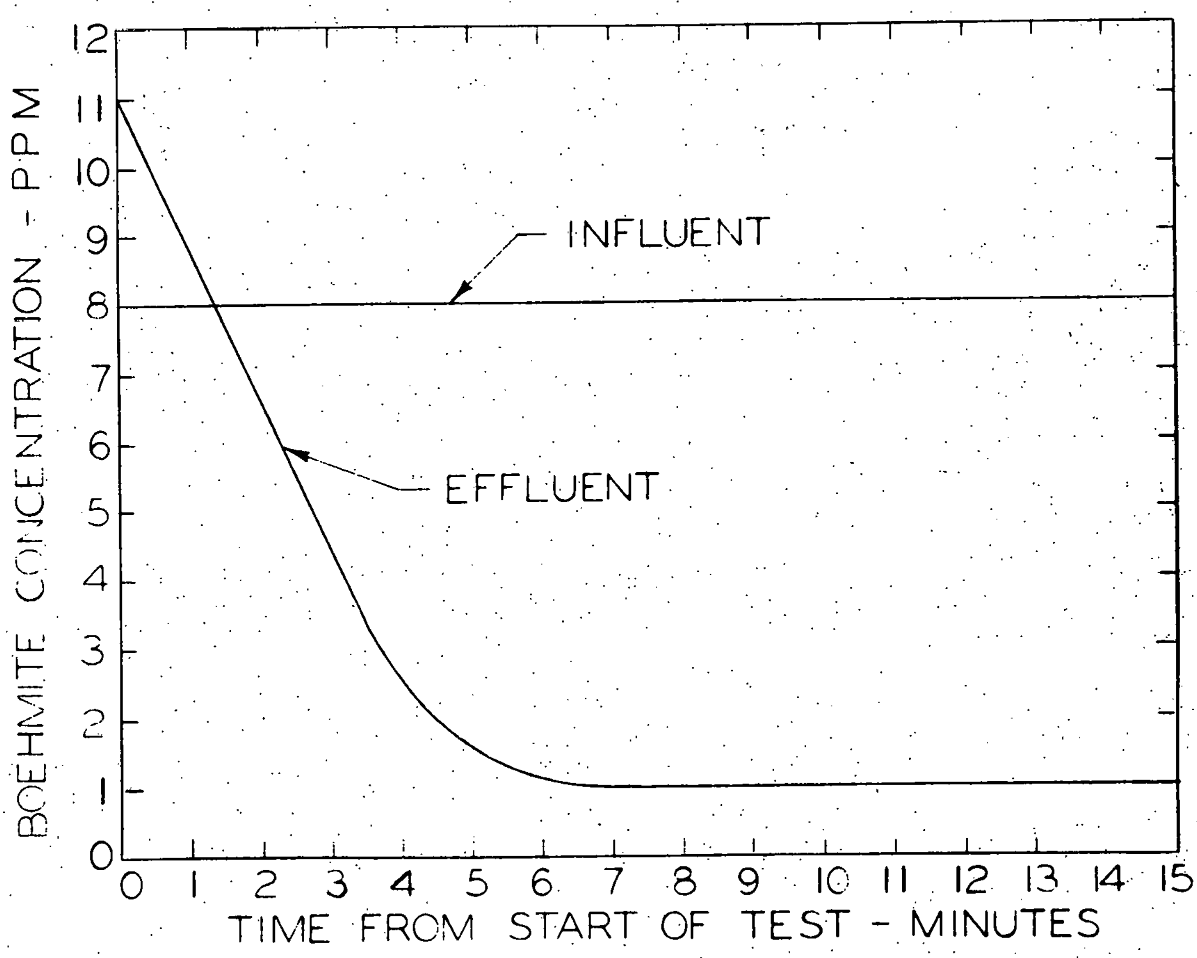

Figure 19. Performance of 12-40 mesh Nalcite HCR-W resin after being backwashed. (AC Dwg 43-024-439)

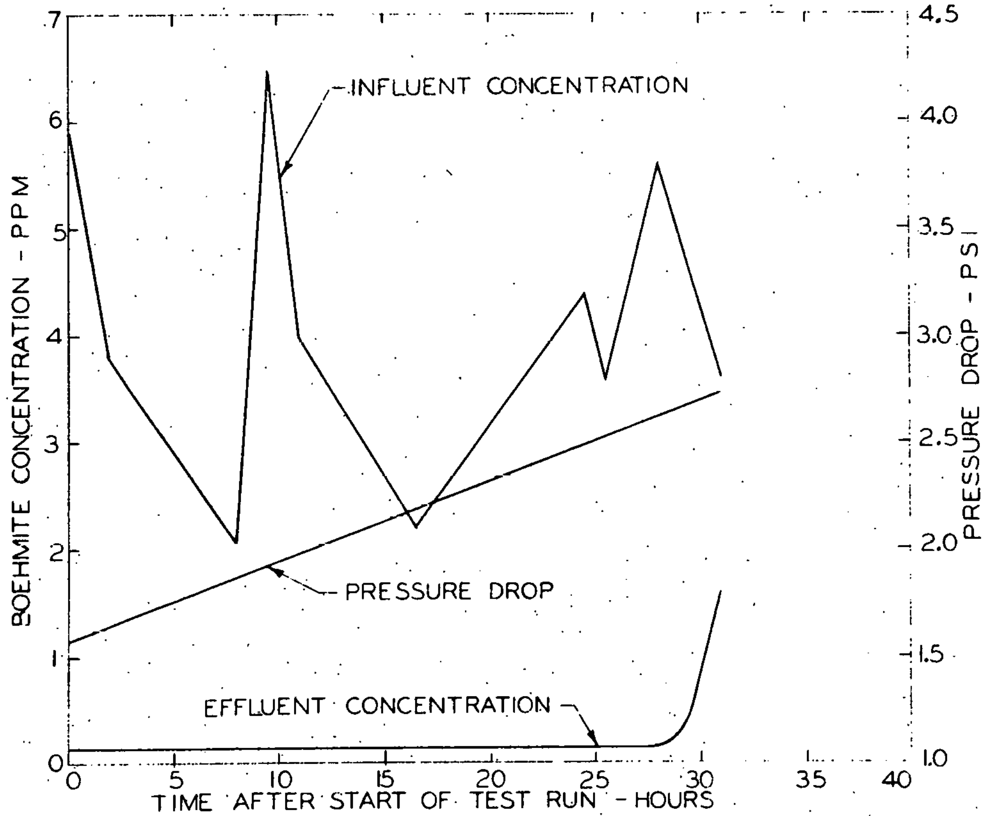

Figure 20. Performance of 40-60 Mesh Nalcite HCR-W Resin in test at flow rate of 5 gpm/sq.ft. (AC Dwg 43-024-445).

shows an increase in pressure drop as the load increases. Flow rate changes had little effect on carry-through of boehmite in these tests. Detailed results are given in Table 13.

The load as a function of bed depth for this resin is shown in Figure 21. The boehmite concentration is high in

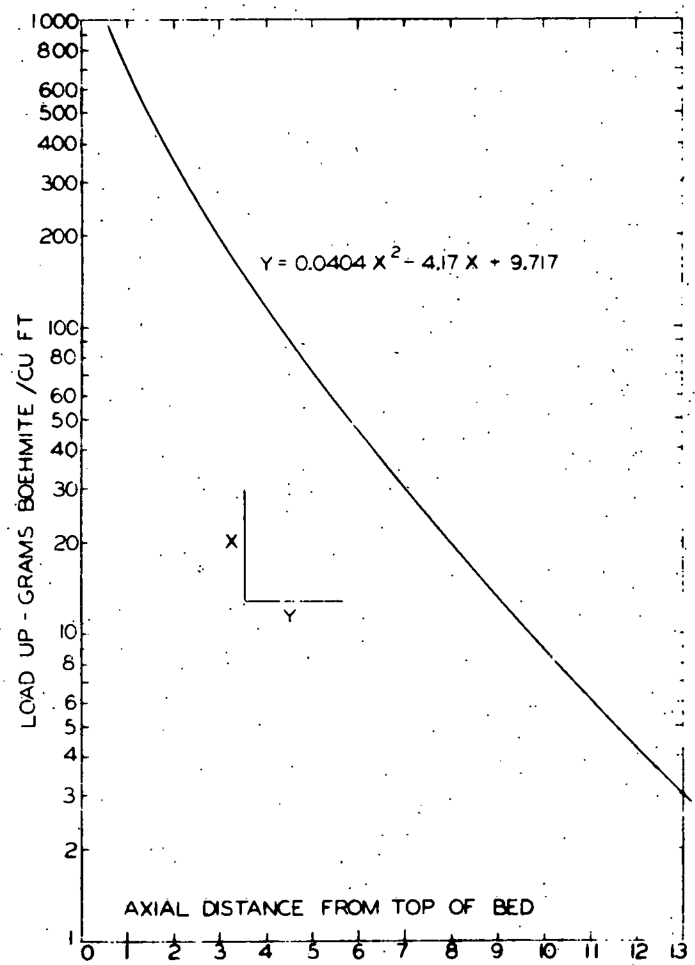

Figure 21. Boehmite load as a function of bed depth for 40-60 Nalcite HCR-W resin. (AC Dwg. 43-024-443).

the top 2 in. of the bed. Expressed in terms of filtering surface area, the load was 250 gm/sq.ft. The test indicates that a resin bed deeper than 18 in. would probably not be required.

Table 13. Test Data for 40-60 Mesh Nalcite HCR-W Resin at 5-gpm/sq.ft. flow rate.

Time	Water Temp.	Flow Rate	Turbidity Influent	Turbidity Effluent
Hrs	(F)	gpm/sq.ft.	(ppm)	
0	118	5	6.0	1.5
1:00	118	5	3.75	1.0
3:15	107	5	4.0	0.0
5:15	106	5	3.5	0.0
6:15	116	5	7.0	0.0
7:30	109	5	2.0	0.0
Stop				
8:00	106	5	10	0.0
8:45	106	5	6.5	0.0
10:45	102	5	4.75	0.0
13:00	104	5	4.35	0.0
14:00	109	5	6.5	0.25
15:00	100	5	2.0	0.25
Stop				
10:00	110	5	7.5	0.25
17:00	106	5	3.25	0.0
18:15	99	5	3.3	0.0
19:35	97	5	4.0	0.25
20:40	98	5	3.0	0.0
21:50	98	5	3.0	0.0
22:45	100	5	4.5	0.25
Stop				
23:15	97	5	8.25	0.0
24:15	98	5	3.5	0.0
25:20	99	5	6.5	0.0
26:20	100	5	5.75	0.0
27:30	102	5	5.0	0.25
29:05	102	5	4.0	1.0
29:30	102	5	3.5	1.5
Stop				

6.3 Duolite S-30. Two tests of Duolite S-30 were conducted. Test data is given in Tables 14 and 15. The resin was not effective in filtering boehmite.

Table 14. Test Data for Duolite S-30 Resin at High Flow Rates

Time	Water Temp.	Flow Rate	Turbidity	
			Influent	Effluent
Hrs	(F)	gpm/sq.ft.	(ppm)	
0:00	122	6	7.5	4.5
0:30	120	5.5	6.5	6.5
1:00	127	5.5	6.5	6.5
1:40	128	10.5	6.5	6.5
1:50	128	12.5	6.5	6.5
2:00	128	13	6.5	6.5
2:10	128	15	6.5	6.5
2:20	128	20	6.5	6.5
2:30	128	23	6.5	6.5
2:40	129	26	6.5	6.5
2:50	130	2.5	6.5	6.5

Table 15. Test Data for Duolite S-30 Resin at 5-gpm/sq.ft. Flow Rate

Time	Water Temp.	Flow Rate	Turbidity	
			Influent	Effluent
hrs	(F)	gpm/sq.ft.	(ppm)	
0:00	112	5	5.0	9.5
0:30	119	5	4.5	4.5
1:00	123	5	5.0	5.0
1:40	123	5	5.0	5.0

6.3 Summary. Resins tested included Nalcite HCR-W and Duolite S-30. The Nalcite HCR-W was effective in filtering boehmite. The Duolite S-30 was not effective.

Tests with 12-40 mesh Nalcite HCR-W showed that the 18-in resin bed removed the boehmite near the surface and adsorptively at depth. Optimum flow rate was about 5 gpm for the 6-in dia. bed. Filter efficiency decreased significantly at higher flow rates, but was not improved at lower flow rates. The filter efficiency was sensitive to flow rate fluctuations resulting in boehmite carry-through. This sensitivity of flow-rate fluctuations increased with load. Average steady-state efficiency of the bed was 85 per cent.

Tests showed that the 12-40 mesh Nalcite HCR-W can be effectively backwashed and re-used with the same results as new resin.

The 40-60 mesh resin had an initial efficiency of 75 per cent. This efficiency increased after 2 hr of operation to better than 95 per cent. This high efficiency was maintained quite consistently until the maximum load was reached, at which point efficiency rapidly decreased. Filter efficiency was relatively unaffected by flow rate fluctuations for flow rates not exceeding 6 gpm.

The use of fine bead resin eliminated many of the problems of the standard resin. From test indications it was deemed not advisable to raise the flow rate. Flow rates of 5 to 6 gpm/sq.ft. would be the maximum advisable design flow.

The boehmite load in the 40-60 mesh resin bed was concentrated in the top 2 in. of the bed. Based on the surface area of the filter, the maximum load was 250 gm/sq.ft. Data on bed loading indicates that a bed 18 in. deep is adequate for removing the boehmite.

There is a wide variety of ion exchange resins available, and a program to evaluate them would be excessively long and costly. It was decided to evaluate the use of a resin bed filter on the basis of the information obtained to this time.

7. PRECOAT FILTERS

Precoat filters are used in removing iron and copper corrosion products to obtain ultra-high purity water, and considerable data has been published on the various types.[5] In investigating their usefulness for removing boehmite, both leaf type and element type filters were at first considered. After consulting with several manufacturers of leaf-type filters, it was concluded that this type could not be satisfactorily backwashed without a water sluicing jet or vibrator. Since this might substantially increase maintenance problems, only element type precoat filters were investigated.

As was previously stated, the addition of a diatomaceous earth precoat to a sintered ceramic element, greatly improved its filtering ability. There is the possibility of leaching silica and other materials from diatomaceous earth, so only Solka-Floc was selected for further study. This material is presently being used for filtration of condensate. Several companies have reported on extensive development work and have shown that Solka-Floc is effective for removal of fine particles and is backwashed effectively.

In view of the extensive development work done by others it was not deemed necessary to initiate a prolonged investigation. Some experiments were carried out by Allis-Chalmers and several filter suppliers.

7.1 Cellulose Precoat Filter. A purified, finely divided wood cellulose precoat filter sold under the trademark, Solka-Floc by Brown Company was tested with various back-up elements to determine its efficiency in filtering boehmite.

Two Micro-Klean 2278-C1 filter cartridges were used for back-up elements. A short initial run at 2 gpm/element and an influent concentration of 6.5 ppm quickly established that the back-up filter was almost completely ineffective for the removal of boehmite. Some BW-100 Solka-Floc was added to the water. The boehmite concentration in the effluent quickly dropped to zero showing almost a 100 per cent filter efficiency. The water became too colored due to leaching from the filter element to continue influent and effluent readings. The test was continued until a pressure drop of 25 psi was reached.

The elements were examined and a 1/16- to 1/8-in coating of boehmite was observed on the outside of the Solka-Floc precoat. Accurate loadup data was not obtained. However, a 1/16-in cake corresponds to approximately 30 gm/sq.ft.

A 6-in piece of Neva-Clog was placed in the under drain of the resin support column and precoated with Solka-Floc. Resin was not present in the column. A short run indicated that the Solka-Floc precoat was almost 100 per cent effective for removing boehmite. Since it was impossible to obtain any load-up information, the run was discontinued after establishing the initial filter efficiency.

<u>7.2 Industrial Filter and Pump Mfg. Tests.</u> Industrial Filter & Pump Mfg. Company was contacted with regard to the filtration of boehmite using a Solka-Floc precoat. A sample of boehmite was furnished them. They ran tests at a constant pressure drop instead of a constant flow rate. For this reason much of their information cannot be compared to Allis-Chalmers tests. A complete report is not available on their work. However, they indicated that the filter was approximately 100 per cent efficient with a load-up of 1/16-in.

7.3 Commercial Filters Corporation Tests. Commercial Filters Corporation also agreed to run some tests in their laboratory. The initial work with uncoated ceramic elements has been previously discussed. A considerable amount of work was done using the 25-μ ceramic element precoated. Diatomaceous earth was first used as the precoat with all later work using BW-100 Solka-Floc. Filter efficiency was determined by quantitative analysis of influent and effluent samples. Filter efficiency in all of their tests was in excess of 99 per cent.

Load-up was determined by using the influent and effluent concentrations to determine the amount of boehmite retained by the filter. Their results indicated that load-up, at 25 psi pressure drop and 3 gpm/sq.ft. flow rate was in excess of 65 gm/sq.ft. This information was not consistent with the other results.

Evaluation showed, however, that due to the high influent concentration (approx. 200 ppm) used in these tests a major portion of the boehmite settled out in the filter vessel and never reached the filter. Actual load-up was a cake approximately 1/16-in thick. A complete report is not available on the work done by Commercial Filters Corporation.

7.4 Summary. The net result for the precoat filter testing was to firmly establish that Solka-Floc precoat was essentially 100 per cent effective for the filtration of the purchased boehmite. Approximately 30 gm/sq.ft. is a reasonable load-up. Varying flow rates from 0.69 to approximately 3 gpm/sq.ft. did not appear to alter the results significantly. This is contrary to what might be expected. However, it must be realized that accurate load-up information was not obtained due to the difficulty of separating boehmite and Solka-Floc.

A precoat filter combines backwash capability with an easily replaceable filter media. The filter can be operated remotely and the waste sluiced to disposal. Since sufficient performance data on precoat filter systems has been published to enable design of a system for Pathfinder, no further tests were conducted.

8. CONCLUSIONS

In all, five types of filters were evaluated. Results of each individual test have been discussed in part, in connection with the test descriptions. A summary of the pertinent results, and a comparison of each filter type will enable a conclusion to be made regarding the type of filter best suited to the intended application, i.e., that of removing relatively large quantities of aluminum corrosion product (boehmite) from a reactor primary system.

The Hi-Lo, wound-wire type element plugs rapidly with influent concentrations of 2.0 ppm and a flow rate starting at approximately 20 gpm. No efficiency or load-up data was obtained. Observation of the filter showed no buildup of a boehmite cake. It would appear that the rapid plugging was caused by discrete particles of boehmite lodging in the individual filter pores.

Backwashing of the filter was somewhat effective when compared to the clean filter; and 100 per cent effective when compared to the start of the first run. The information is insufficient to predict backwashing effectiveness for long term operation.

Lower flow rates would undoubtedly prolong the operating cycle between one backwash and the next. The cost of the necessary filter elements required to extend this cycle to a practical limit, for use in the intended system, would be prohibitive.

Results obtained with the un-precoated ceramic elements closely approximated those of the Hi-Lo filter. The plugging mechanism appears to be the same. Backwashing, however, proved to be ineffective. When compared to other filters tested, performance of both the wound-wire and ceramic type filters is poor when removing boehmite from a water system.

Testing of cotton cartridge filters was extensive. The filter utilizes both the element depth and surface cake for removing particles, as compared to the wound-wire element, which employs only a surface mechanism.

Tests showed type 19x10 - 2CV Fulflo elements to be too coarse to effectively remove boehmite. The finer 27R10CV element offers some improvement having an average efficiency of 45 per cent. It is seen, however, that a load-up of only 15 gm/element of boehmite is achieved before the pressure drop becomes excessive. An average efficiency of 62 per cent was eventually achieved for the finest cotton wound element (39R10CV), but a slight reduction in load-up is also observed.

It is of interest to note that a reduction of flow rate to 1/2 gpm/element from 2 gpm/element results in no improvement of either filter efficiency or final load-up on a per element basis.

Substantial improvement is seen in the performance of the Cuno, felted-type element. Tests show that the felted filter retains in excess of 35 gm/element before pressure drop becomes excessive. This is more than twice the load-up on the cotton wound element.

Comparison of typical cotton wound and felted elements when loaded to capacity with boehmite and when loaded with rust products from a ferrous system show that felted elements removes 230 gm of rust per element compared to the 35 gm of boehmite per element removed by the same type element.

One of the most significant observations made in the test program is brought out by this comparison, i.e., there is very little porosity associated with a boehmite cake. Instead of developing to a thick porous layer, as rust does, boehmite forms a thin gelatinous film which quickly becomes a flow barrier.

As is shown in all of the pressure drop vs. load-up curves, little can be gained by allowing pressure drop to increase above 25 psi. In this range a very large increase in pressure drop is accompanied by little increase in load-up.

In view of these results it may be stated that experience with cotton cartridge type filters in primarily ferrous systems is not completely applicable to aluminum systems.

Considerable success was obtained using ion exchange resin as a filter for boehmite. The collected boehmite could be removed from the ion exchange resin by backwashing. Standard size resin was very sensitive to flow rate and/or changes in flow rate. This problem was alleviated by a change to a fine (40-60) mesh resin. Maximum design flow for a resin bed filter was found to be 5-6 gpm/sq.ft. The boehmite collected by the standard resin was distributed through some depth of the bed whereas the fine resin acted more as a surface filter. Filter efficiency is seen to be excellent until break-through of the boehmite.

Backwashing of the standard resin was successful. The fine resin backwashed much the same as the standard resin. Some development work might be necessary to find the optimum procedure for backwashing the fine resin.

The quantity of backwash water and the large filtration area required are two drawbacks to the use of this type of filter; especially with a system that has high flows (approximately 250 gpm). For a relatively clean system an ion exchange filter would be very satisfactory. However, for the system under consideration it would be a second choice.

If we consider a low flow system with a light filtration load, the resin bed filter becomes more desirable. A logical development for a system also containing an ion exchanger would be the elimination of the filter and using the ion exchanger as a filter also.

Initially, the precoat filter was not considered. However, as testing proceeded, it became obvious that an element type filter, if used, would require frequent renewal or replacement. A precoat filter permits this change of filter media to be accomplished quickly and remotely, which is particularly desirable for a radioactive water purification system.

Solka-Floc was selected as a precoat media for testing. Work with this material established that it was essentially 100 per cent efficient for the removal of boehmite from water. This efficiency was confirmed by others.

Considerable experimental work using precoat filters with high purity water has been reported. It was not deemed necessary to investigate the mechanics of operation of this type of filter.

Load-up for a precoat filter was obtained indirectly through extrapolation of data from cotton filter tests, and was established at approximately 30 gm/sq.ft. at 25 psi pressure drop. Flow rate was varied from 1 to 4 gm/sq.ft. This load-up corresponds to approximately a 1/16-in thick coat. In a precoat filter a low load-up is not as critical as with cotton cartridges since the precoat may be changed easily and quickly.

The flow rate in a precoat filter may be varied over a wide range with little loss in filter efficiency. However, flow must be maintained at some minimum rate to hold the precoat in position.

All factors considered, the precoat filter seems most desirable for use in a reactor water purification system where considerable flows and a high filtration load are expected. Careful design will provide a filter installation that is dependable and requires little maintenance. All operations can be accomplished remotely, minimizing personal exposure to reactor water.

APPENDIX A CALCULATIONS AND DEFINITION OF TERMS

1. Cotton Cartridge Tests - Outline of Method Used for Correlating Filter Load with Efficiency and Pressure Drop.

1.1 Nomenclature

ΔP Pressure drop (psi)

η Denotes the particular time segment being considered

A_η Measured area in particular time segment

K Conversion factor from measured (in^2) to (ppm-hours)

P_τ Grams load up at any time (hours) following start of test

τ Time in hours after start of test

$\bar{\eta}_n$ Average filter efficiency throughout arbitrary time segment (%)

$\bar{e}_{in}$ Average influent concentration (ppm)

$\bar{e}_{out}$ Average effluent concentration (ppm)

$\Delta\bar{e}_\eta$ Average difference between influent and effluent concentration in any time segment (η).

ω Maximum load up in grams - as determined from weight measurements

1.2 Pressure Drops vs. Load-Up - Procedure. Plot all recorded data (concentration in and out, pressure drop) vs. running time in hours. For arbitrarly selected time intervals, graphically integrate the area between influent and effluent turbidity curves. This gives values for (A_n). Determine total area from $\tau = o$ to $\tau =$ end of test.

$$A_{total} = \sum_{\tau=0}^{\tau_e} A_\eta \qquad \text{where } \tau_e = \text{total running time of test.}$$

Assume that A_{total} is proportional to maximum load up (ω)

$$A_{total} \sim \omega \text{ or } A_{total} = F\omega \qquad \text{where F is a proportionality constant.}$$

Determine load up in grams (ρ_τ) for each hour (τ).

$$\rho_\tau = \frac{\sum_{o}^{\tau} A_n}{A_{total}} \times \omega$$

With values of (ρ_τ) from above, ΔP points from curves in the first step can be correlated for each value of (τ).

ΔP may then be plotted vs. ρ_τ, i.e., pressure drop vs. load up.

1.3 Efficiency vs. Load Up - Procedure

Define filter efficiency (η) = $\left[\frac{e_{in} - e_{out}}{e_{in}}\right] \times 100$

Determine average values for filter efficiency for each hourly segment from data plots as follows:

$$\bar{\eta}_n = \left[\frac{\bar{e}_{in} - \bar{e}_{out}}{e_{in}}\right] \times 100 = \frac{\Delta \bar{e}_n}{\bar{e}_{in}} \times 100$$

where $\Delta \bar{e}_n = \frac{k A_n}{\Delta \tau}$

Since values for ρ_τ have already been established. $\bar{\eta}_n$ may now be plotted vs. ρ_n

$\bar{\eta}_n$ points are actually considered to fall half way through each hourly segment so as to represent an average for that segment.

2. Definition of Terms

Backwash - A reverse flow through a filter the purpose of which is to remove any collected solids or a combination of precoat and solids.

Efficiency (Filter) - $\frac{\text{influent concentration - effluent concentration}}{\text{influent concentration}} \times 100$

or, the percentage of the solids in the filtrate which is removed as it passes through the filter.

Load Up (maximum) - Quantity of solids that have been retained by a filter when shut off conditions are reached.

Load Up (Per Cent) - $\frac{\text{Load Up at any Time}}{\text{maximum Load up}} \times 100$

Precoat Filter - One which uses a porous back-up material, coated with a second material that acts as a filter. The back up material is reused, while the coating material is periodically replaced.

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