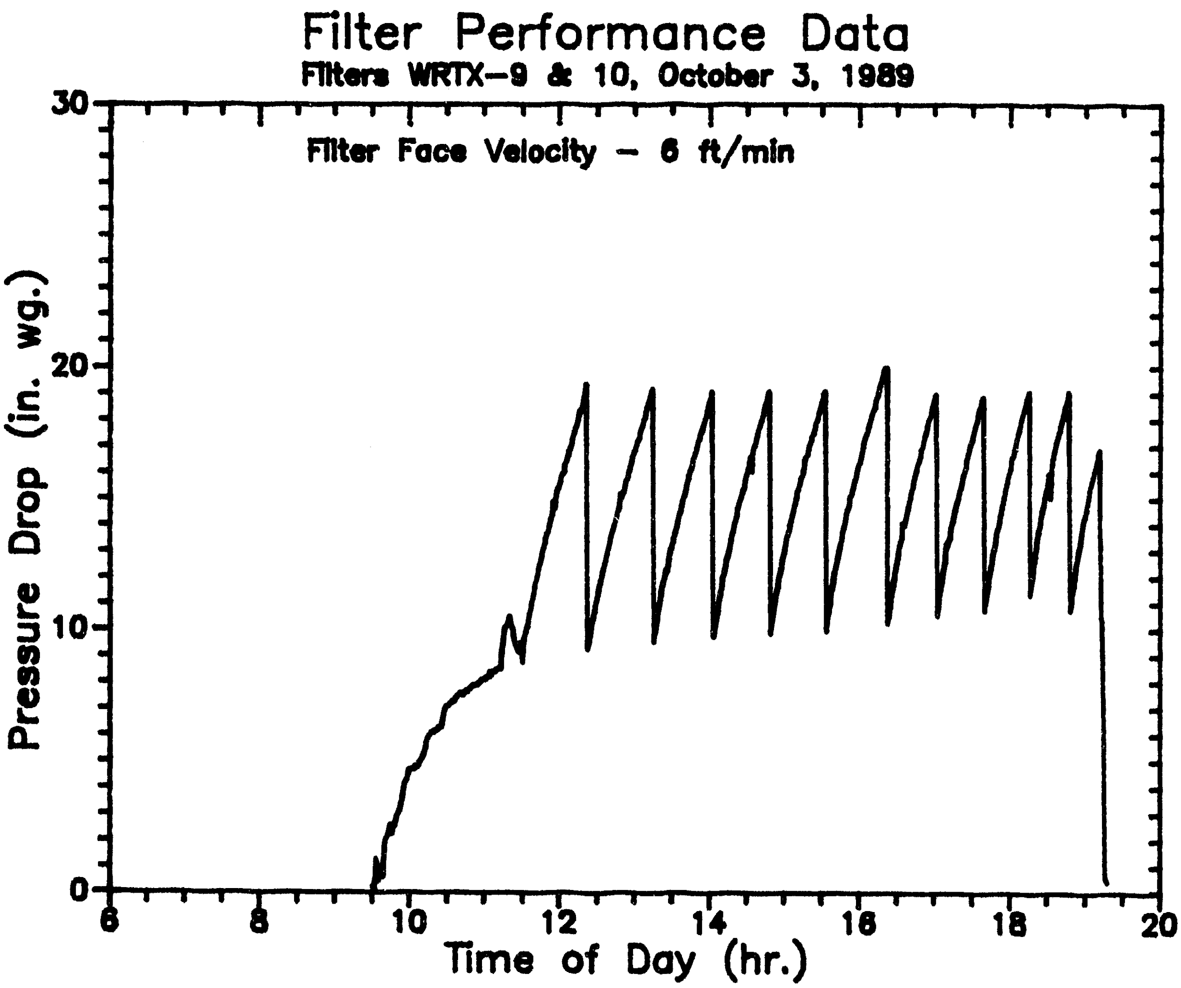
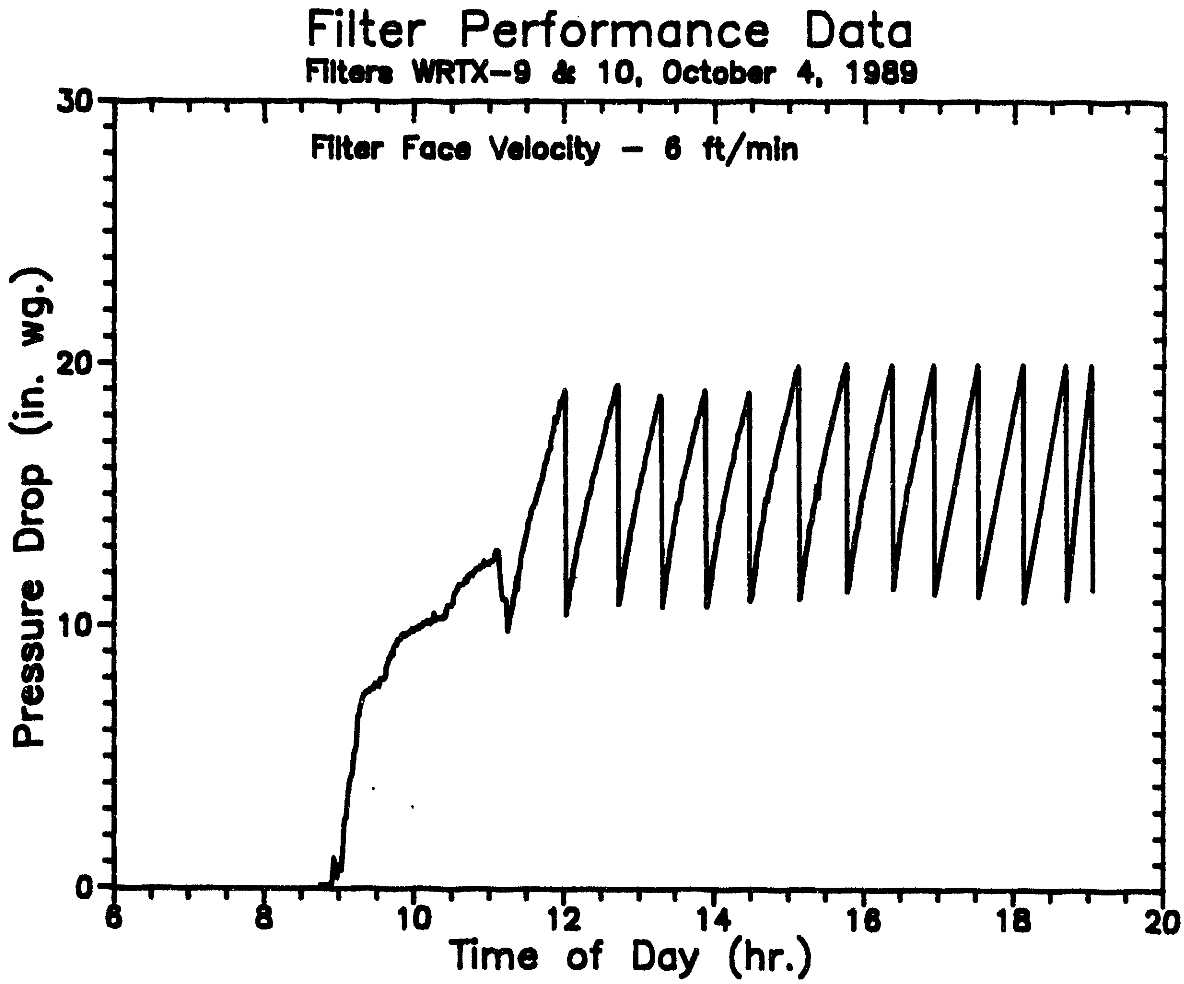
APPENDIX D

PRESSURE DROP TRACES FROM PFBC SIMULATOR FILTER TEST WRTX-9 AND WRTX-11



Operation Notes for October 3, 1989:
12 hour test, includes startup and shutdown
ΔP Trigger = 19.0" WC
Pulse Cleaning - 250 psig/0.1 sec

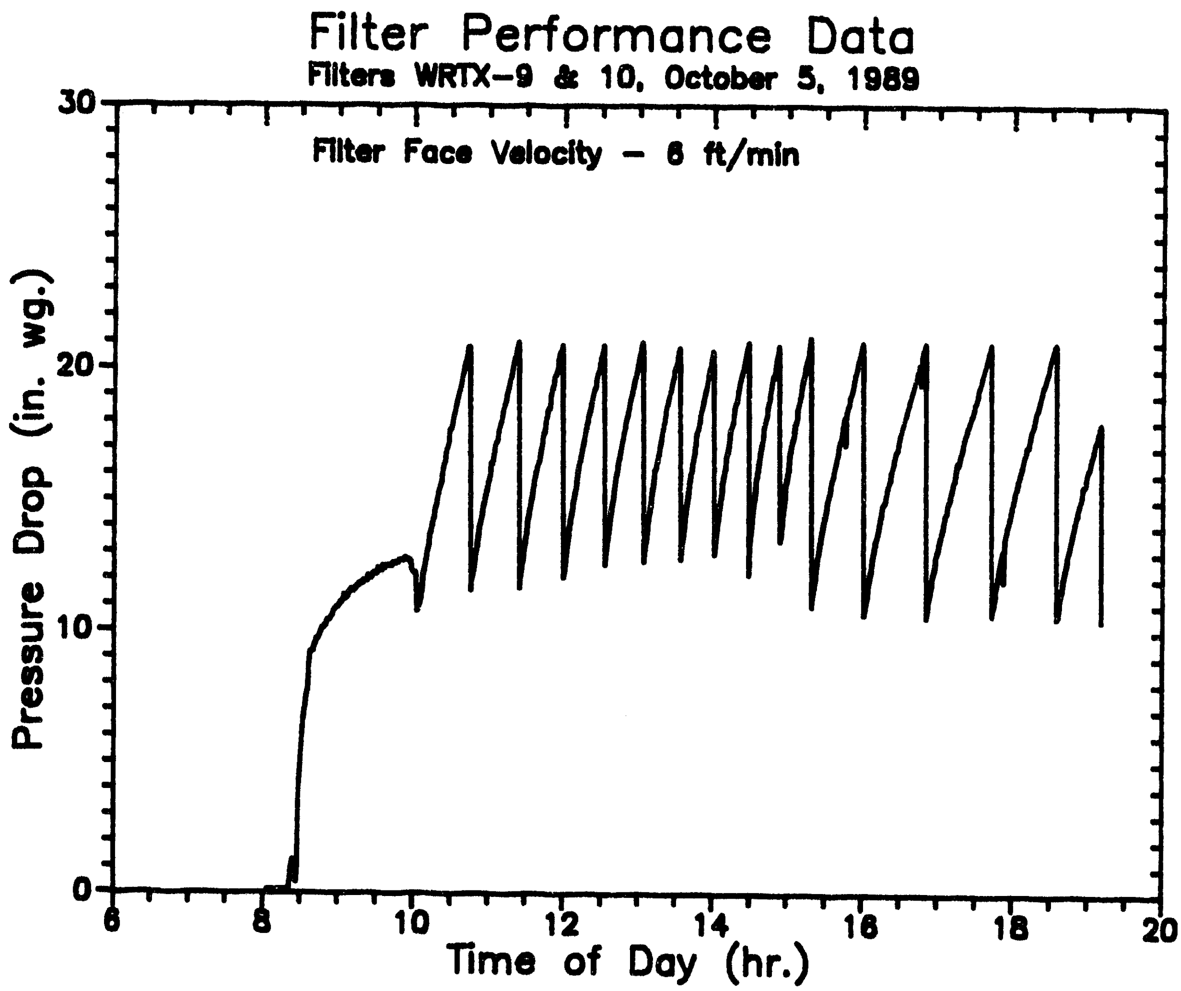


Operation Notes for October 4, 1989:

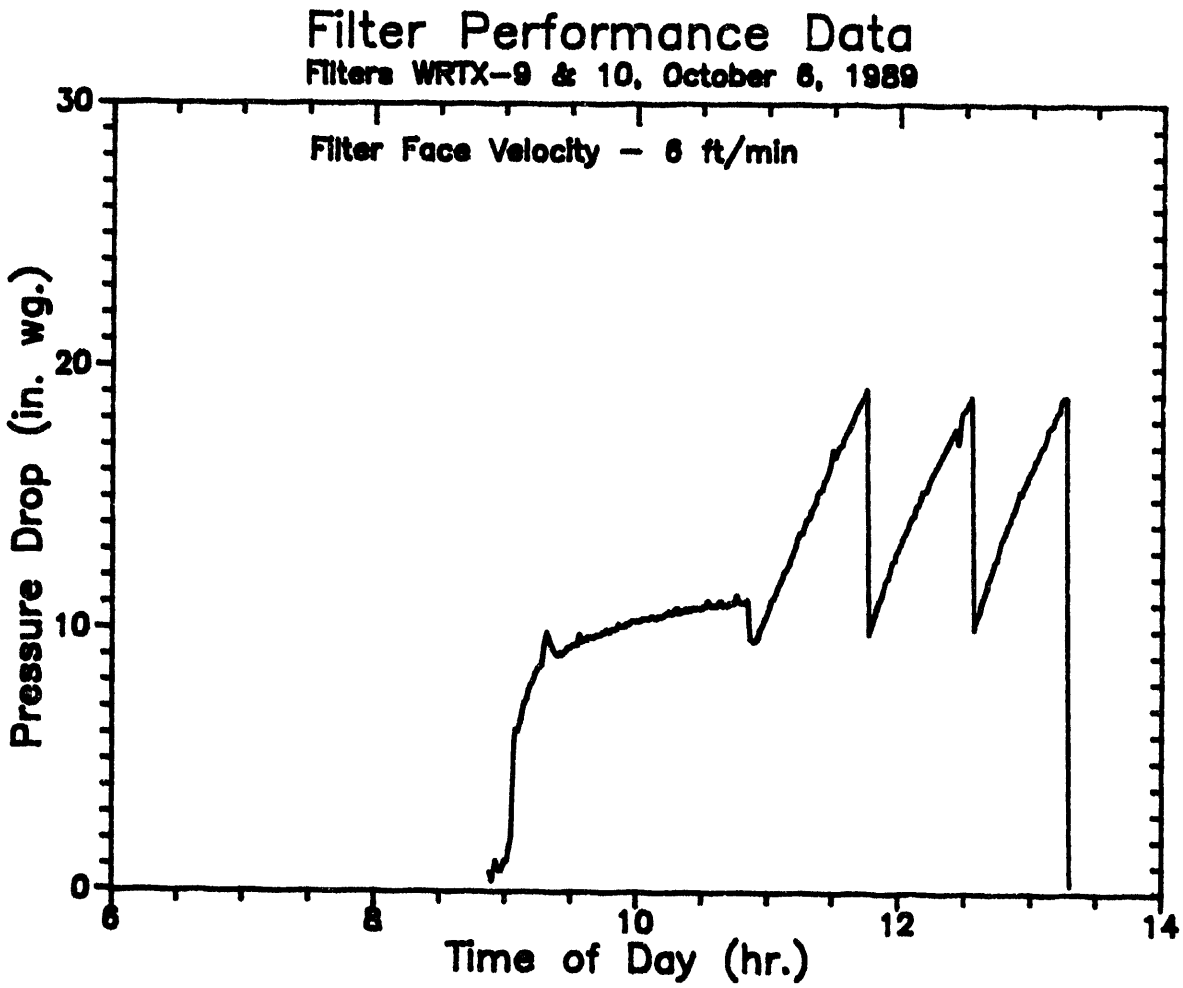
12 hour test, includes startup and shutdown

ΔP Trigger = 19.0" WC then increased to 20.0" WC

Pulse Cleaning - 250 psig/0.1 sec

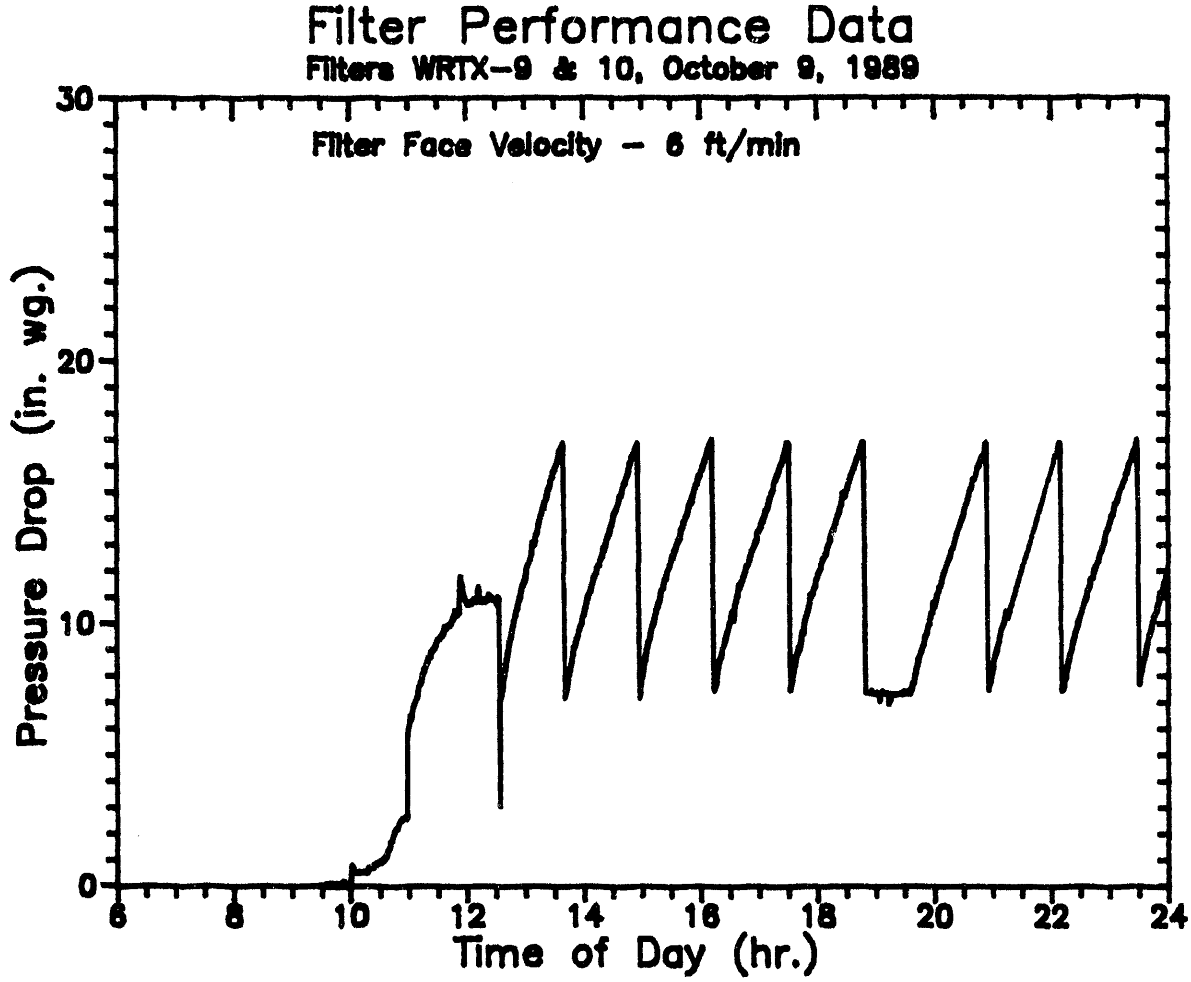


Operation Notes for October 5, 1989:
12 hour test, includes startup and shutdown
ΔP Trigger = 21.0" WC
Pulse Cleaning - 1045 - 250 psig/0.1 sec
1455 - 280 psig/0.1 sec



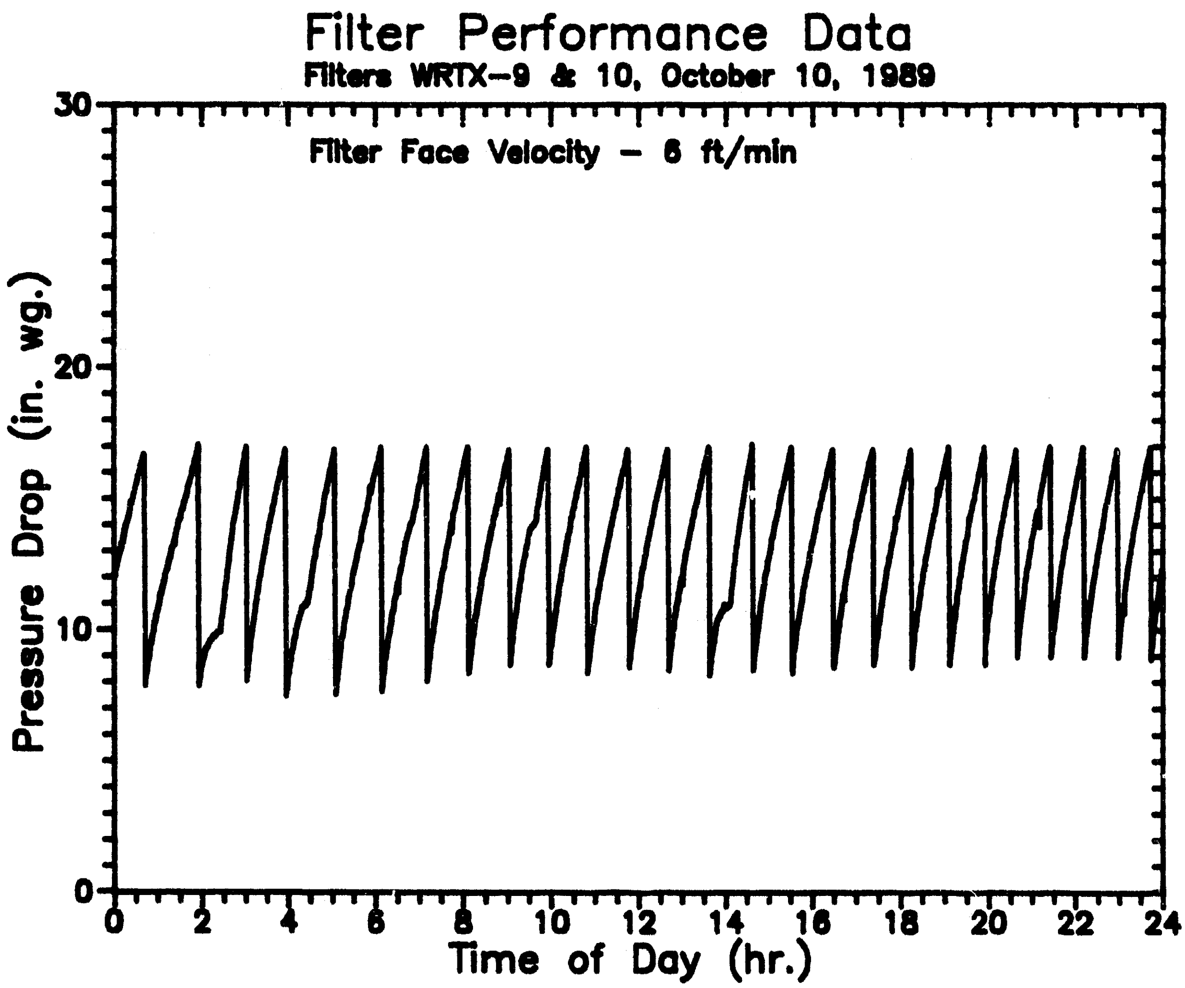
Operation Notes for October 6, 1989:

8 hour test, includes startup and shutdown
ΔP Trigger = 19.0" WC
Pulse Cleaning - 280 psig/0.1 sec

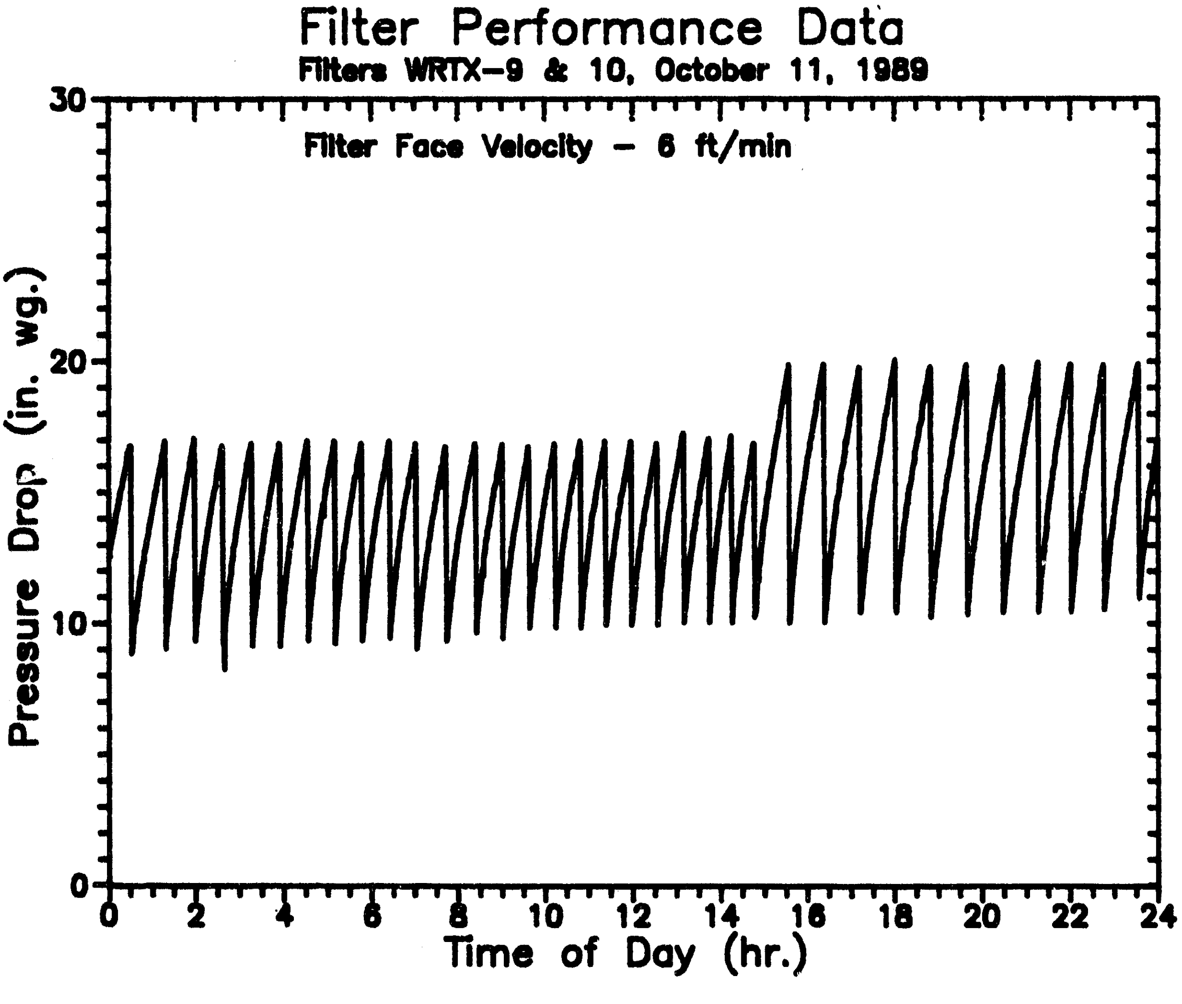


Operation Notes for October 9, 1989:

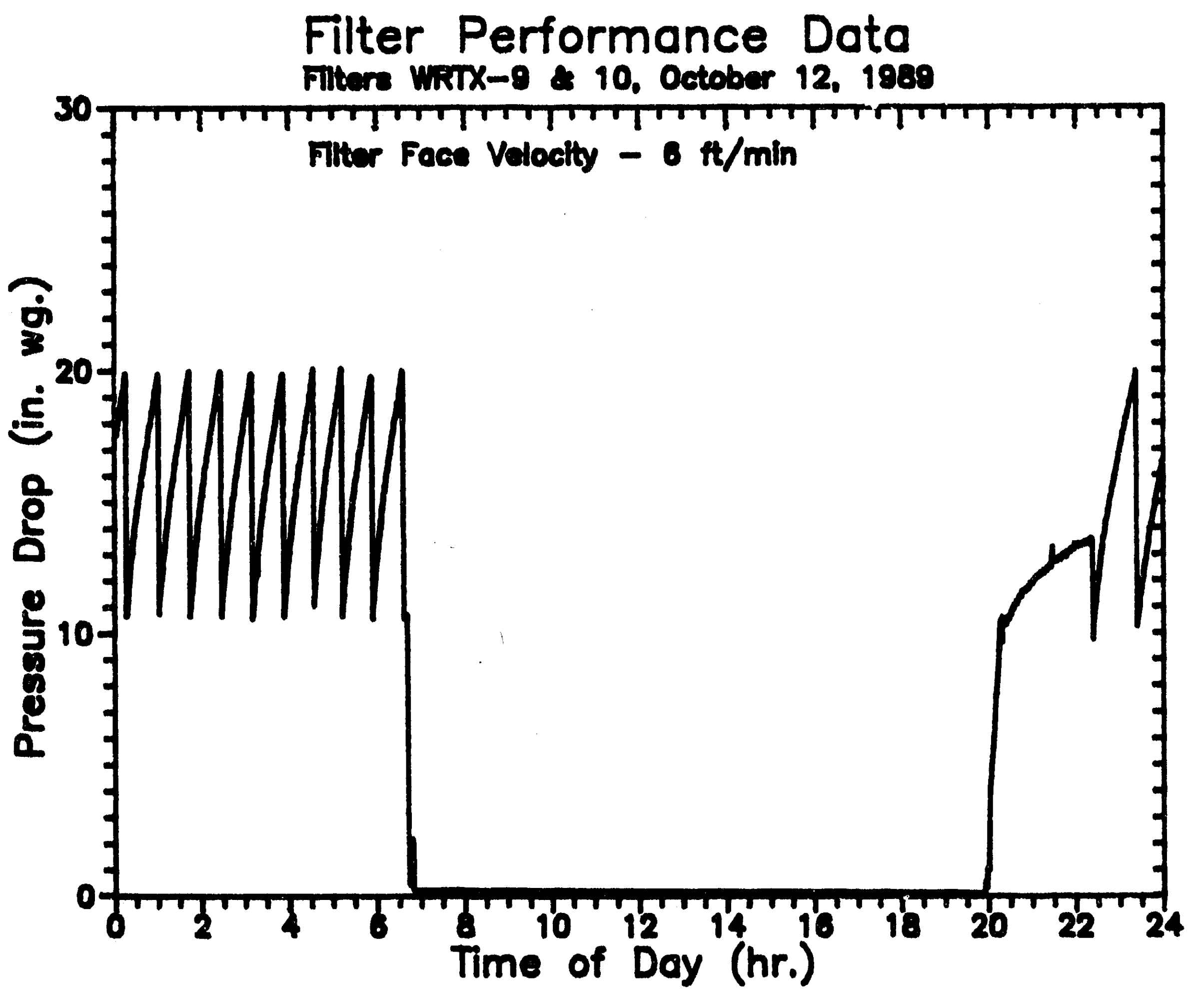
Begin week long test
Startup
ΔP Trigger = 17.0" WC
Pulse Cleaning - 280 psig/0.1 sec



Operation Notes for October 10, 1989:
ΔP Trigger = 17.0" WC
Pulse Cleaning - 280 psig/0.1 sec

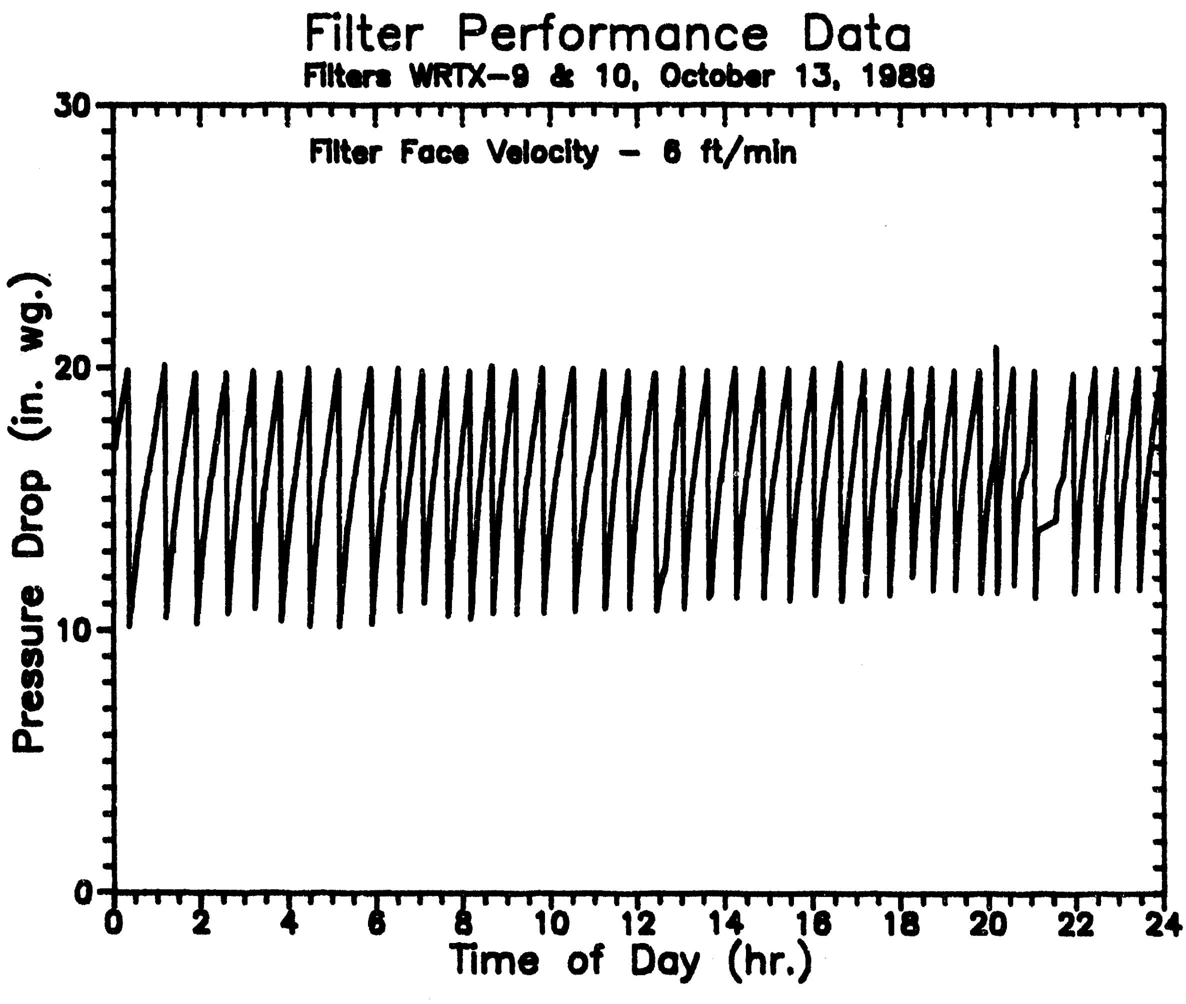


Operation Notes for October 11, 1989:
ΔP Trigger initially 17.0" WC increased to 20" WC
Pulse Cleaning - 280 psig/0.1 sec

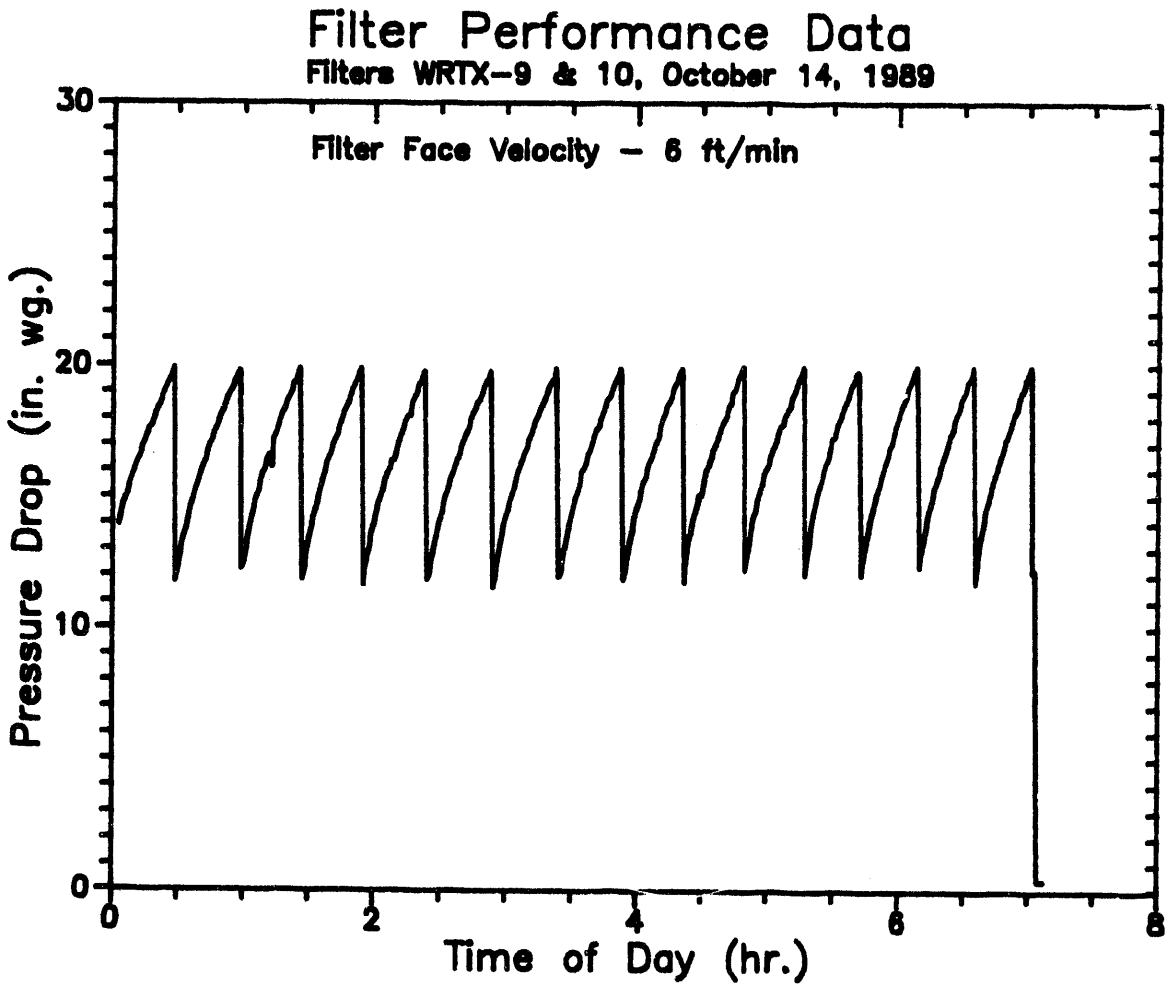


Operation Notes for October 12, 1989:

- Scheduled shutdown
- Dust added to vessel
- Restart @ 20:00 hr
- ΔP Trigger = 20.0" WC
- Pulse Cleaning - 280 psig/0.1 sec

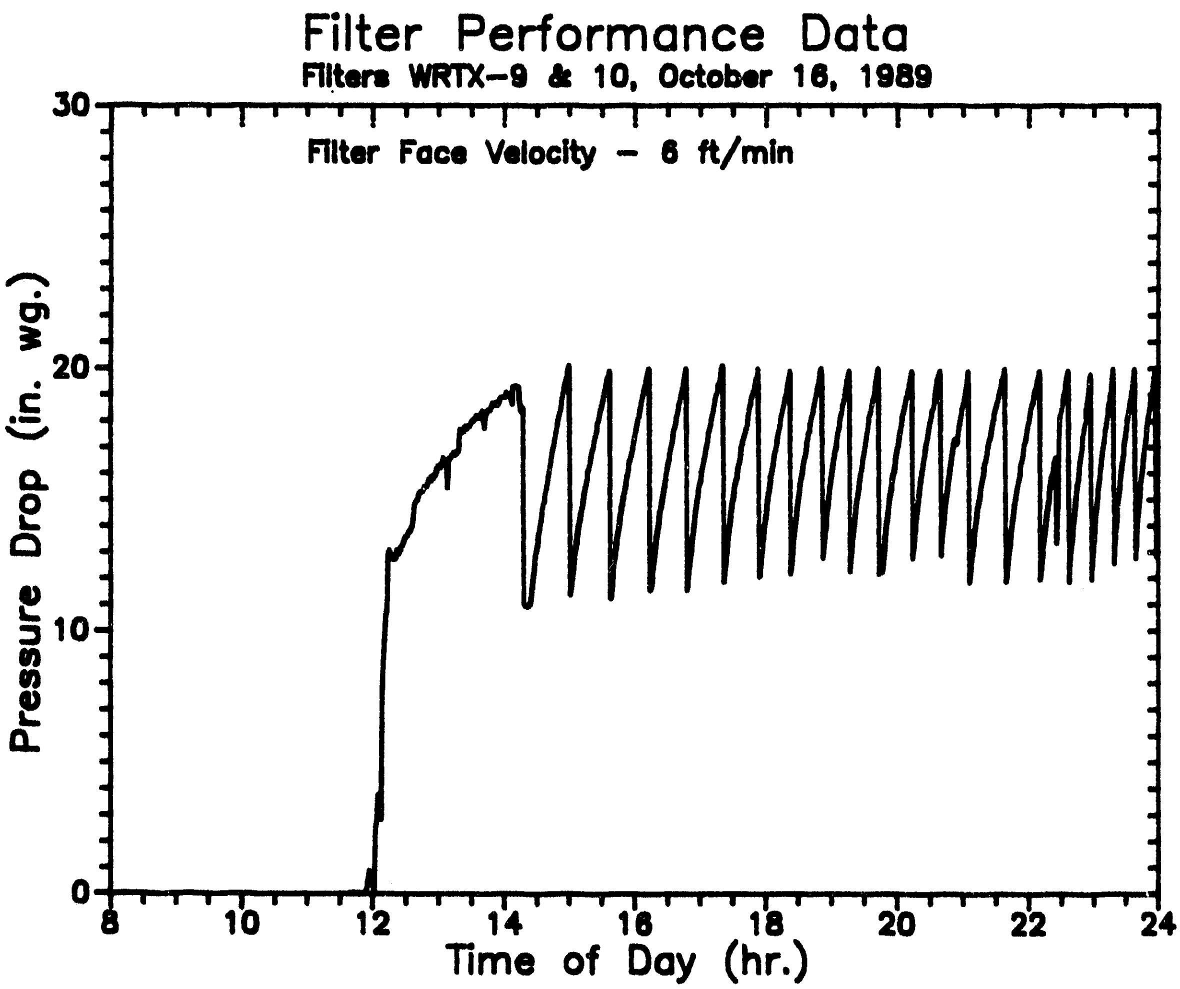


Operation Notes for October 13, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 280 psig/0.1 sec



Operation Notes for October 14, 1989:

Week long test completion.
Scheduled shutdown
ΔP Trigger = 20.0" WC
Pulse Cleaning - 280 psig/0.1 sec



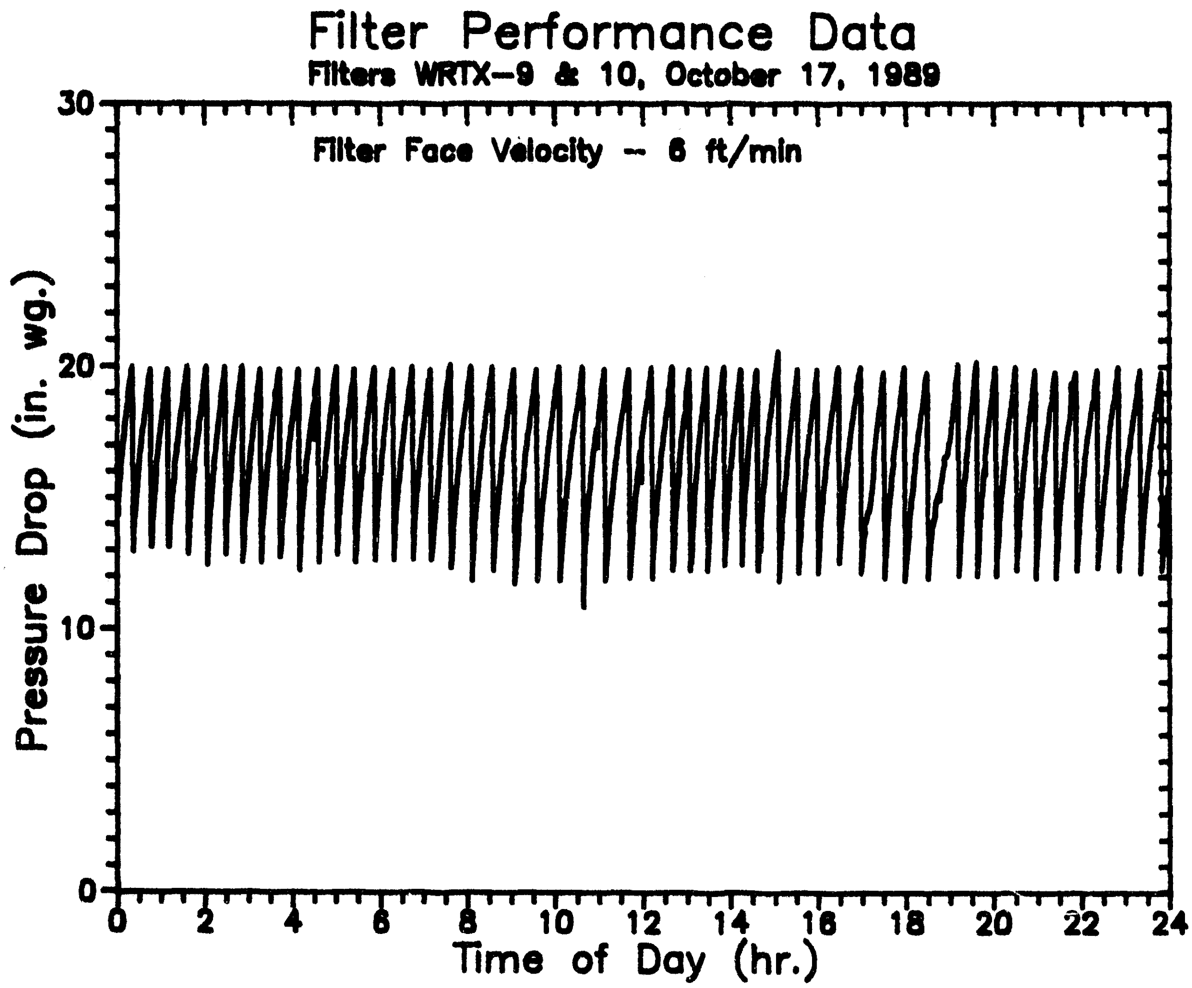
Operation Notes for October 16, 1989:

Week long test startup

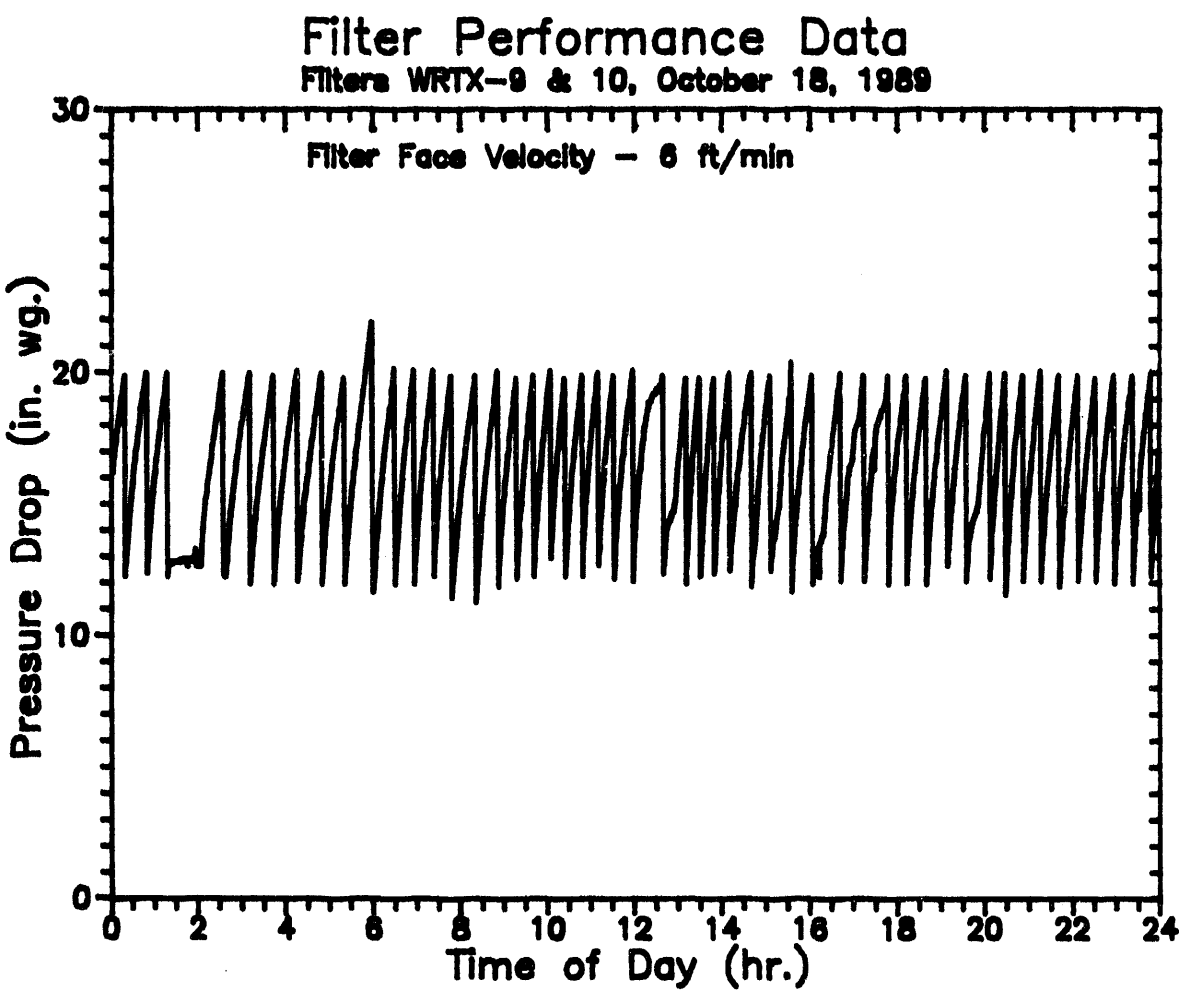
ΔP Trigger = 20.0" WC

Pulse Cleaning - 280 psig/0.1 sec

Spike in cycle @ 2227 is system pressure drop caused by compressor shutdown, corrected, no flame out.



Operation Notes for October 17, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning -
0000 - 280 psig/0.1 sec
0738 - 290 psig/0.1 sec
2253 - 285 psig/0.1 sec



Operation Notes for October 18, 1989:

ΔP Trigger = 20.0" WC

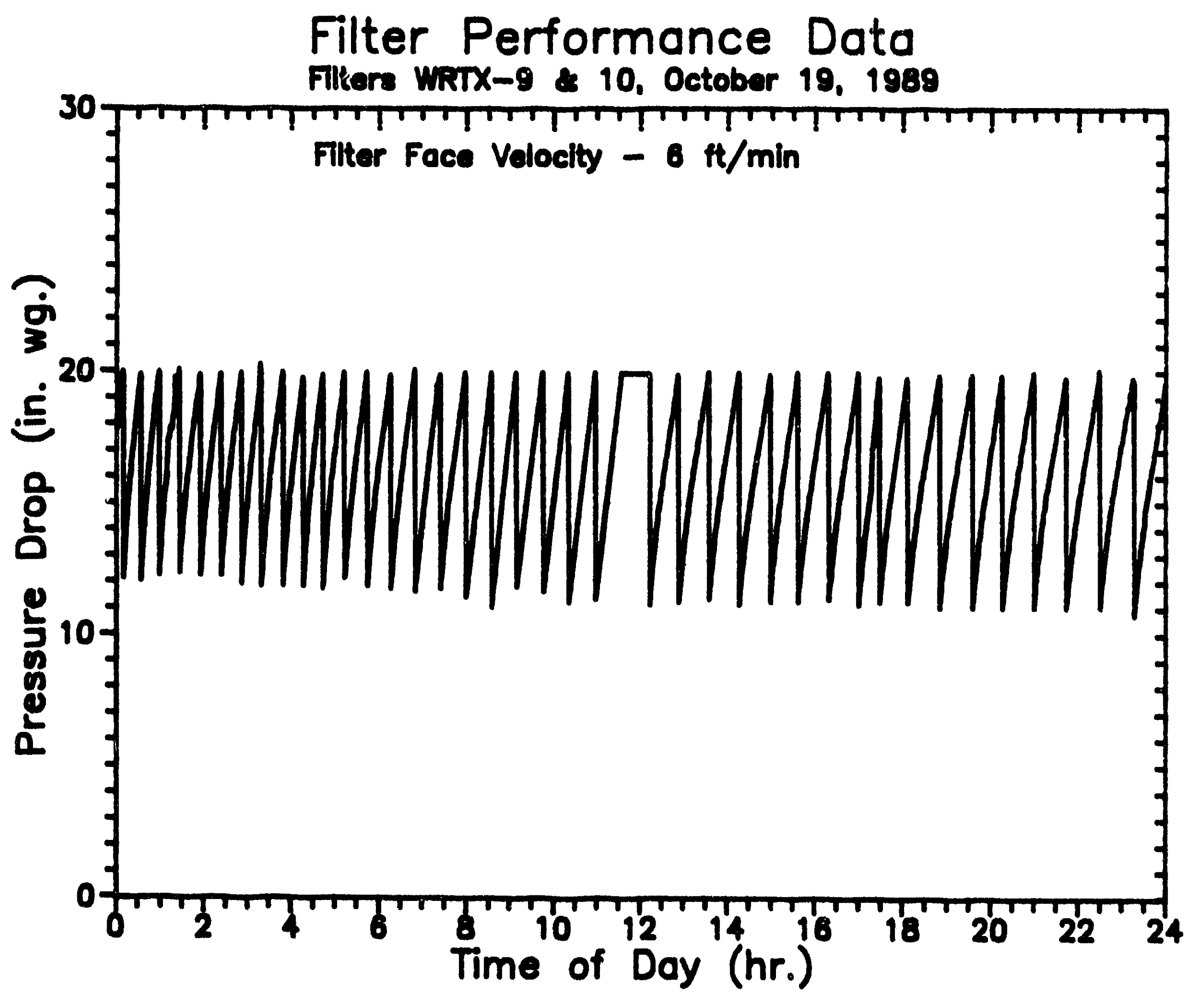
Pulse Cleaning - 280 psig/0.1 sec until 0749

290 psig/0.1 sec

Then dust off, dust added to the vessel @ 0119.

Dust on - 0207

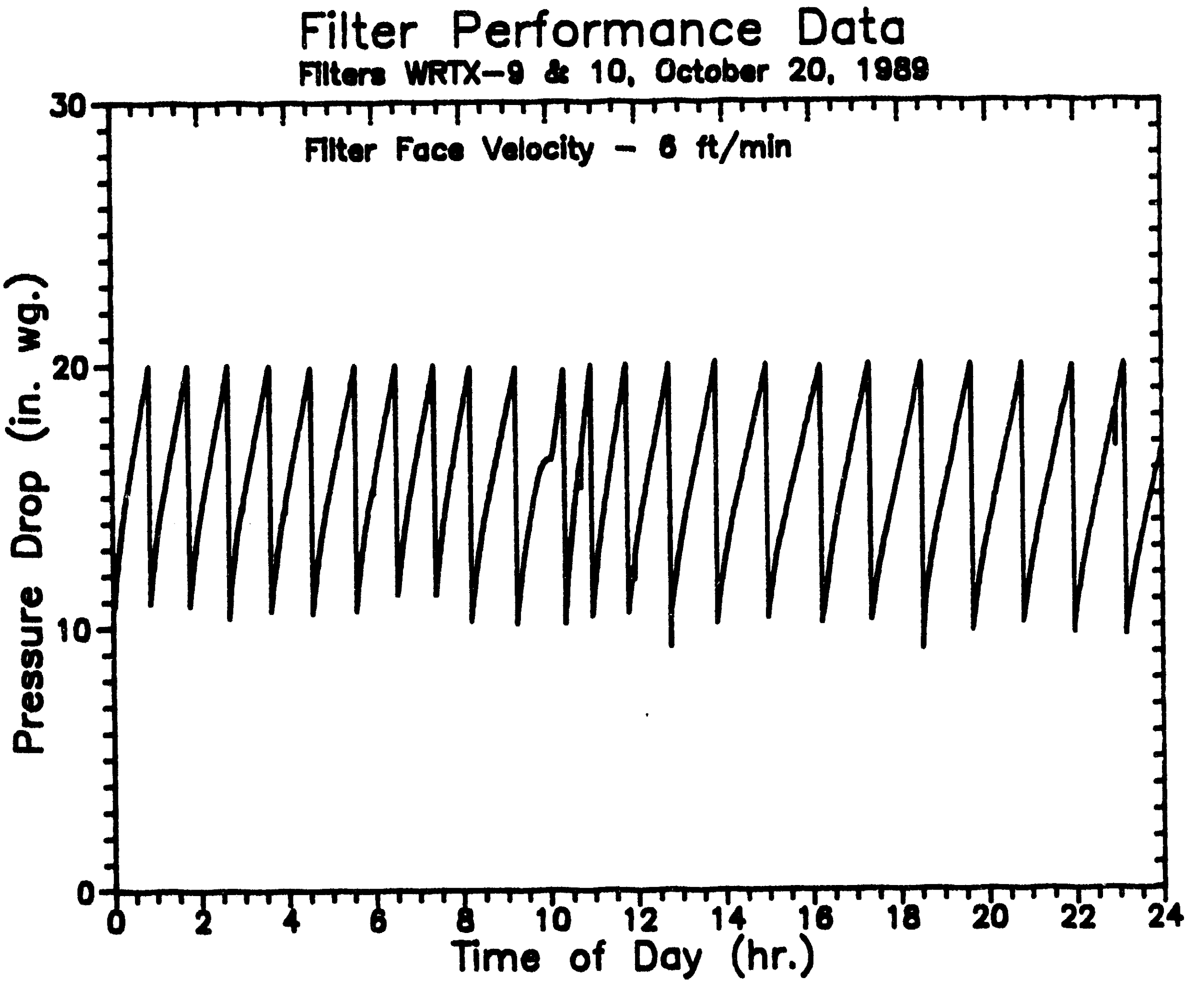
1242 erratic dust feed



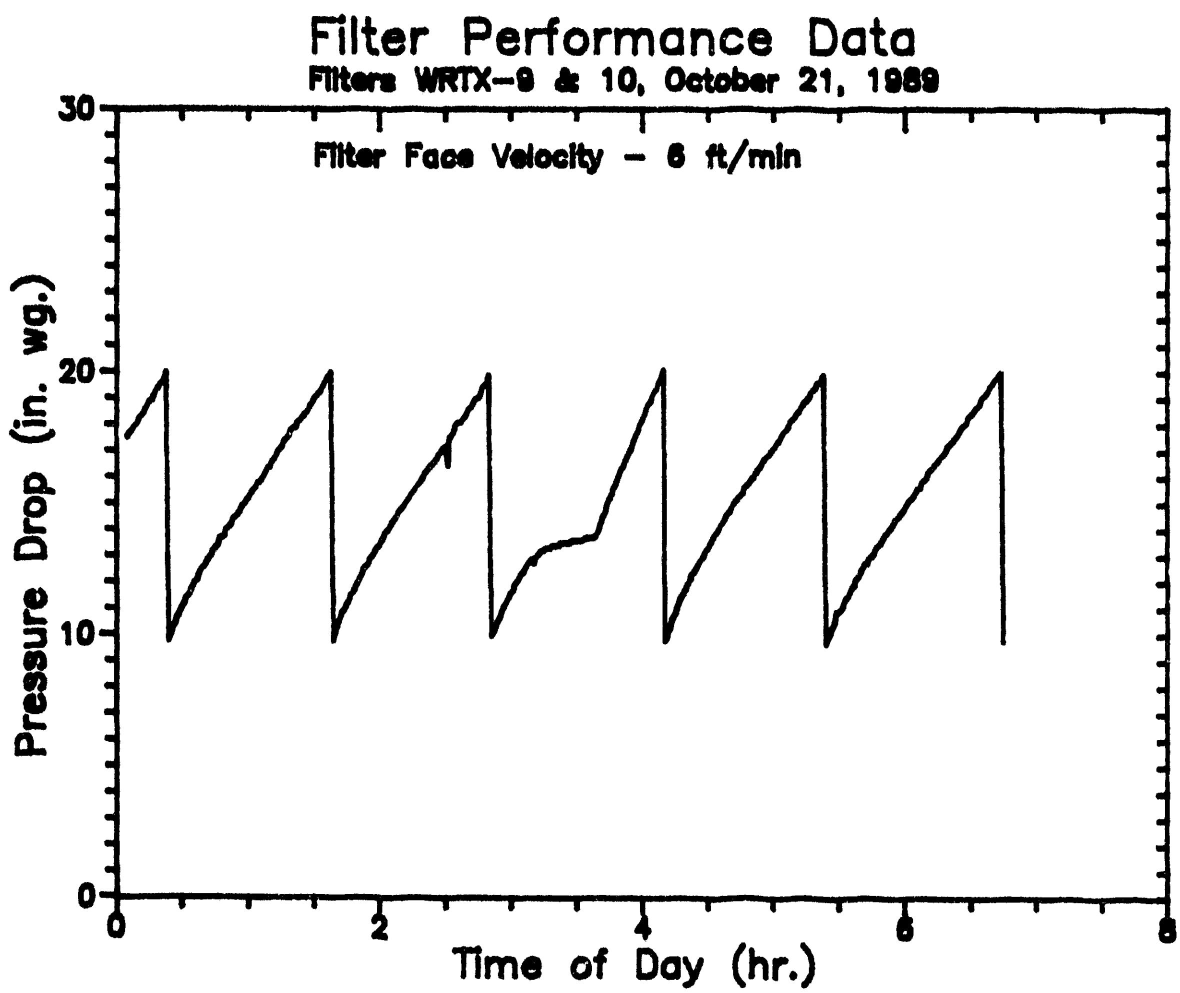
Operation Notes for October 19, 1989:

ΔP Trigger = 20.0" WC

Pulse Cleaning - 290 psig/0.1 sec

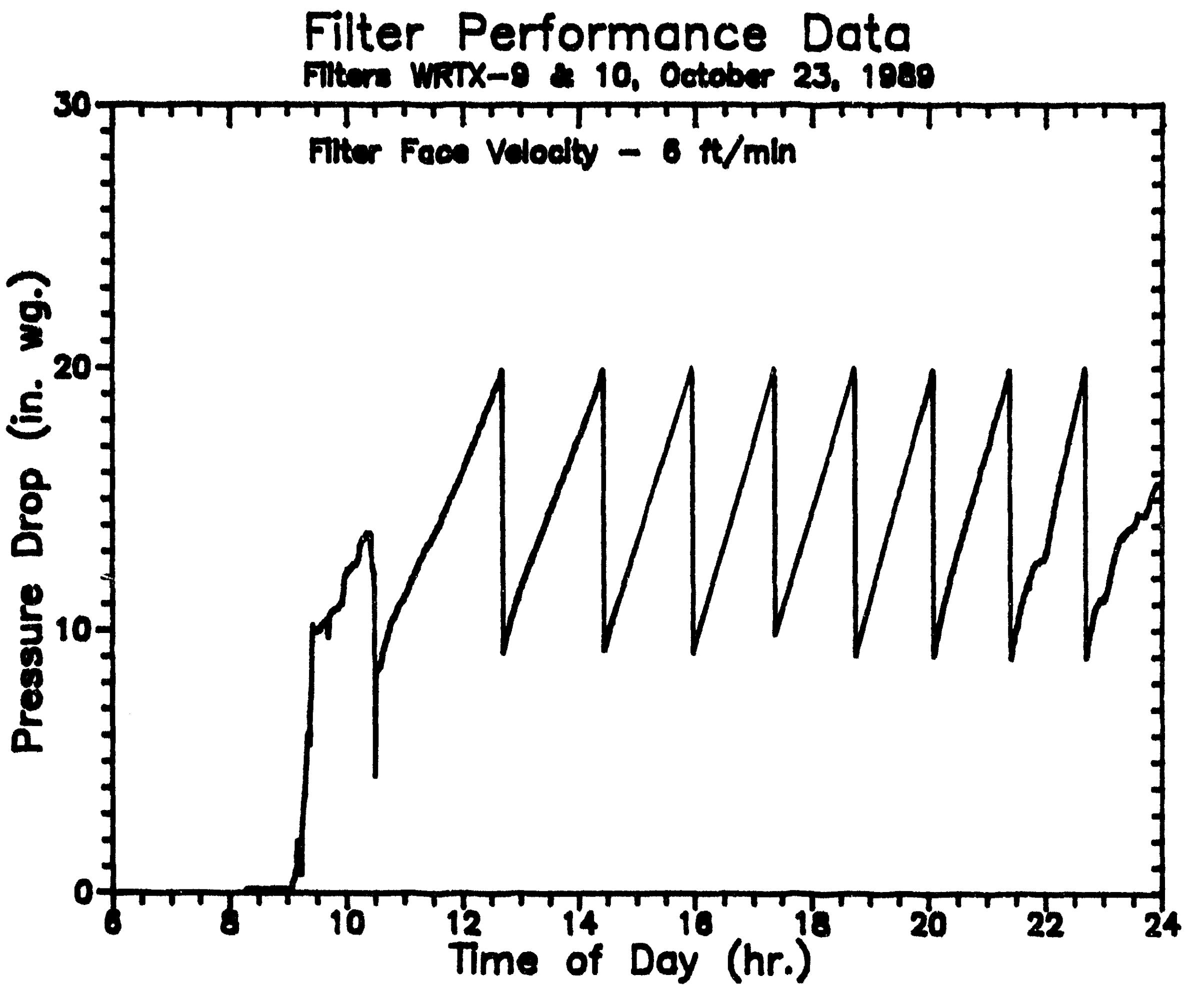


Operation Notes for October 20, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec



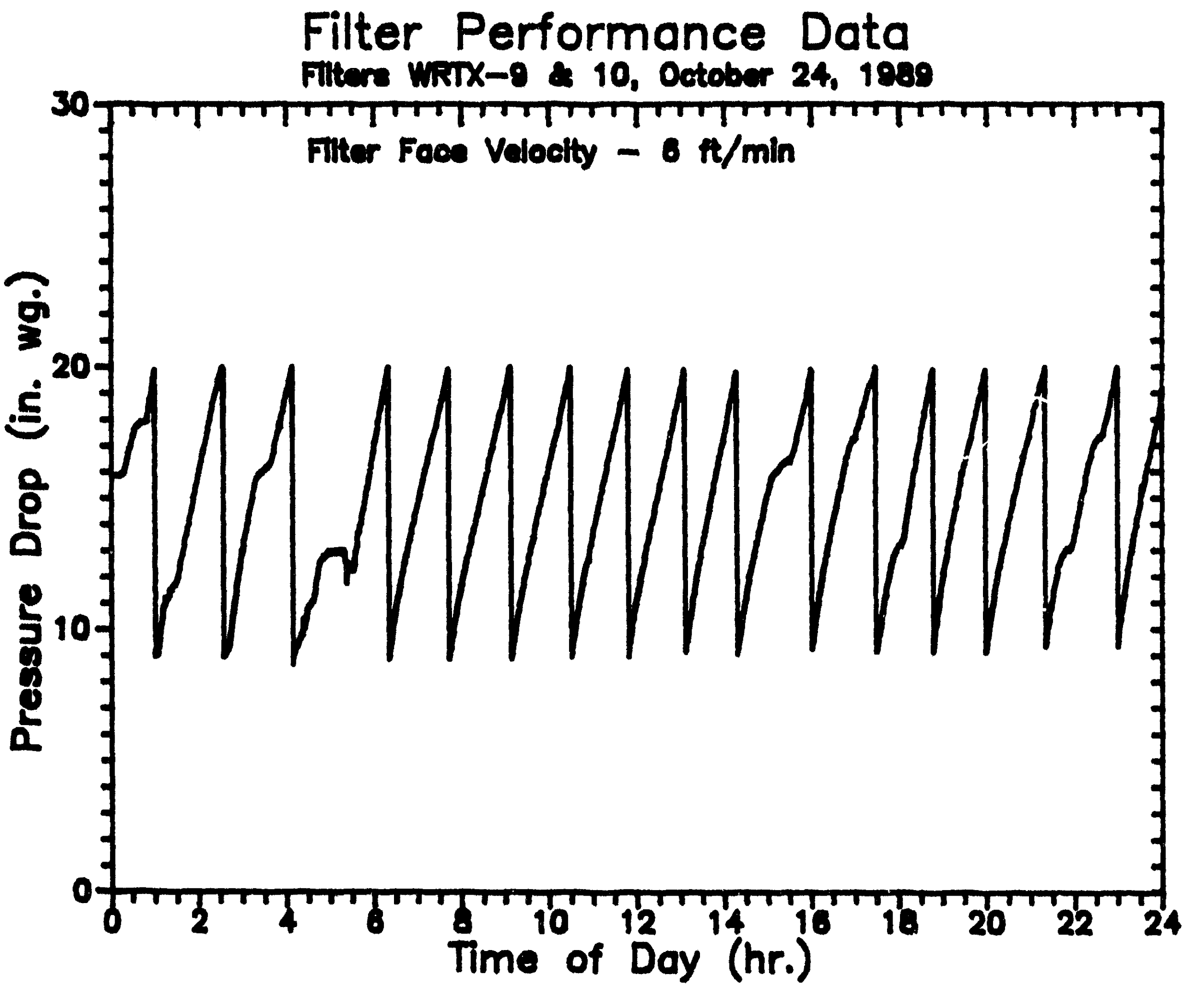
Operation Notes for October 21, 1989:

End week long test
Scheduled shutdown
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec

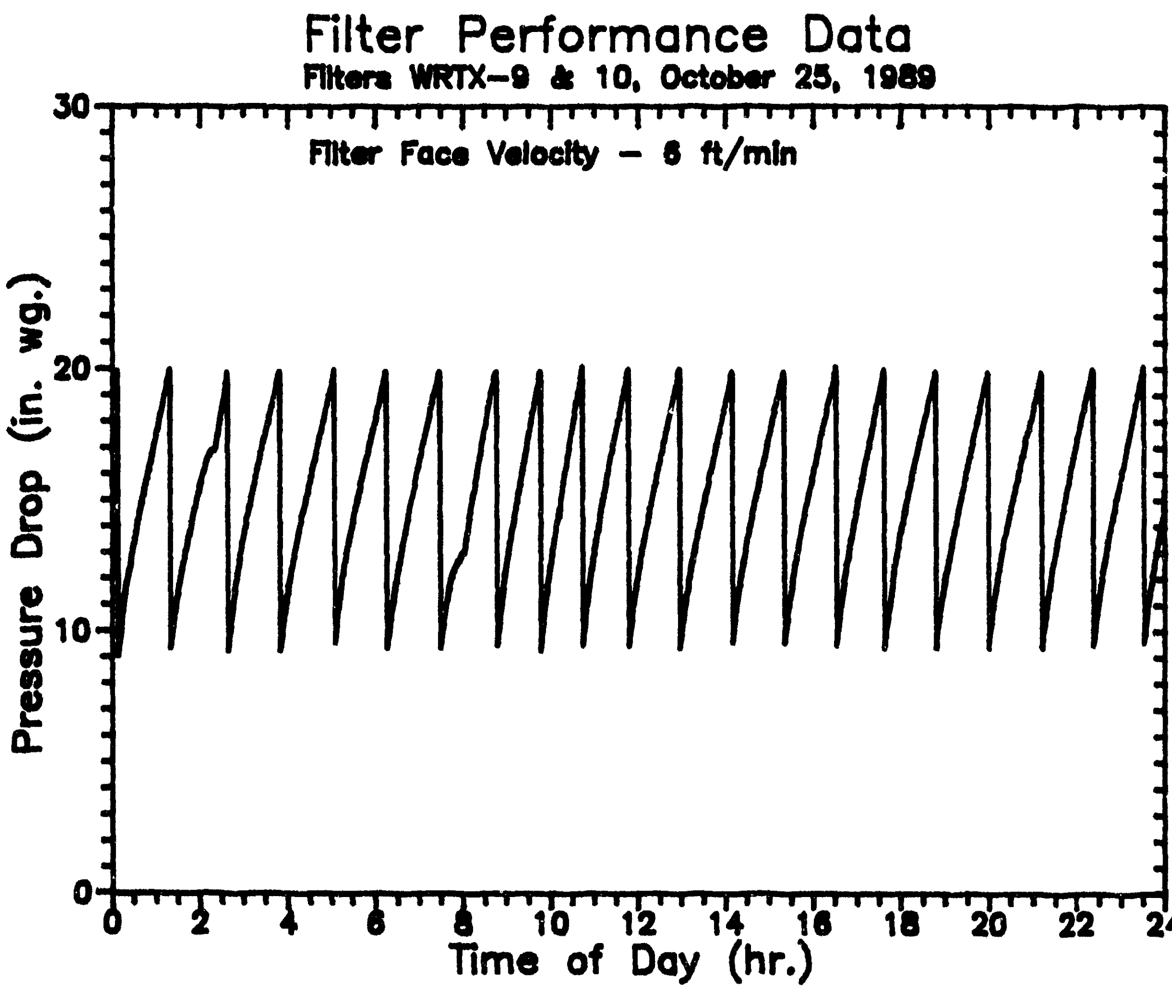


Operation Notes for October 23, 1989:

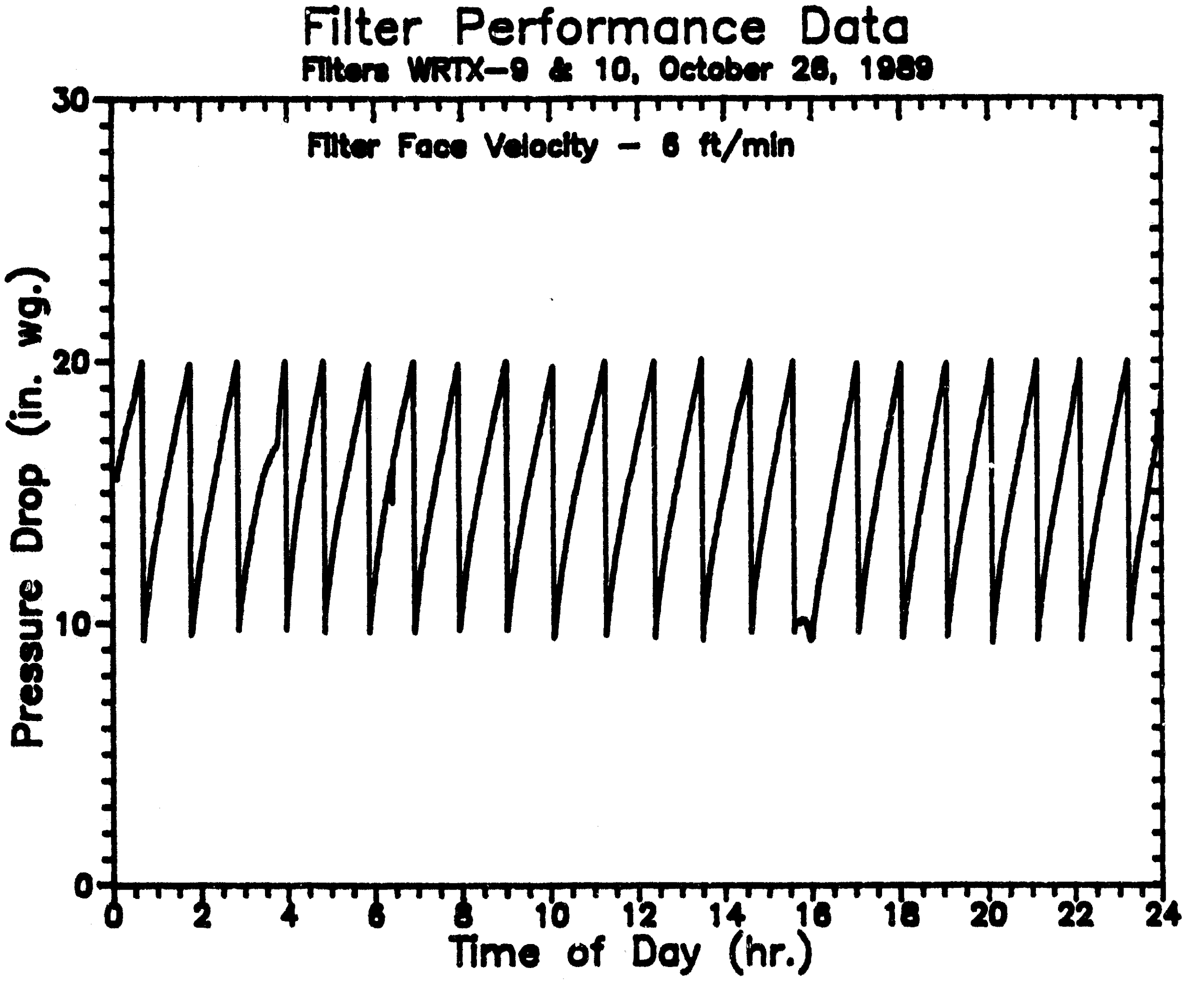
Begin week long test
Startup
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec



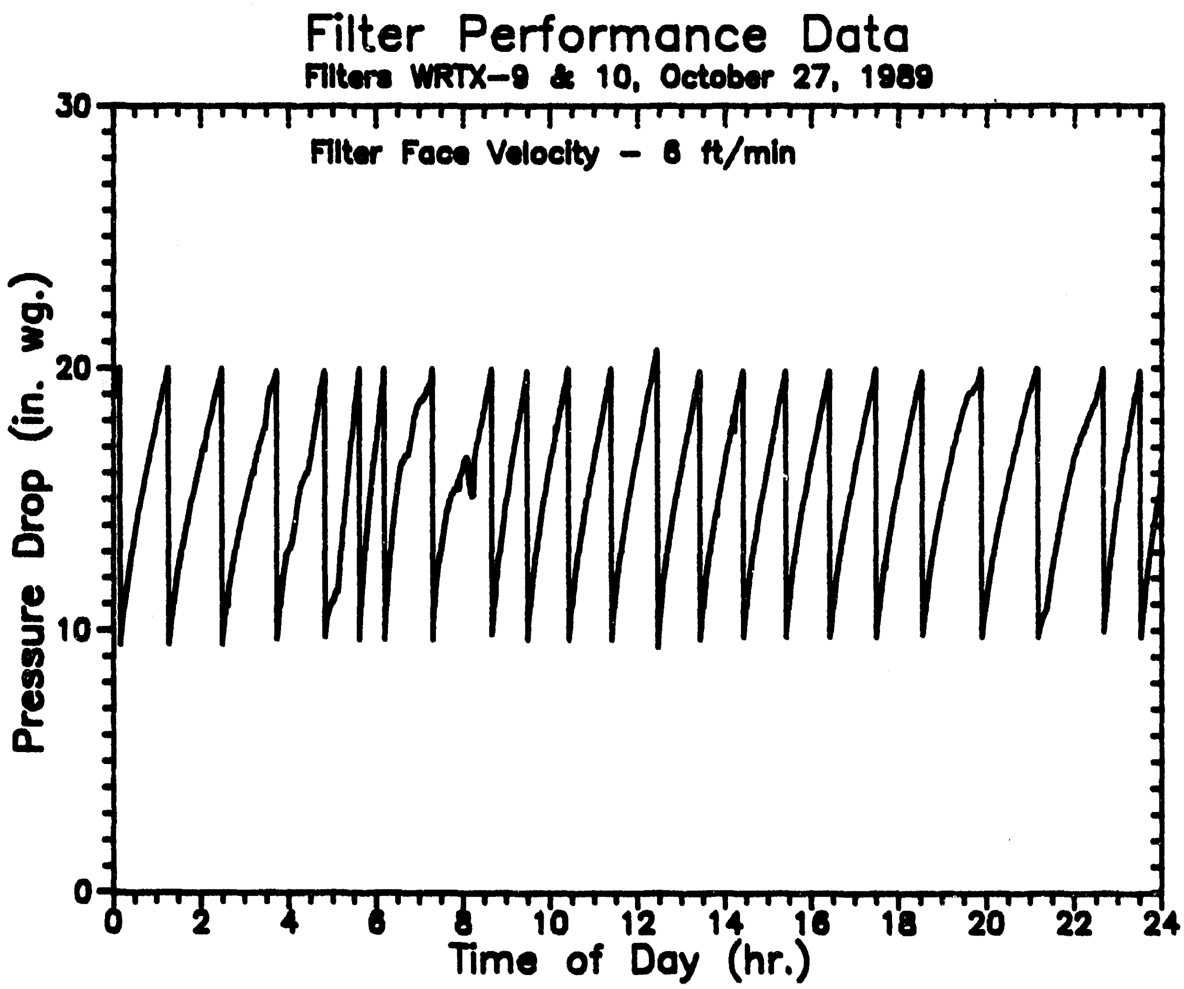
Operation Notes for October 24, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 280 psig/0.1 sec
Erratic dust feed:
0001→0059
0400→0530
2140→2230



Operation Notes for October 25, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec

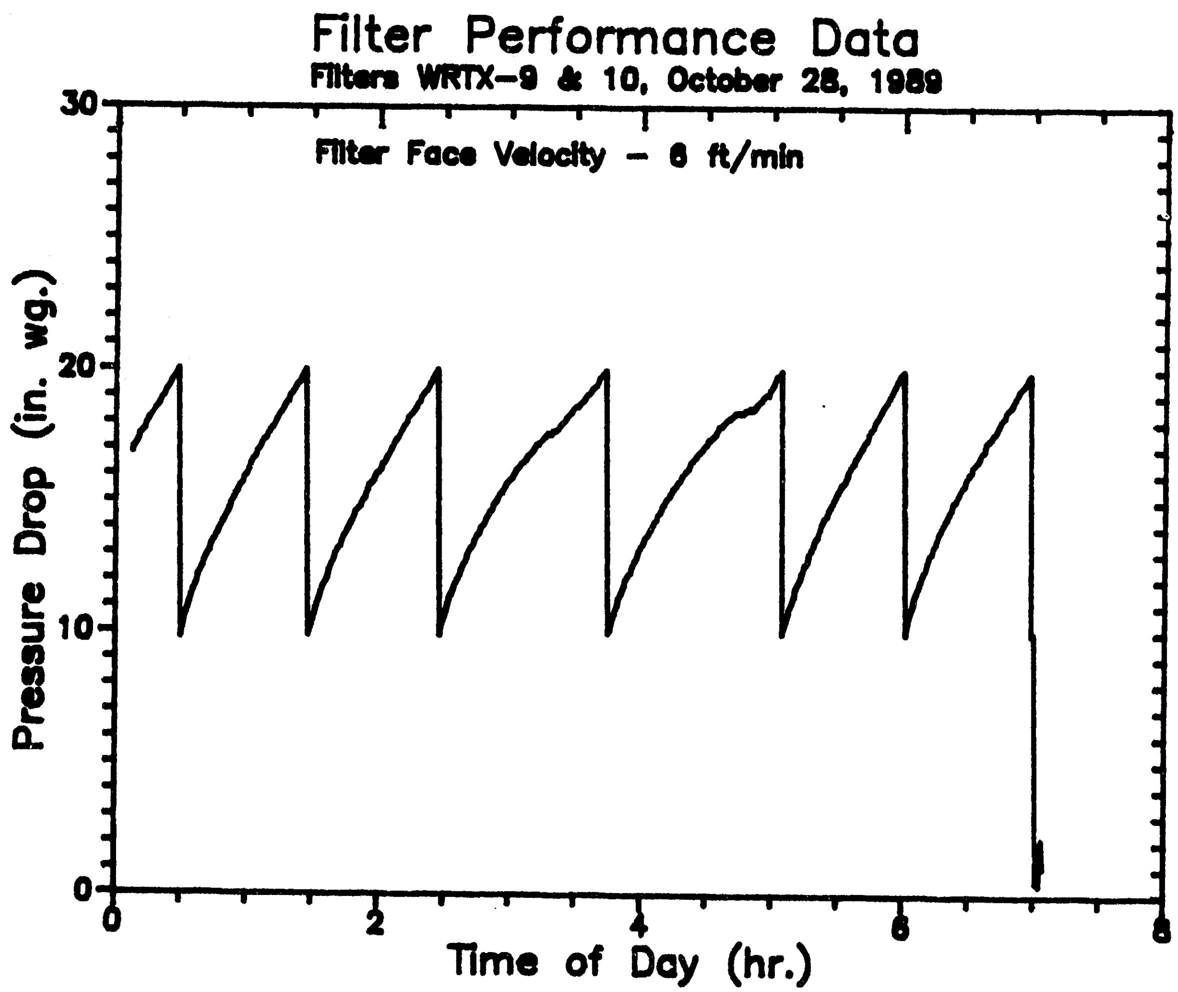


Operation Notes for October 26, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec
1536 - dust feed off
Dust added to dust vessel
1605 - dust feed on

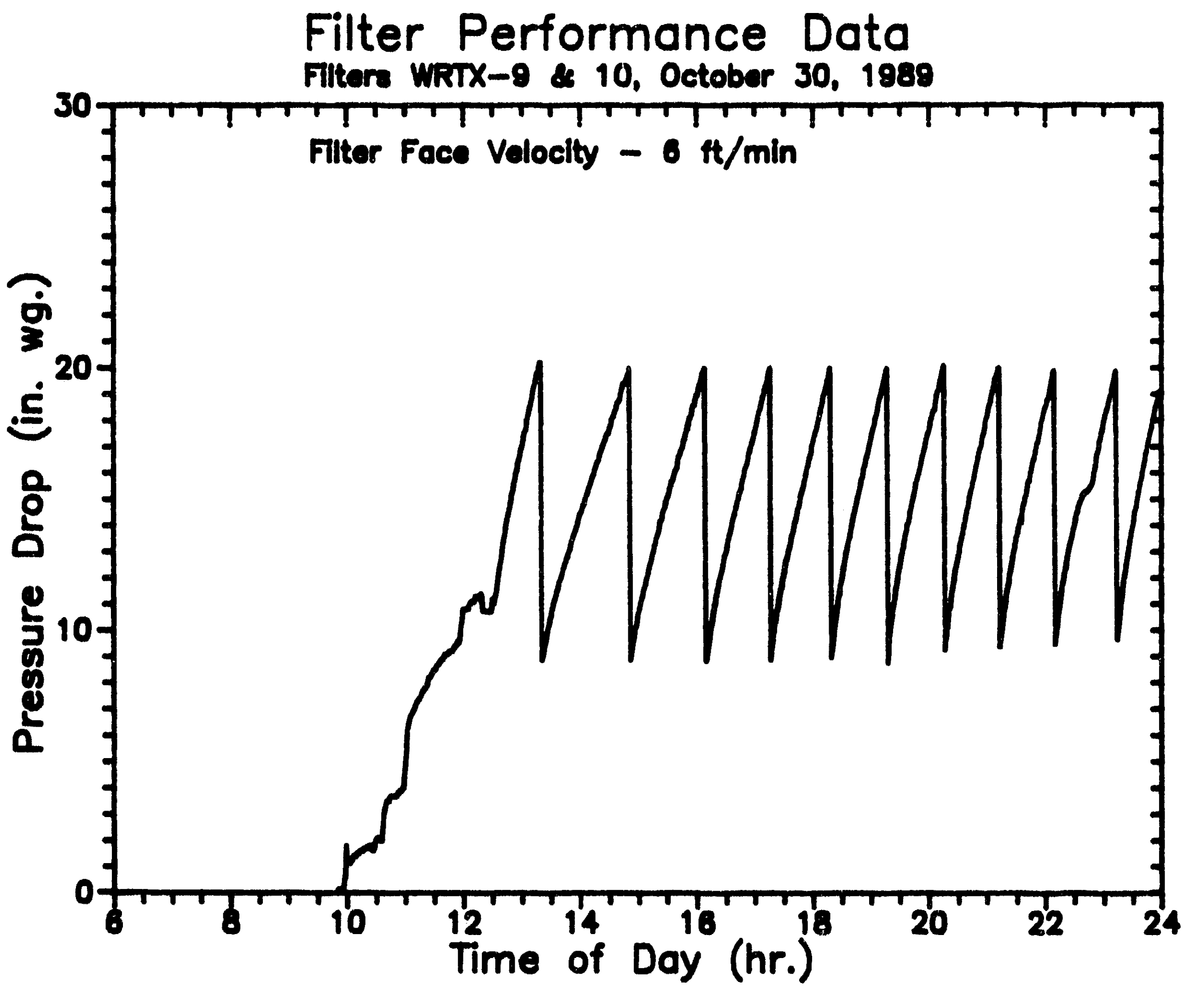


Operation Notes for October 27, 1989:

ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec
0537→0800
Erratic dust feed, unable to correct online
Dust off. Dust vessel depressurized, dust stirred.
Repressurized. Dust on @ 0816

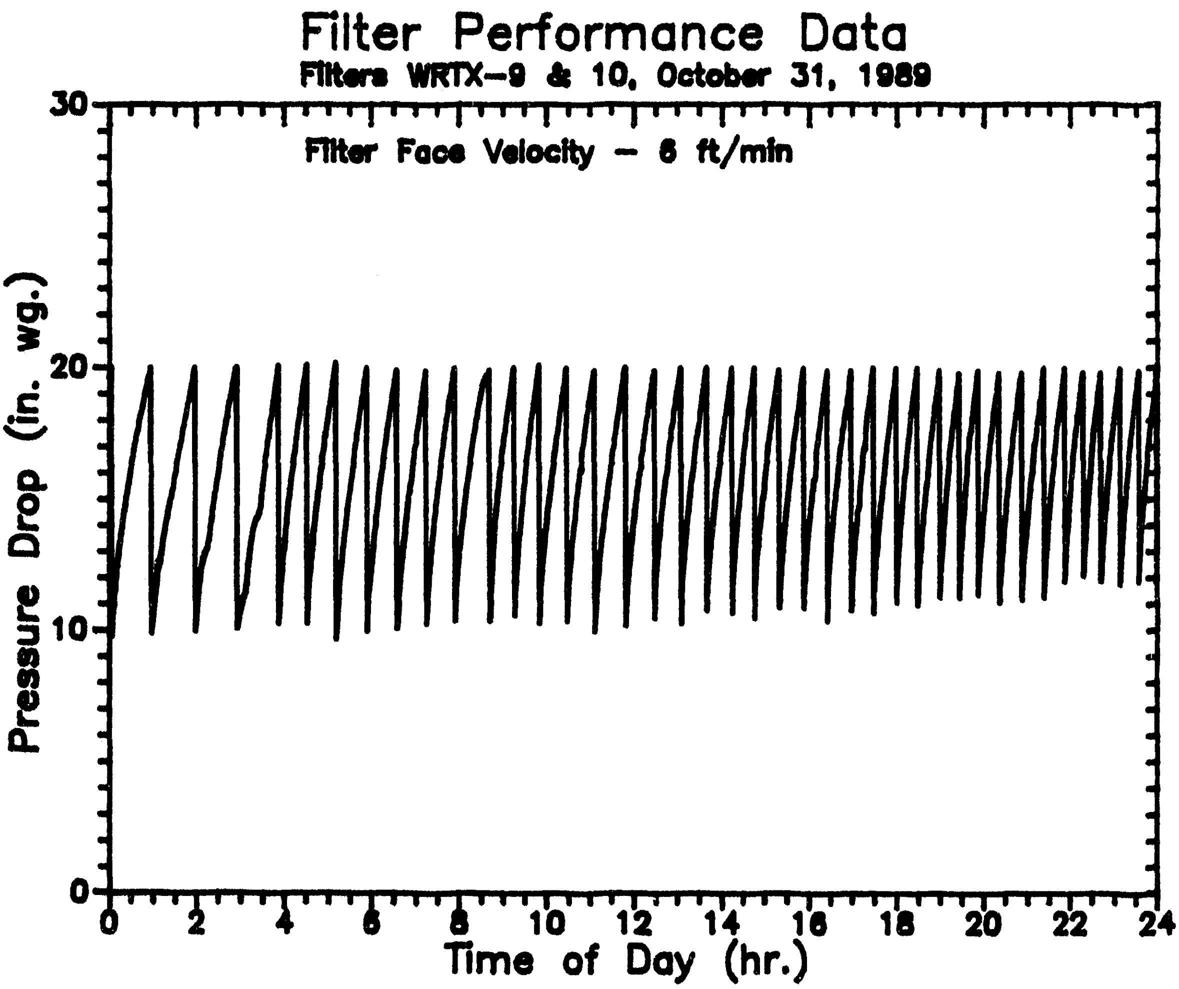


Operation Notes for October 28, 1989:
End week long test
Scheduled shutdown
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec

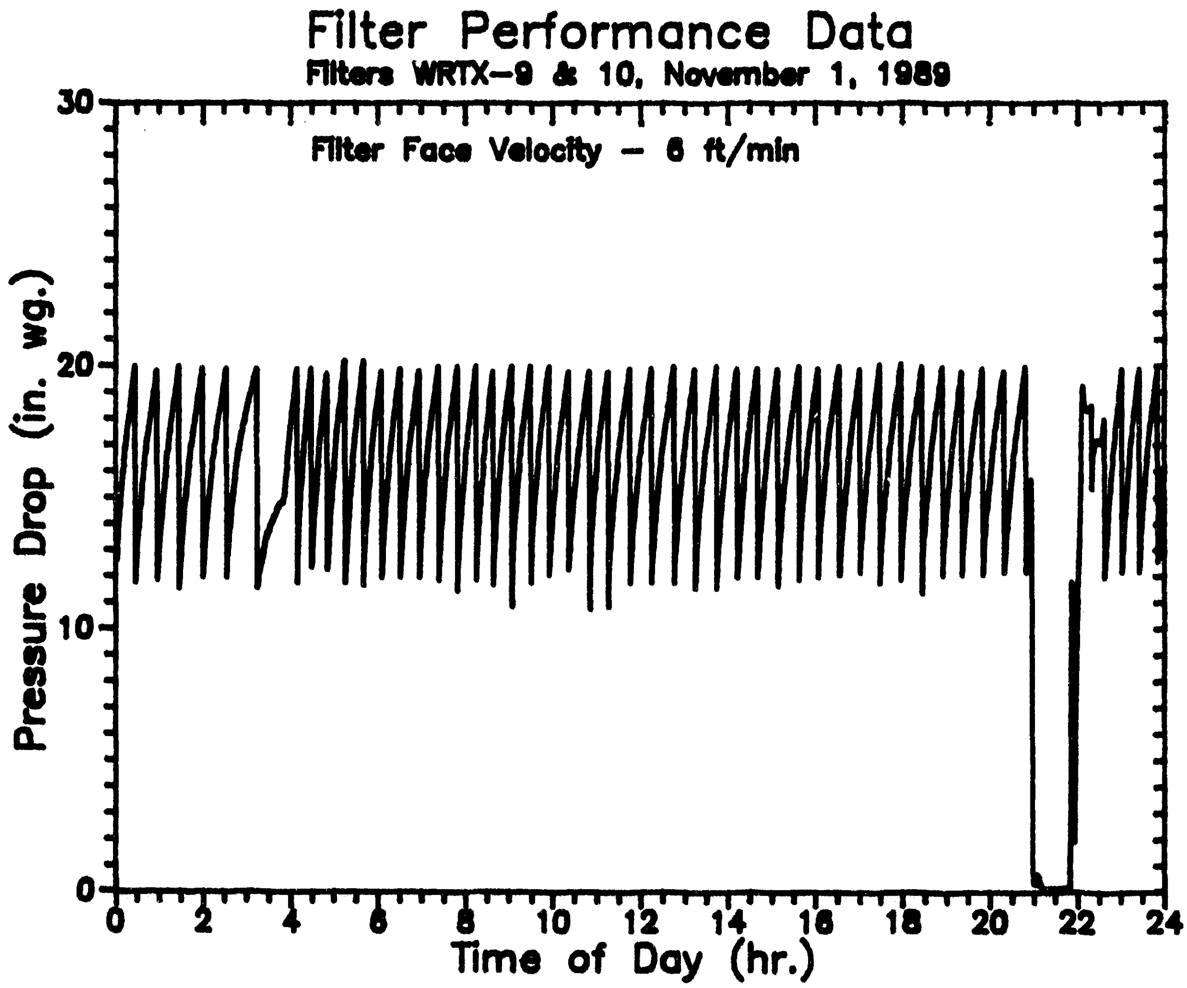


Operation Notes for October 30, 1989:

Start week long test
Startup
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec

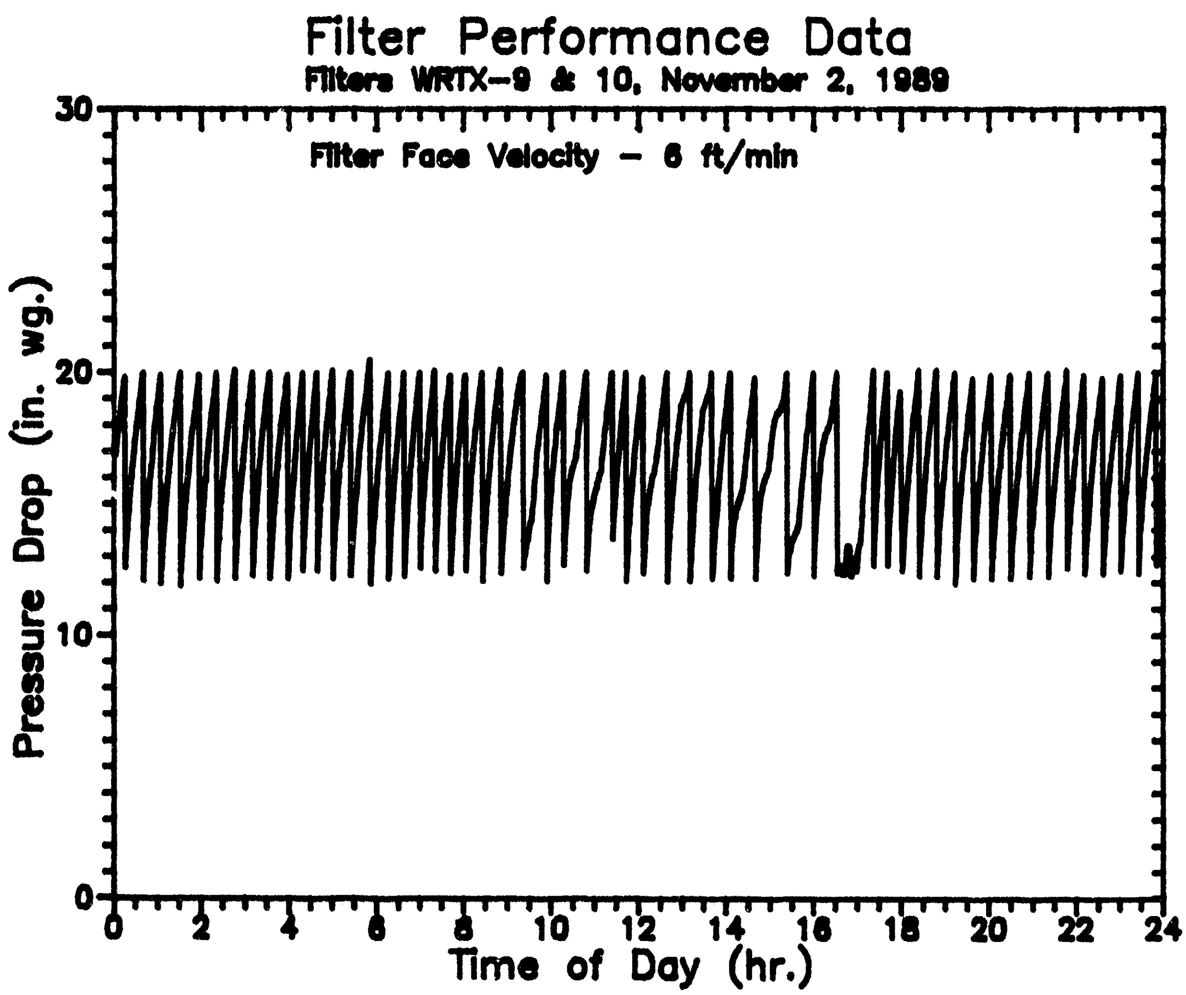


Operation Notes for October 31, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec



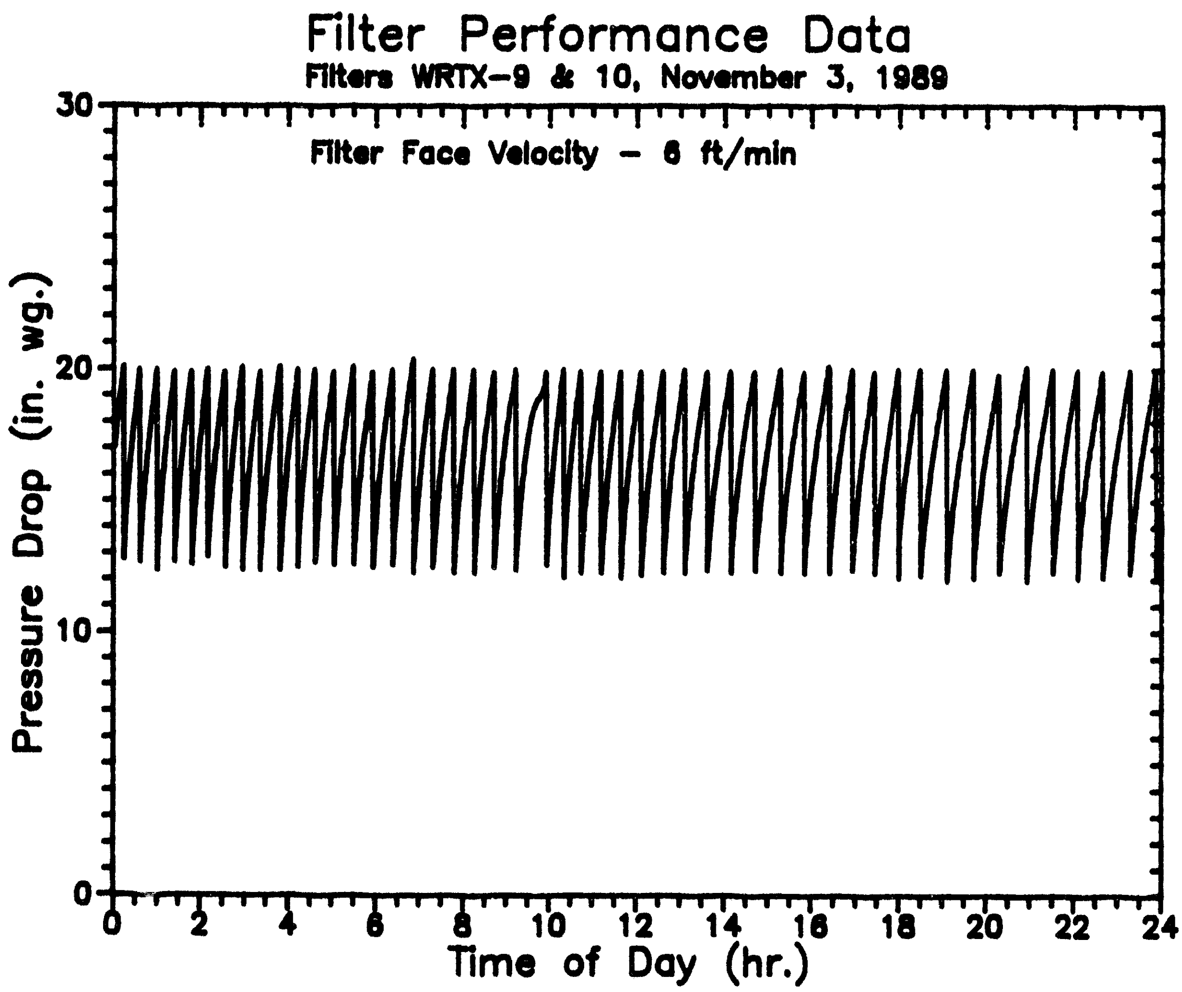
Operation Notes for November 1, 1989:

ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec
Unscheduled shutdown 2057
Compressor shutdown due to low recirculating water pressure.
Problem corrected.
Restart - 2153

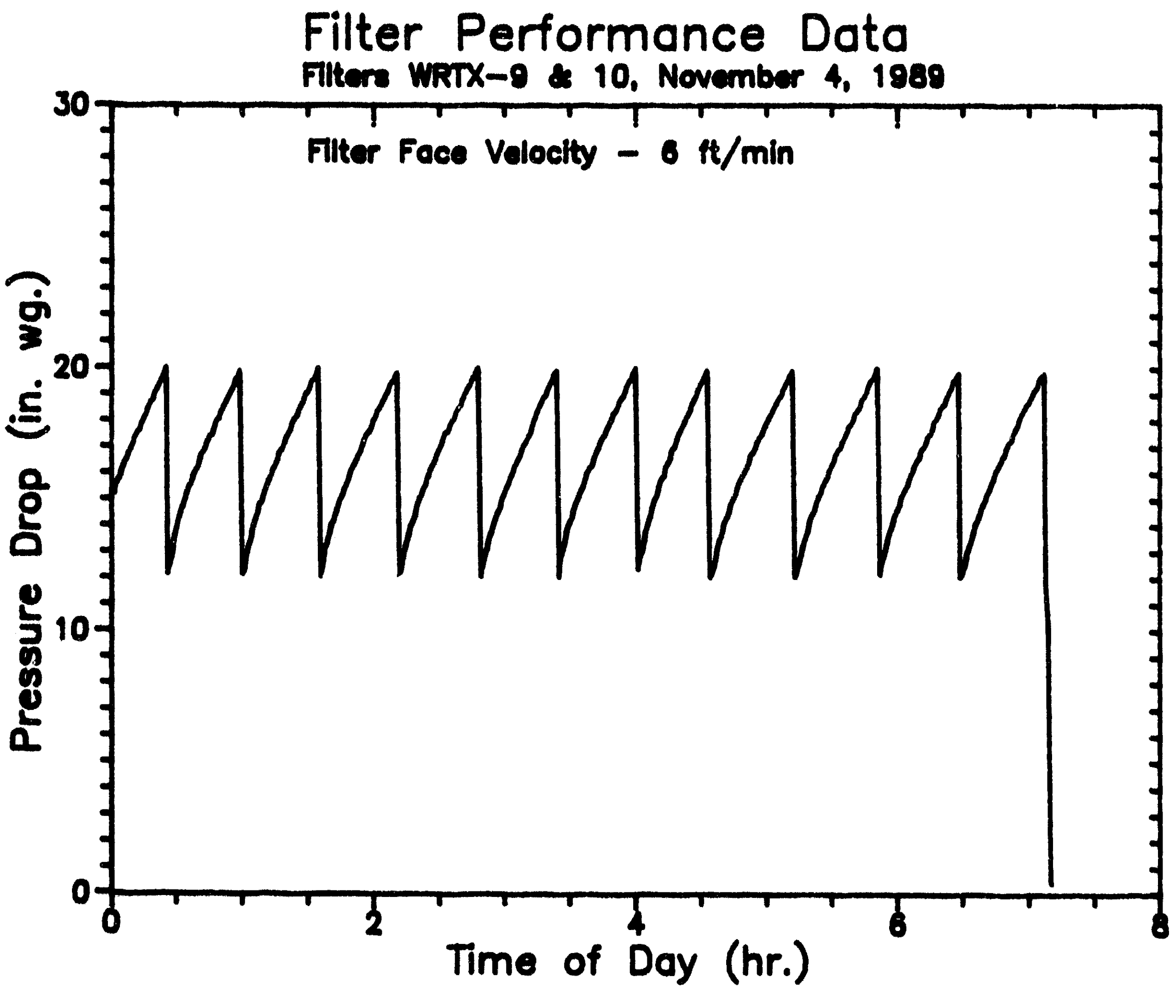


Operation Notes for November 2, 1989:

ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec
Erratic dust feed
1634 - dust off, vessel depressurized, dust stirred for even feeding
1705 dust on

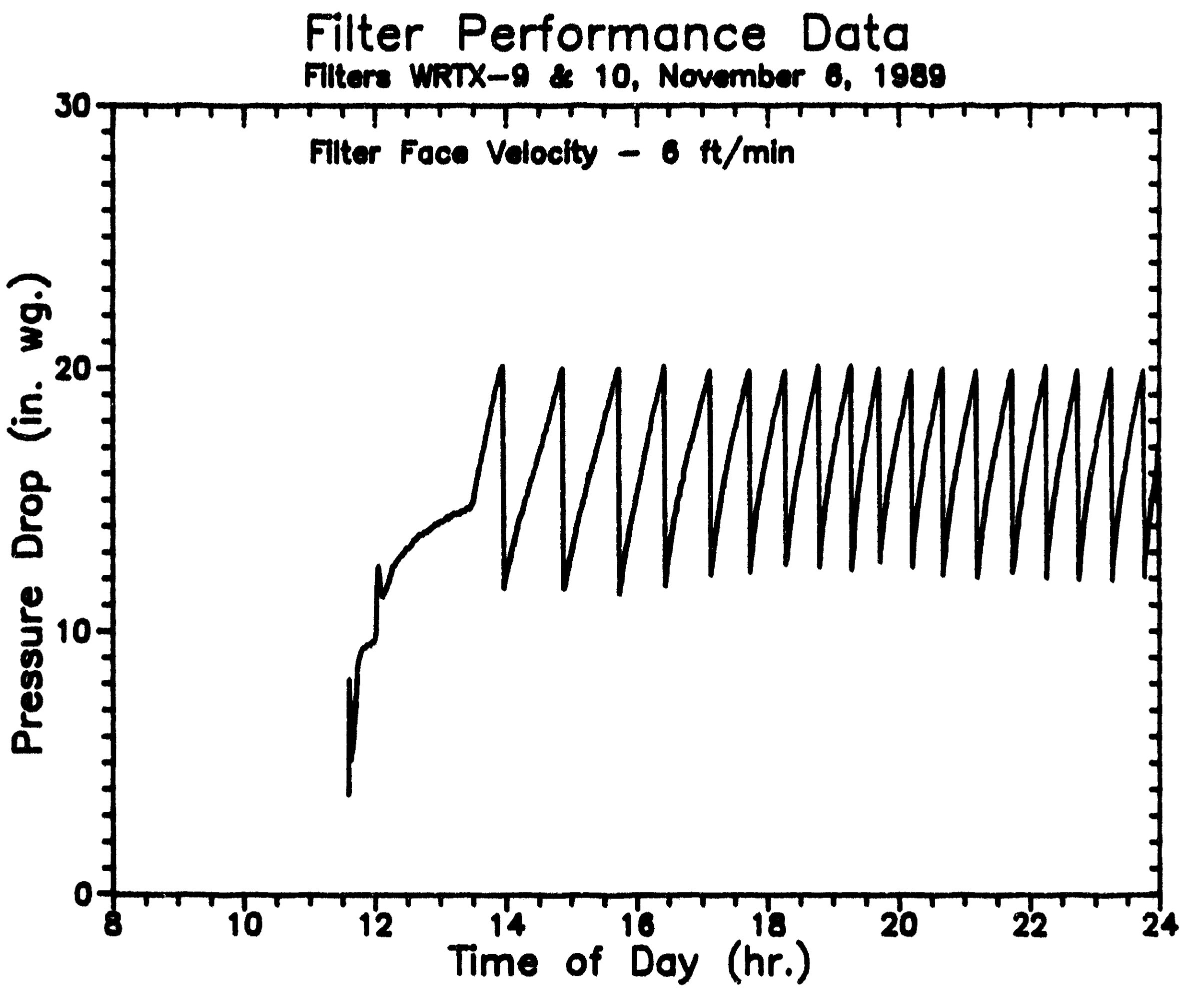


Operation Notes for November 3, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for November 4, 1989:

End of week long test
Scheduled shutdown
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for November 6, 1989:

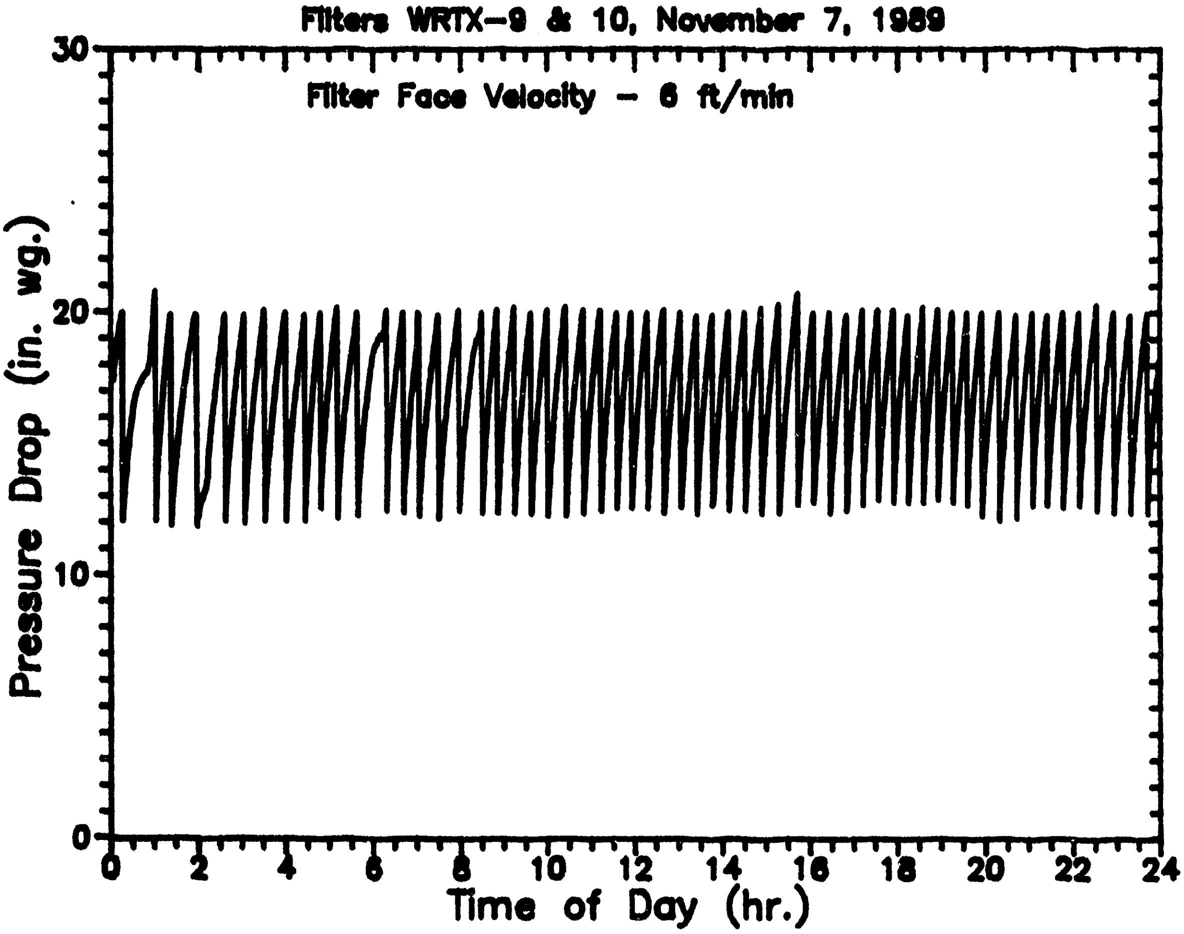
Start week long test

Startup

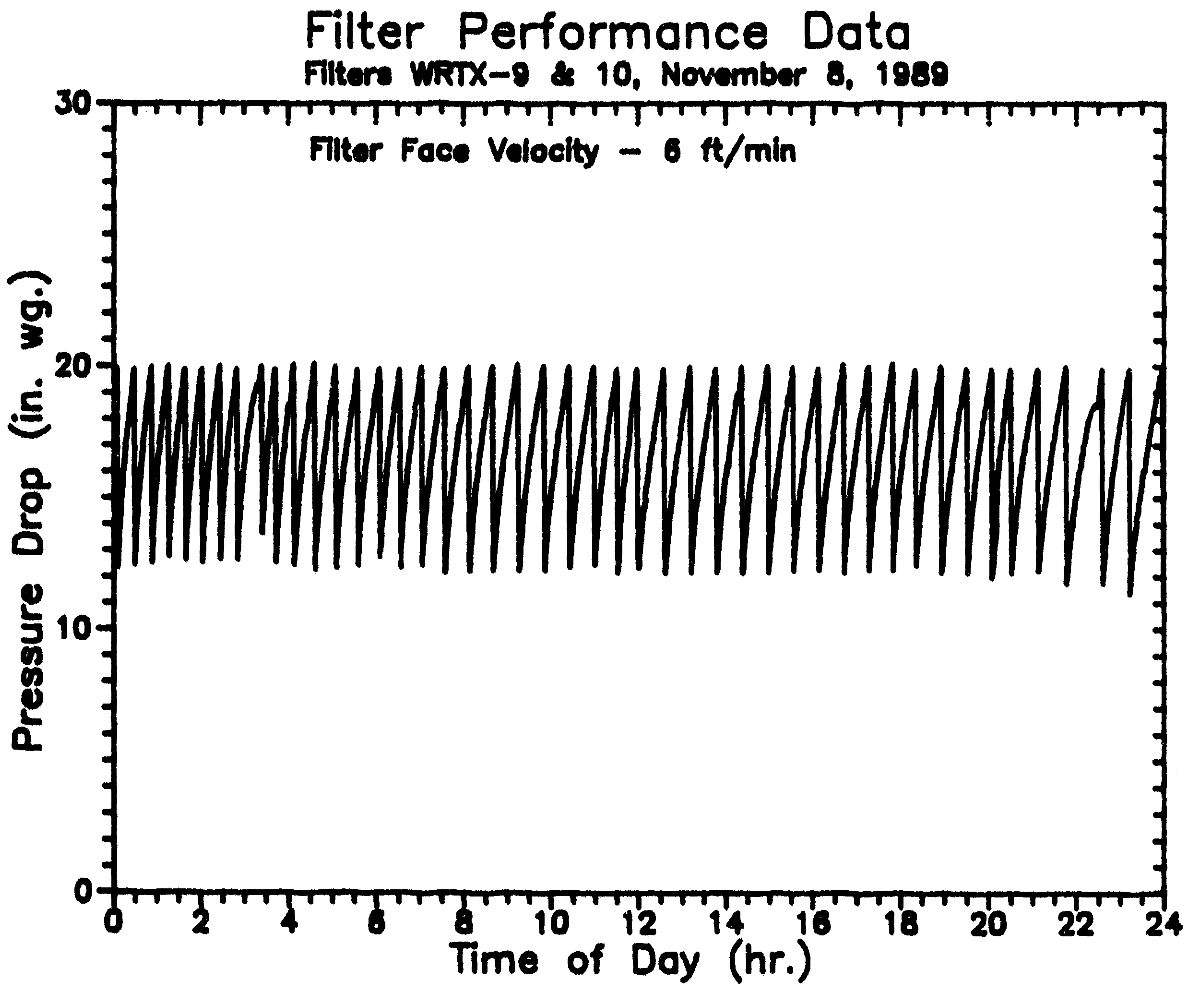
ΔP Trigger = 20.0" WC

Pulse Cleaning - 290 psig/0.1 sec

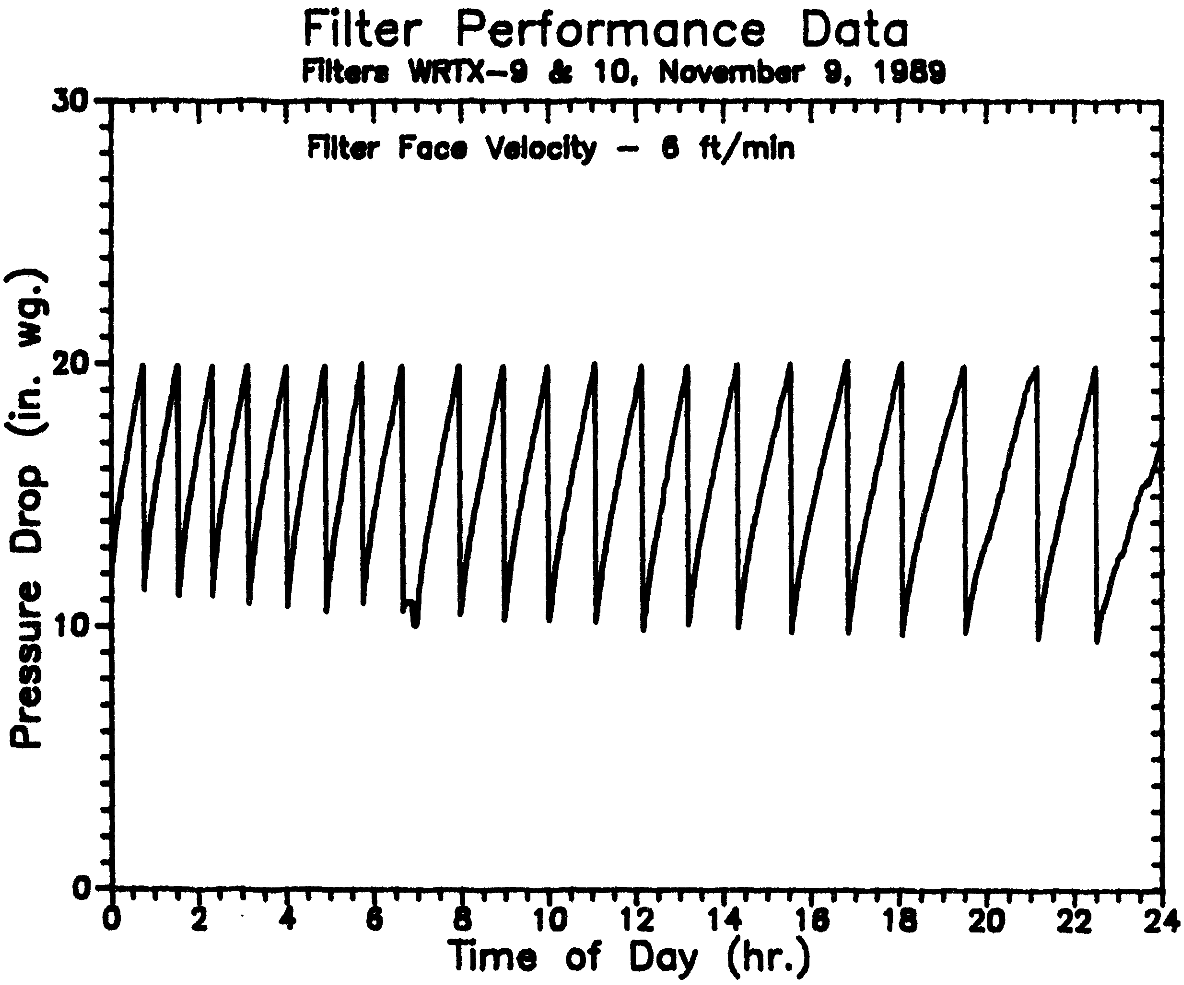
Filter Performance Data



Operation Notes for November 7, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec

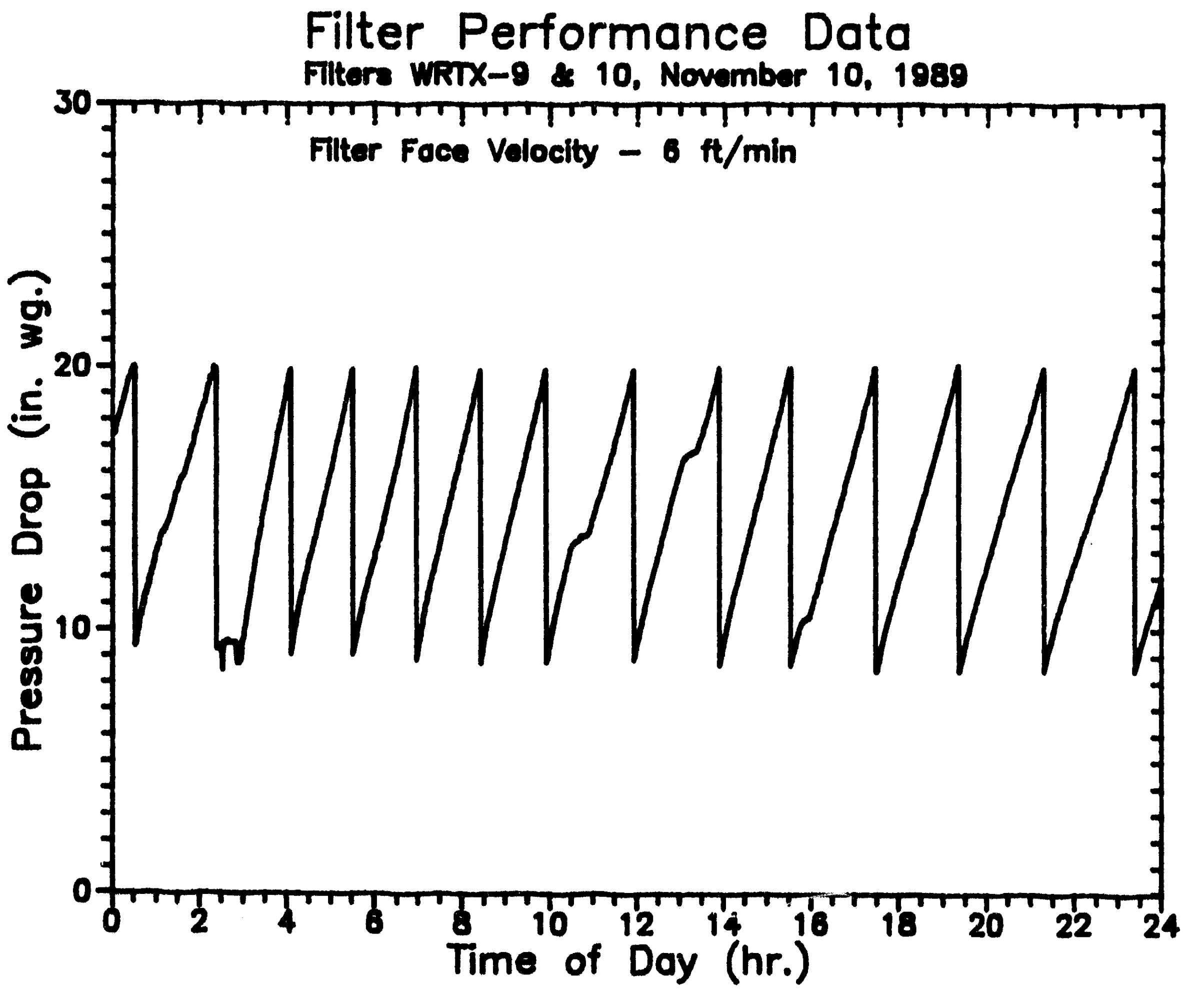


Operation Notes for November 8, 1989:
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec



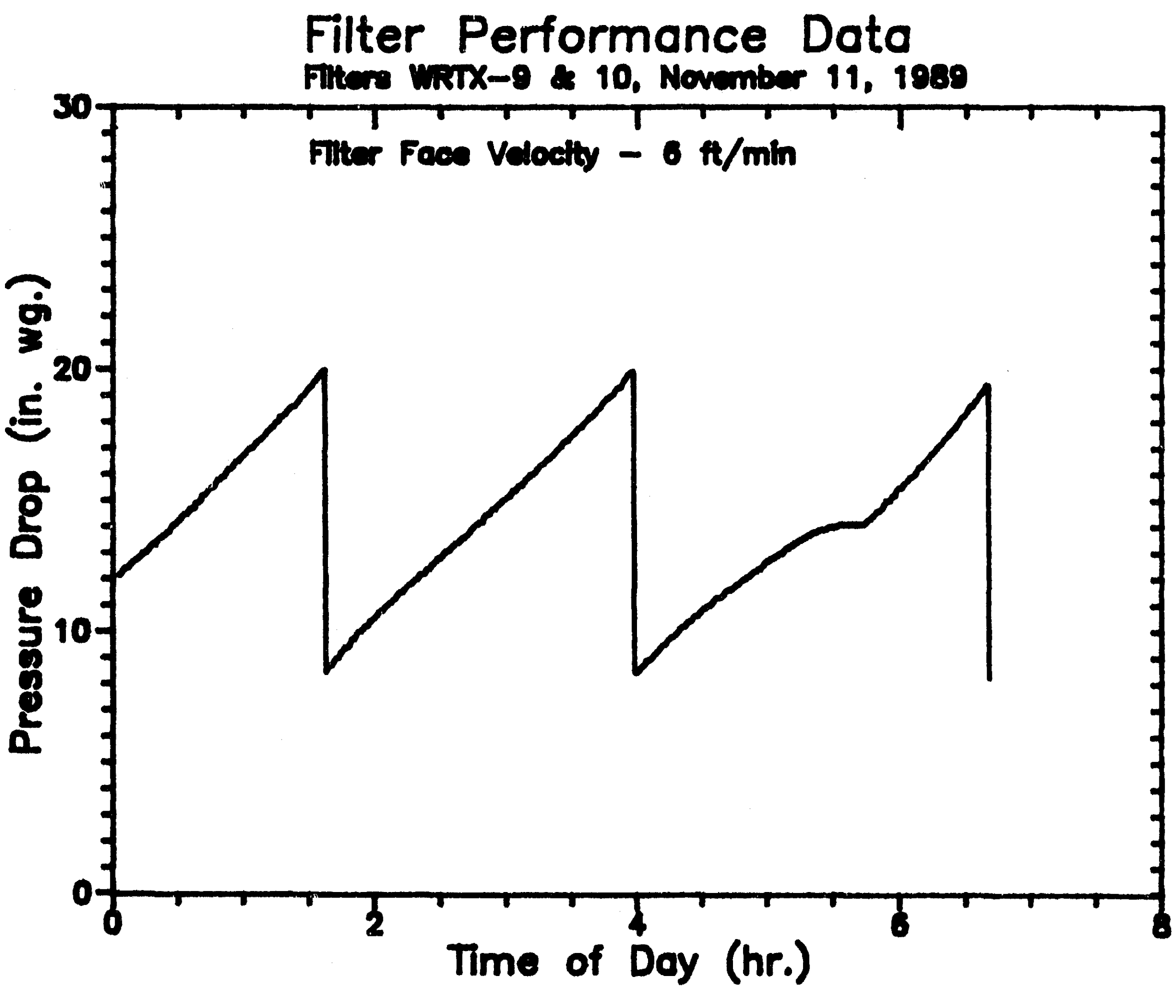
Operation Notes for November 9, 1989:

ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec
0639 dust off
Vessel depressurized; dust added to vessel
Repressurized
0702 dust on



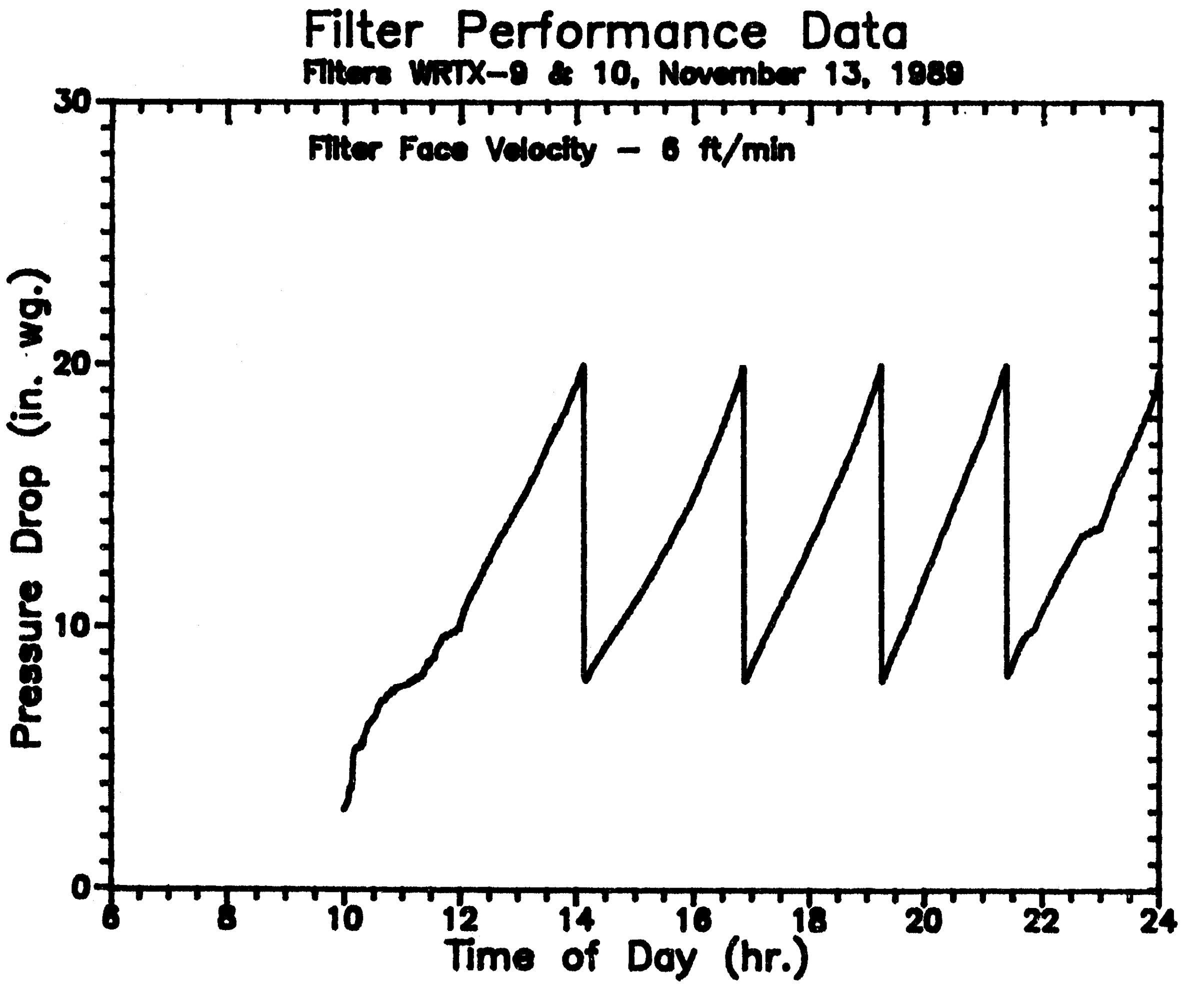
Operation Notes for November 10, 1989:

ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec
0227 - dust off
Depressurized vessel, dust stirred & added
0300 - dust on
1055 - erratic dust feed - corrected

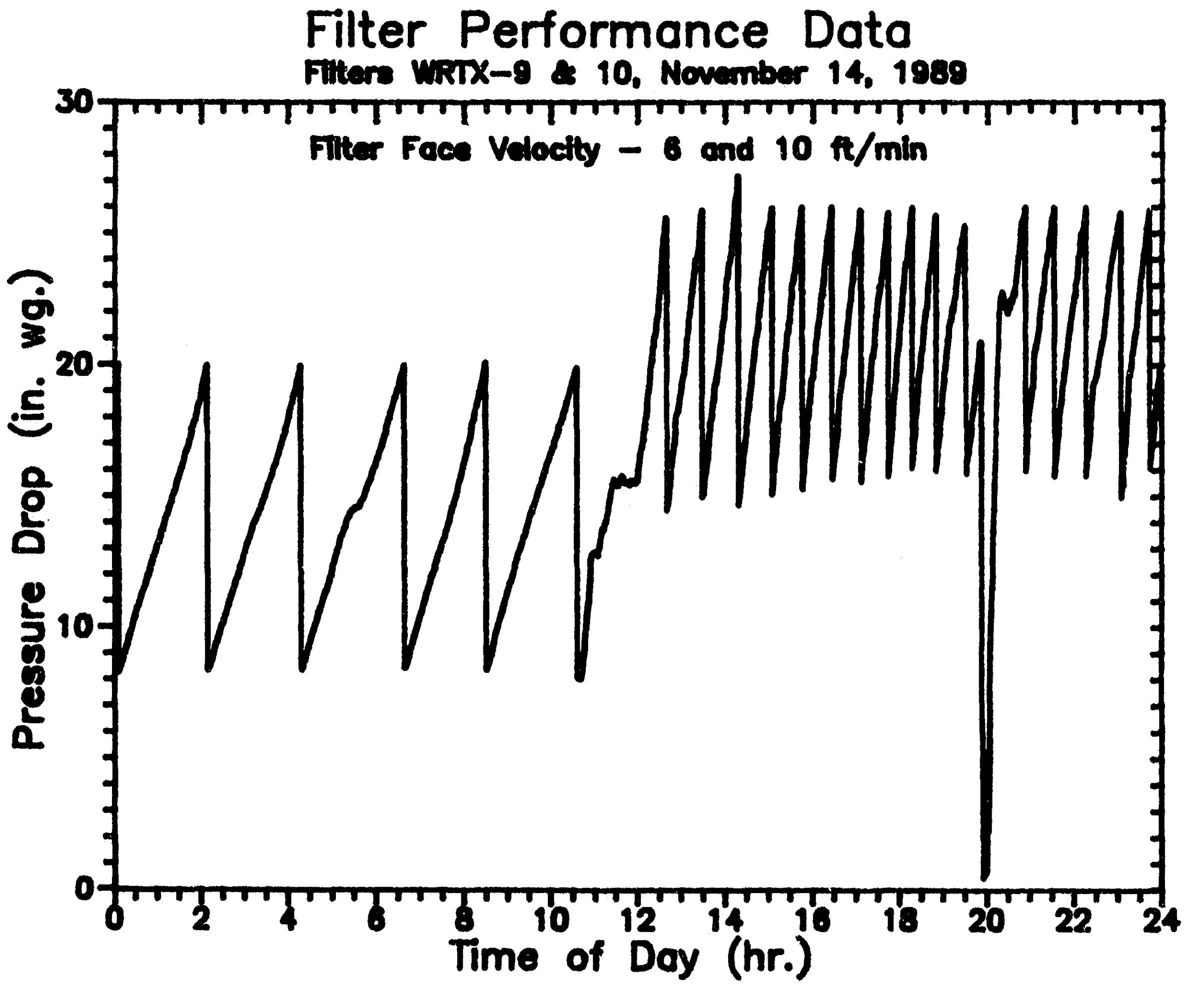


Operation Notes for November 11, 1989:

End week long test
Scheduled shutdown
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec

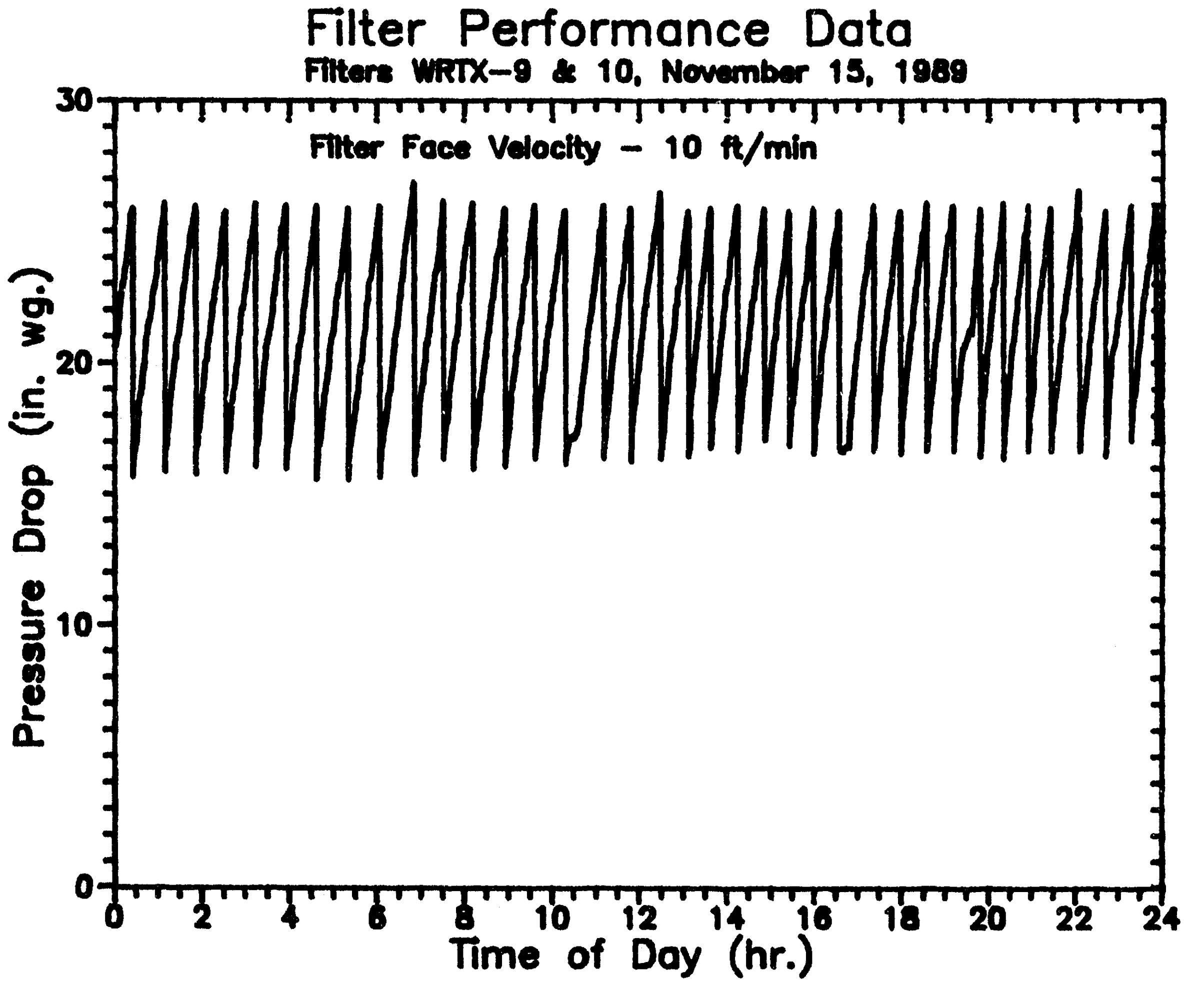


Operation Notes for November 13, 1989:
Begin week long test
Startup
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for November 14, 1989:

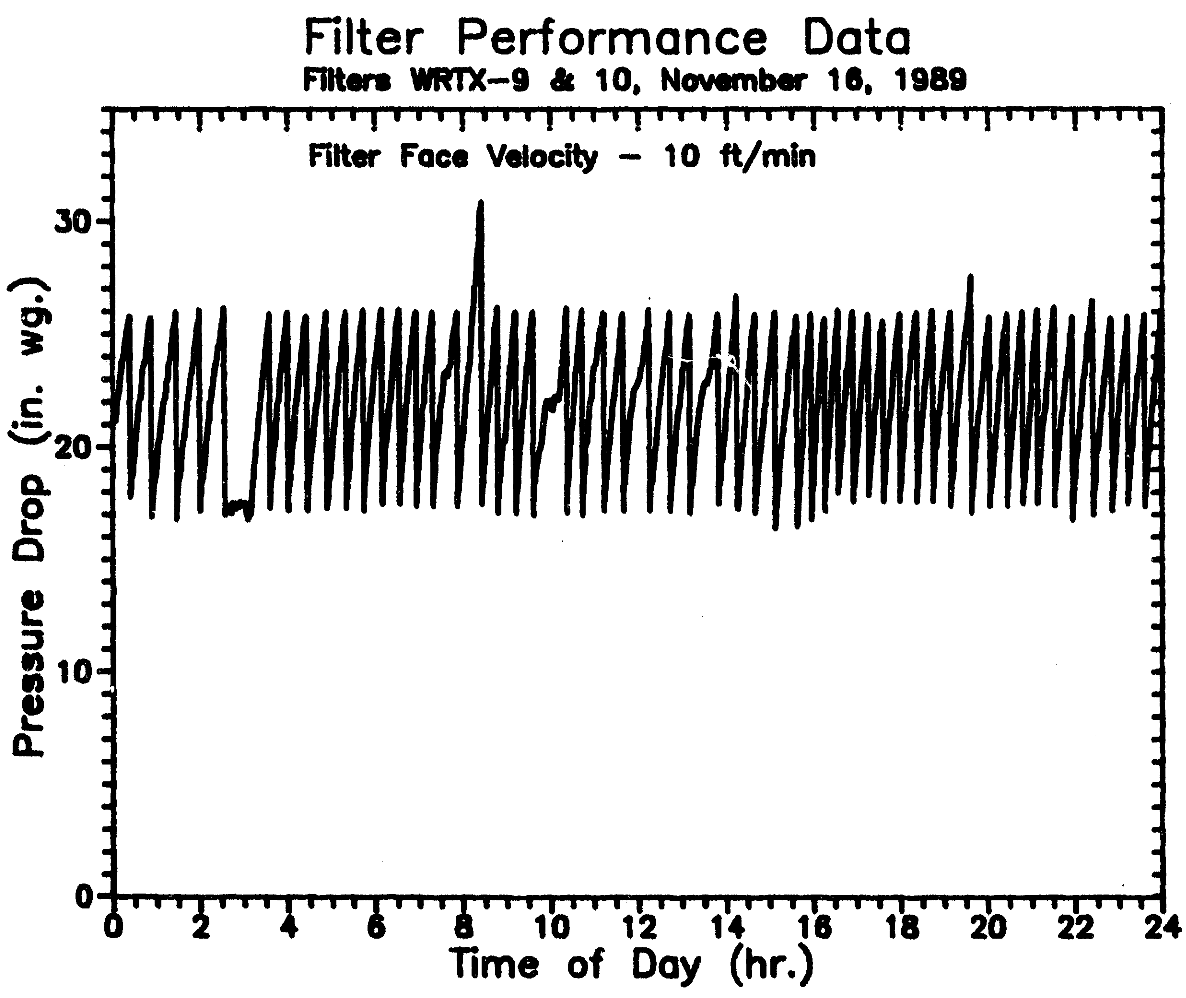
ΔP Trigger = 20.0" WC
Pulse Cleaning - 290 psig/0.1 sec
1040 - conditions changed to 10 ft/min; dust feed rate increased
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
1954 - Unscheduled shutdown power loss; heat tape short
Blown fuse, corrected
Restart: 2000



Operation Notes for November 15, 1989:

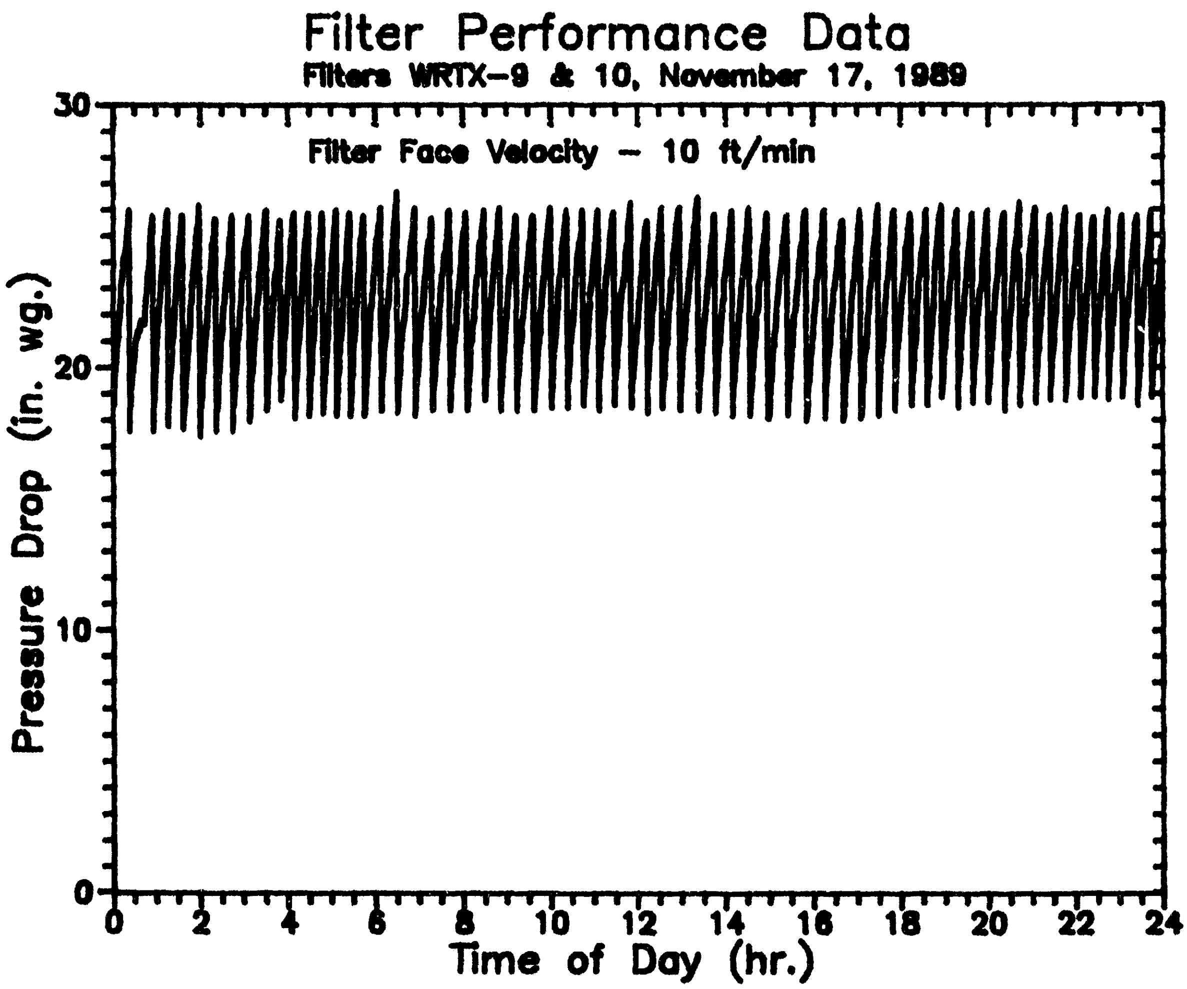
ΔP Trigger = 26.0" WC

Pulse Cleaning - 290 psig/0.1 sec

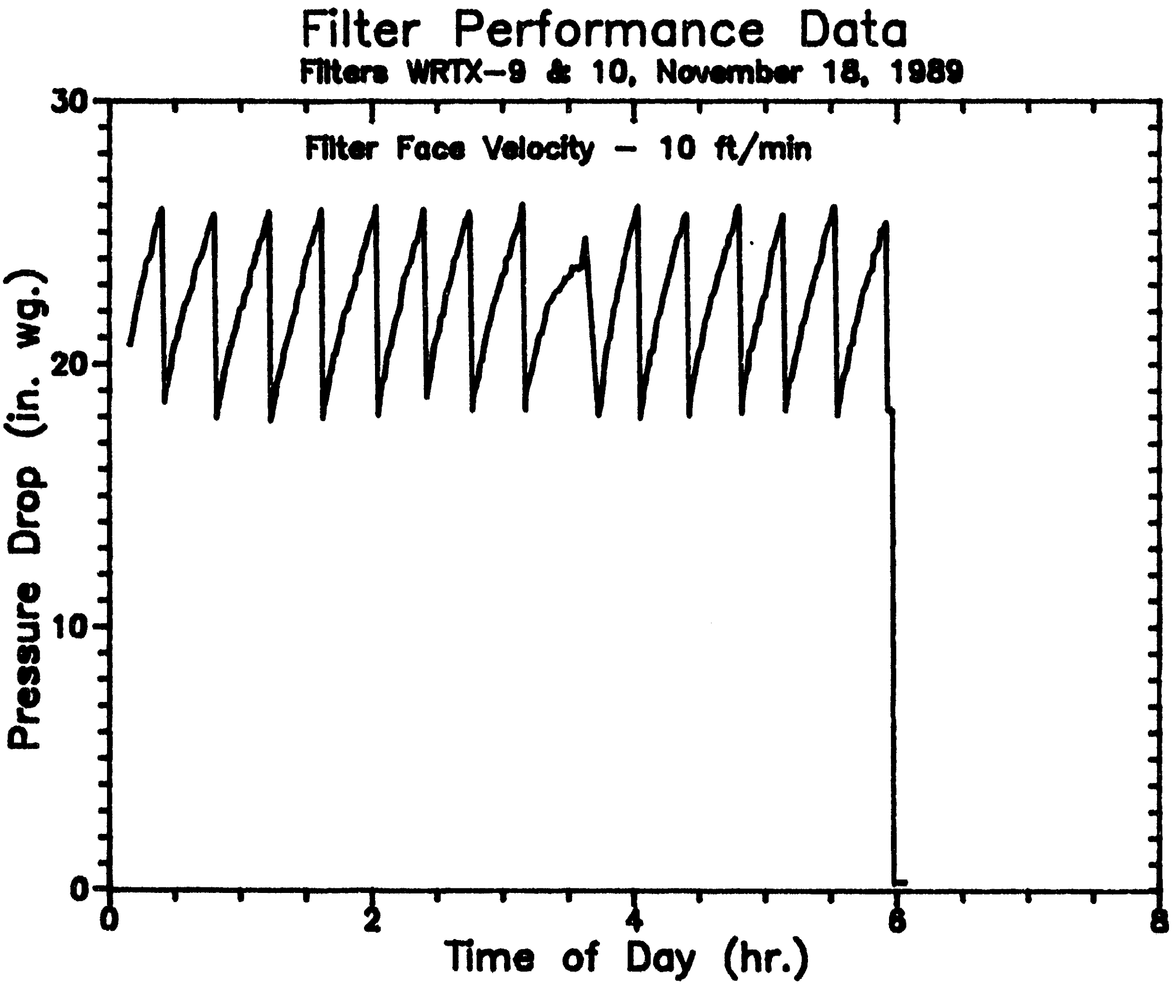


Operation Notes for November 16, 1989:

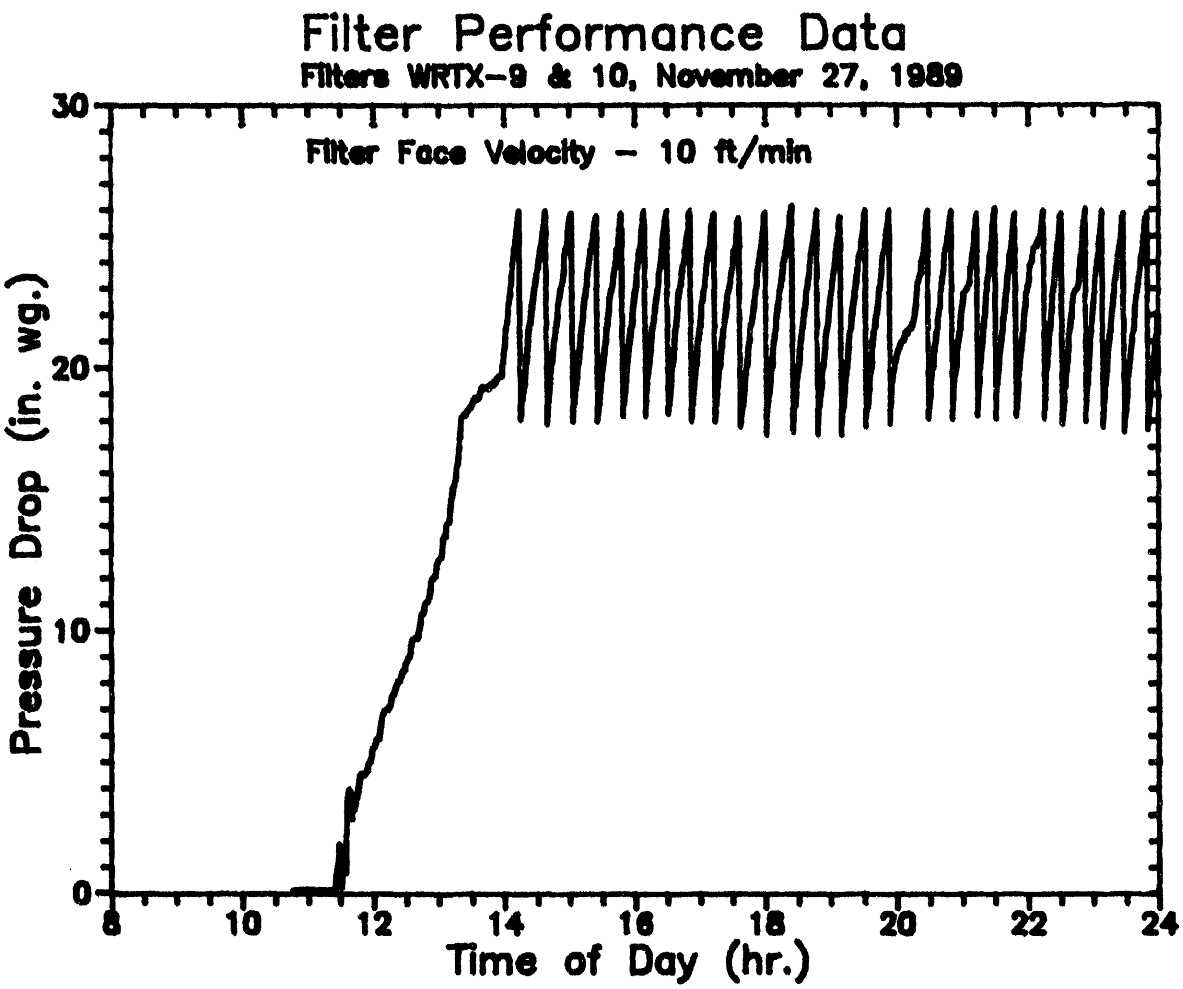
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
0234 - dust off
Depressurize vessel, dust added
0311 - dust on
Occasional erratic dust feed



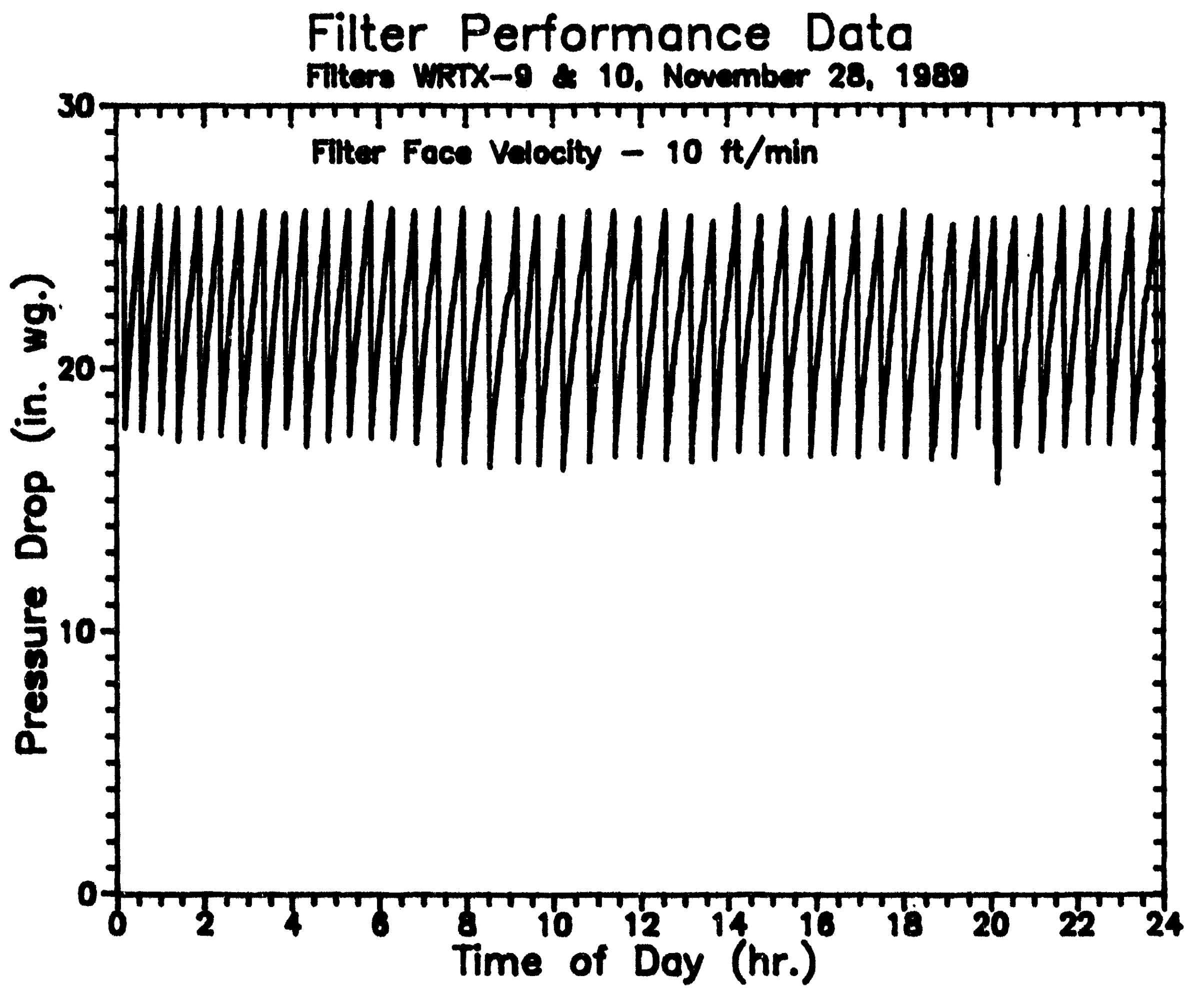
Operation Notes for November 17, 1989:
ΔP Trigger = 26.0" WC
Pulse Cleaning 290 psig/0.1 sec



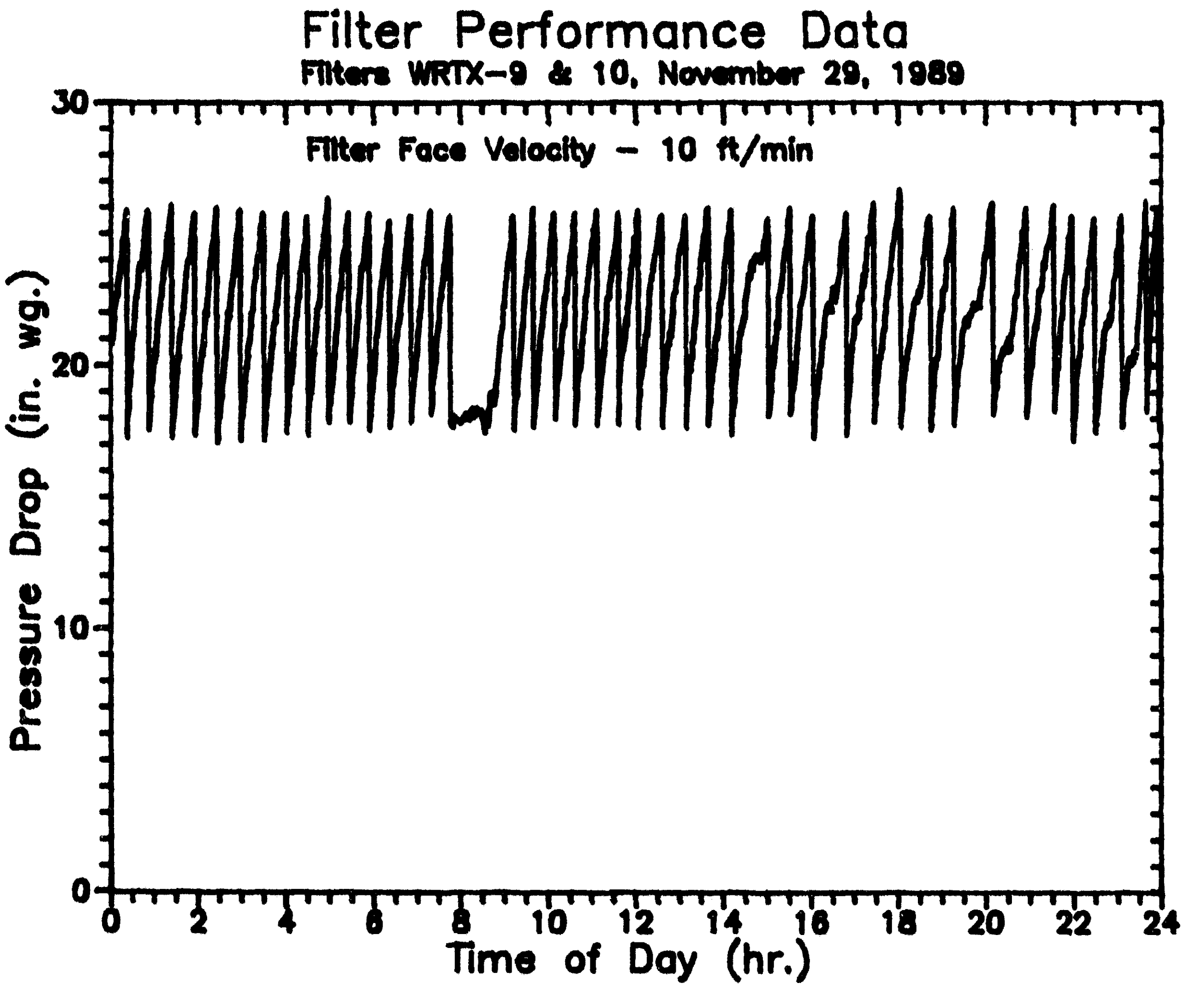
Operation Notes for November 18, 1989:
End of week long test
Scheduled shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for November 27, 1989:
- Begin week long test
- Startup
- ΔP Trigger = 26.0" WC
- Pulse Cleaning - 290 psig/0.1 sec

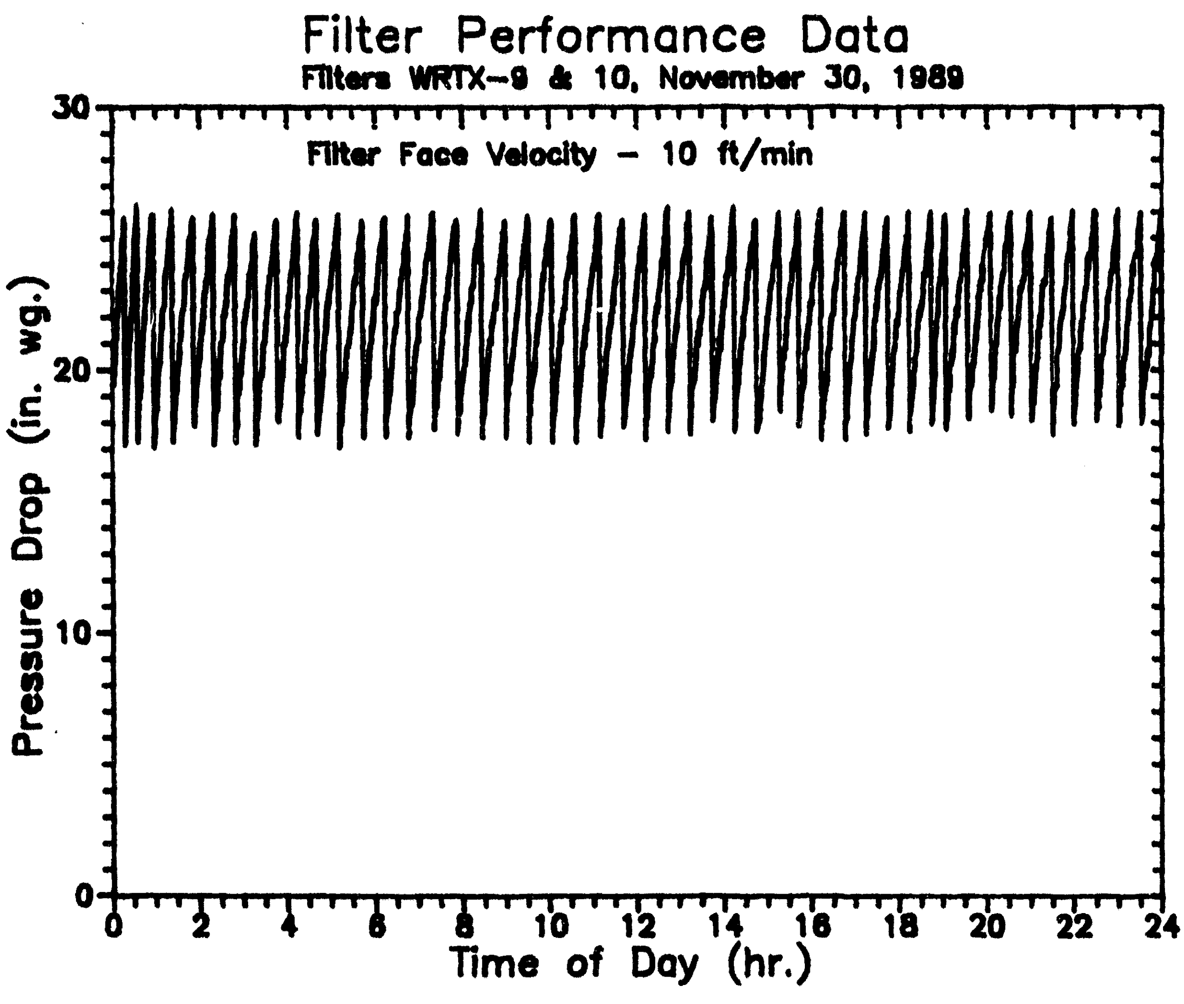


Operation Notes for November 28, 1989:
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

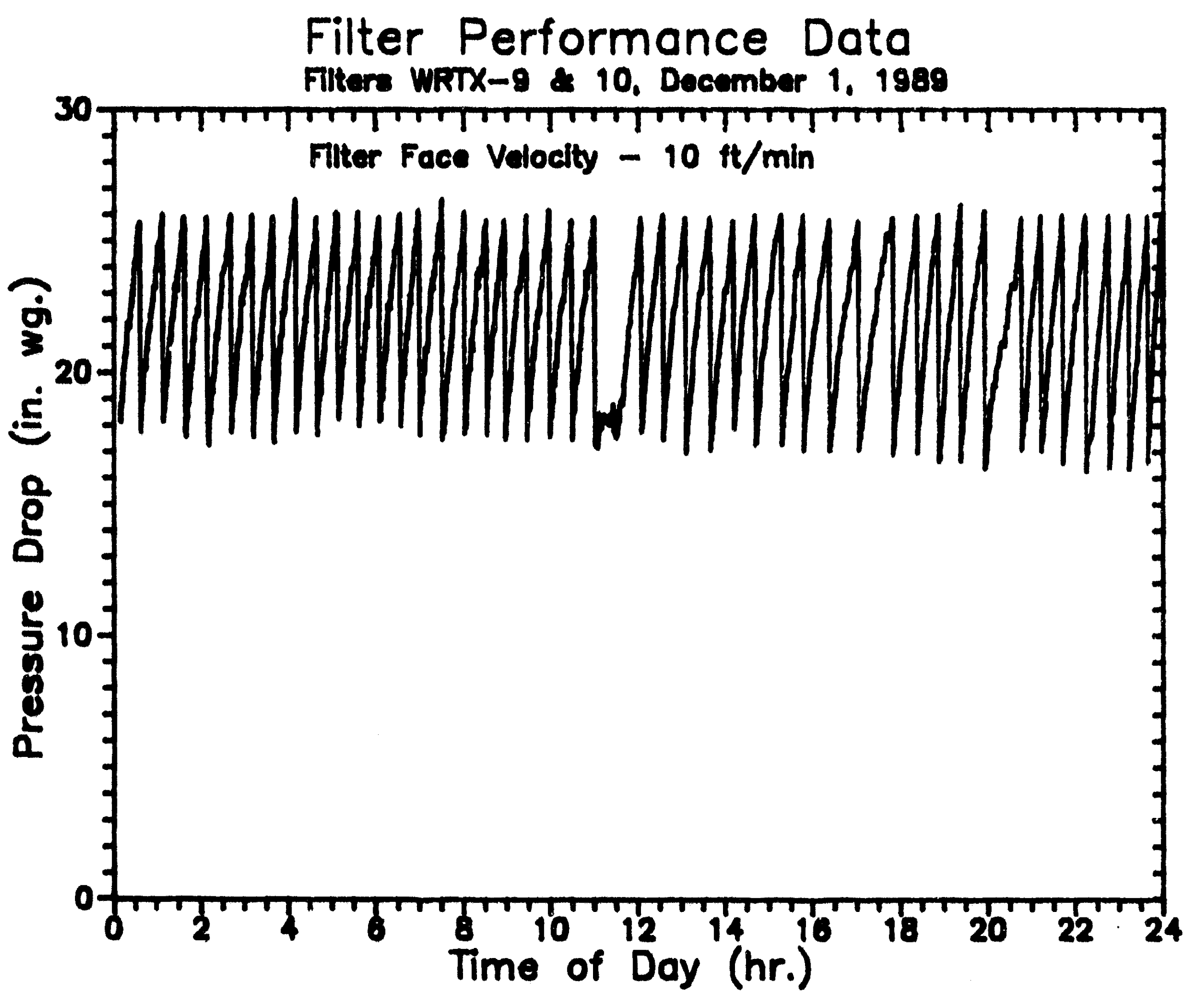


Operation Notes for November 29, 1989:

ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
0747 - dust off, dust added to vessel
0846 - dust on
1400 - erratic feed

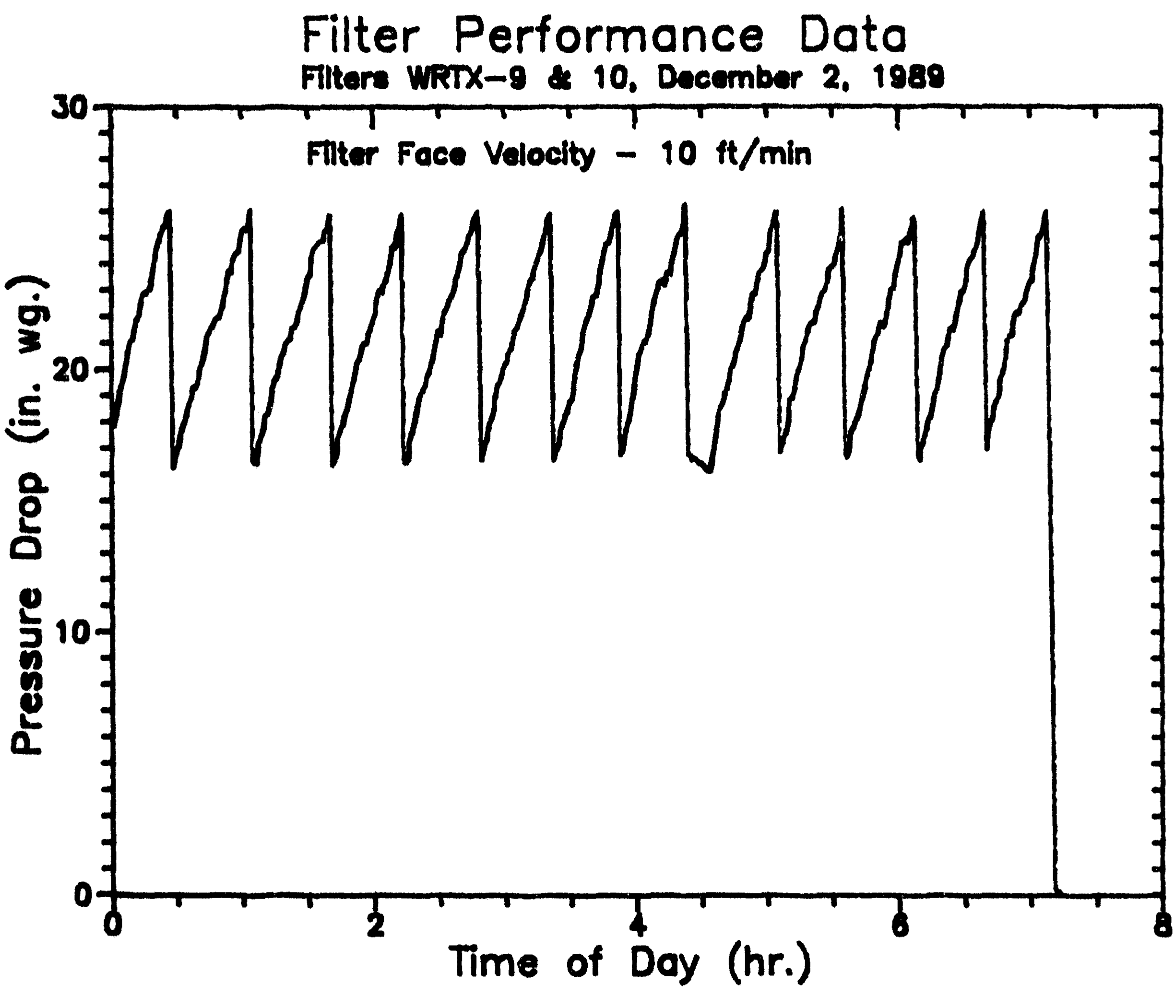


Operation Notes for November 30, 1989:
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



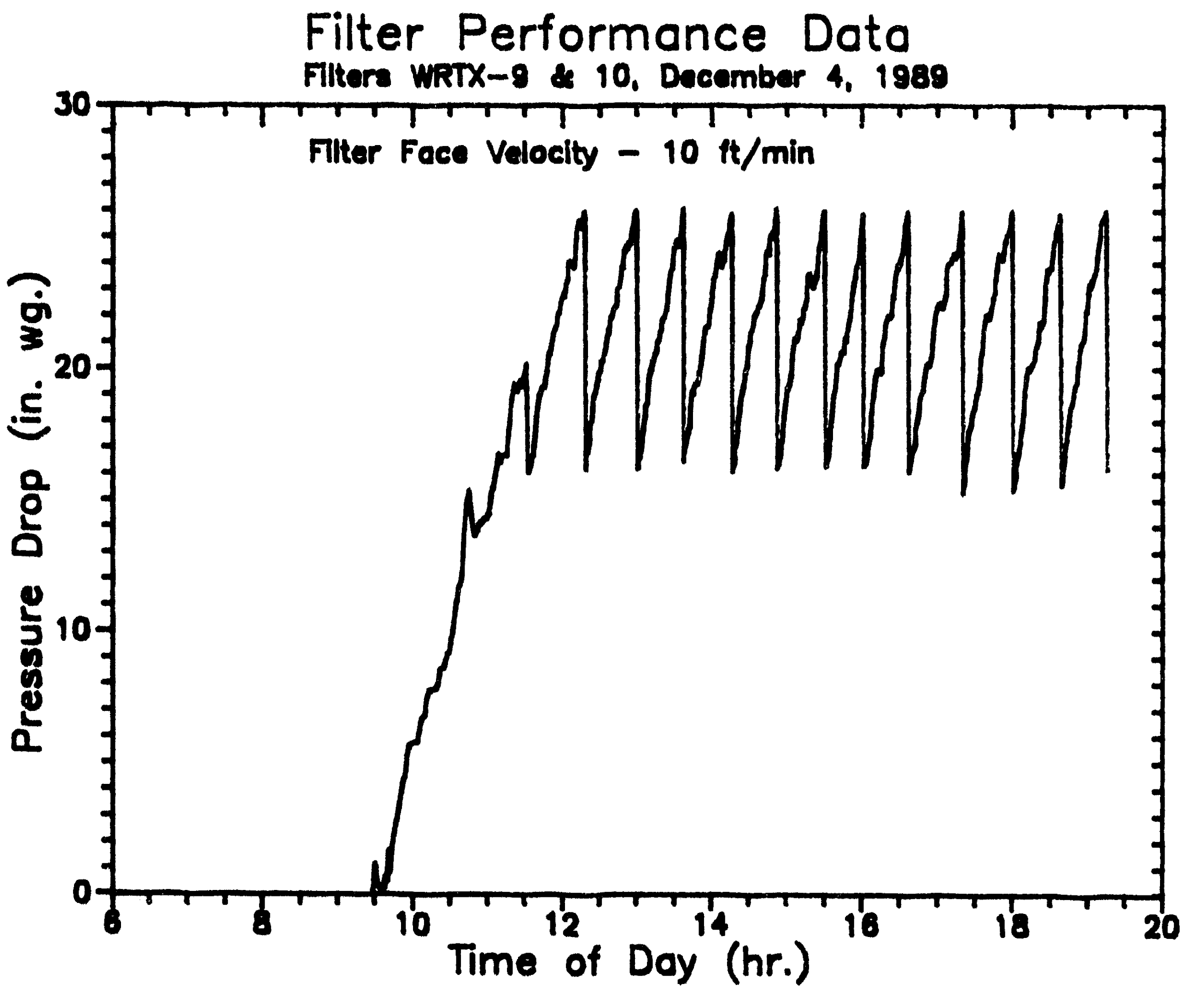
Operation Notes for December 1, 1989:

ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
11:00 dust off, dust added to vessel
11:37 dust on



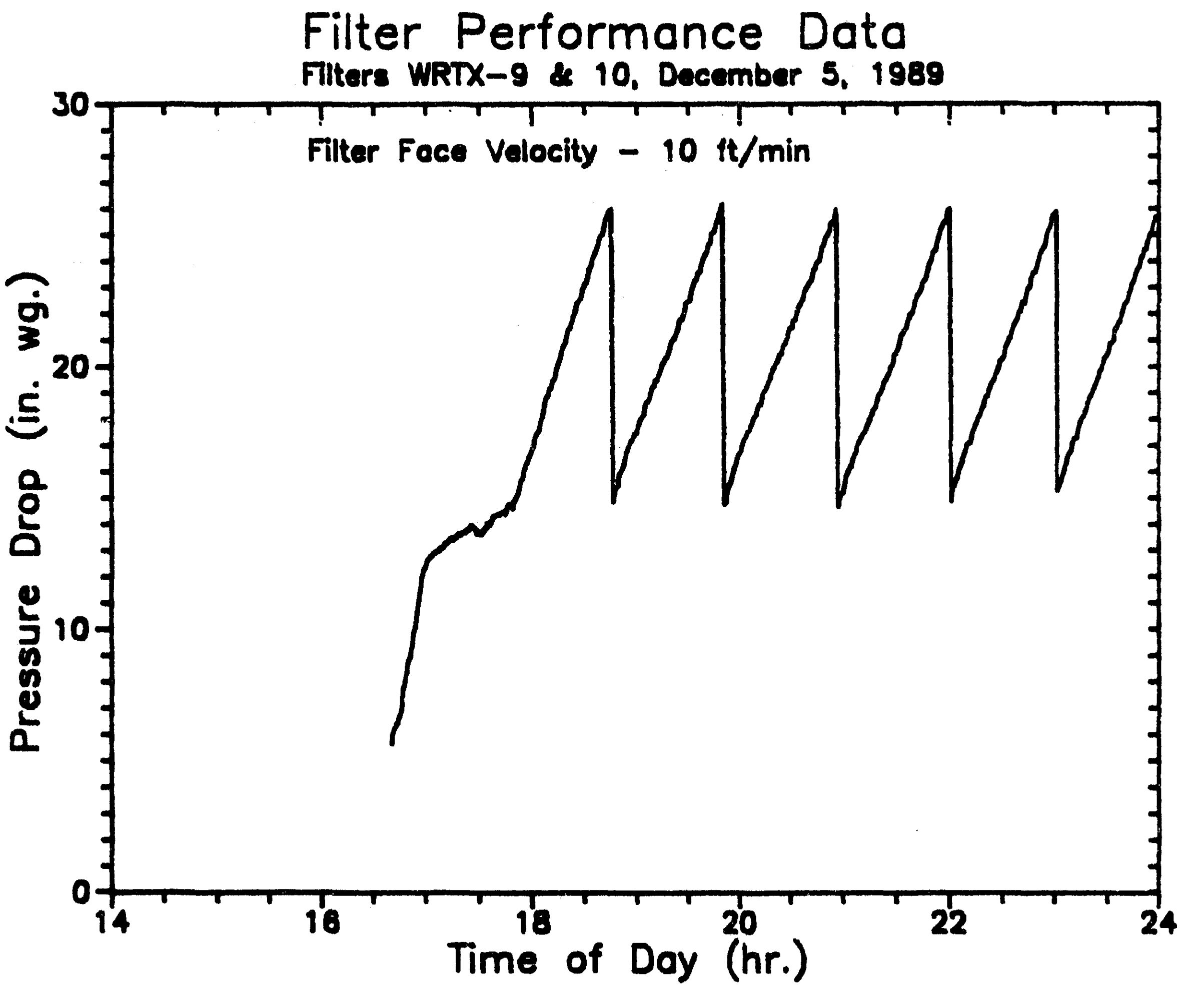
Operation Notes for December 2, 1989:

End week long test
Scheduled shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
0424 to 0435 Dust feed off

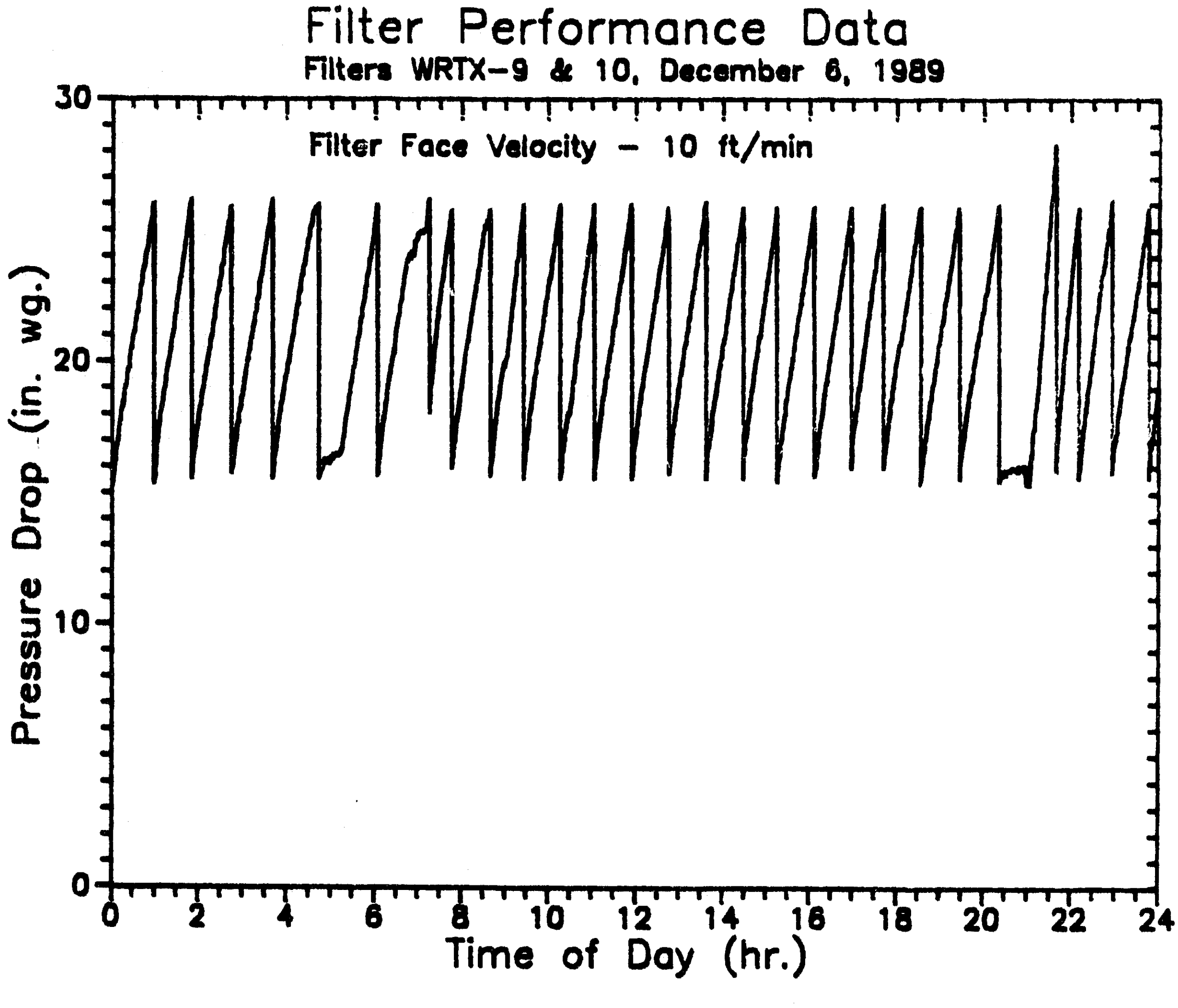


Operation Notes for December 4, 1989:

Begin week long test
Startup
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
~2400 - Data acquisition off
0608 - Unscheduled shutdown - flame out
Hot spot at combustor

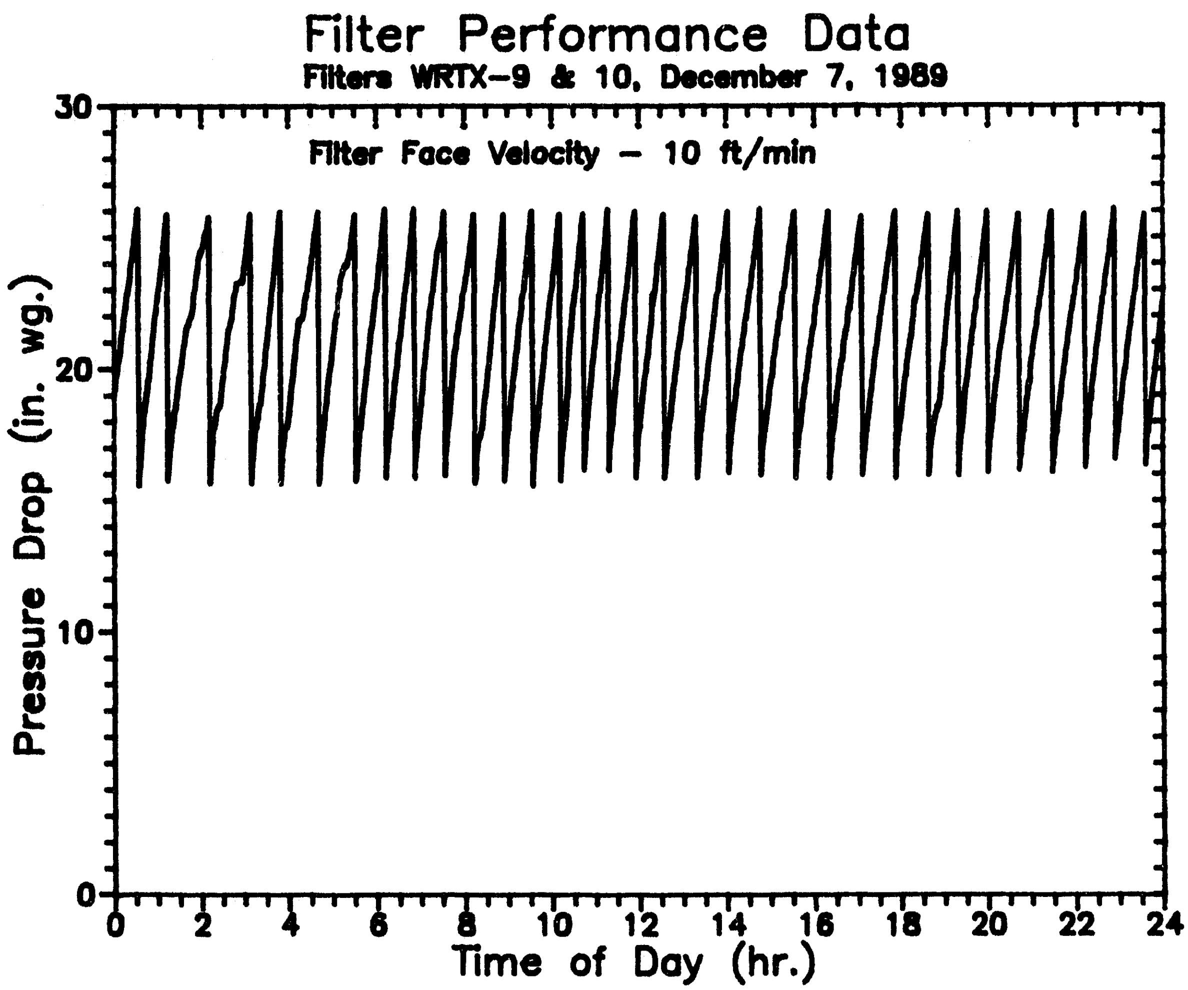


Operation Notes for December 5, 1989:
Combustor liner replaced
Restart week long test
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

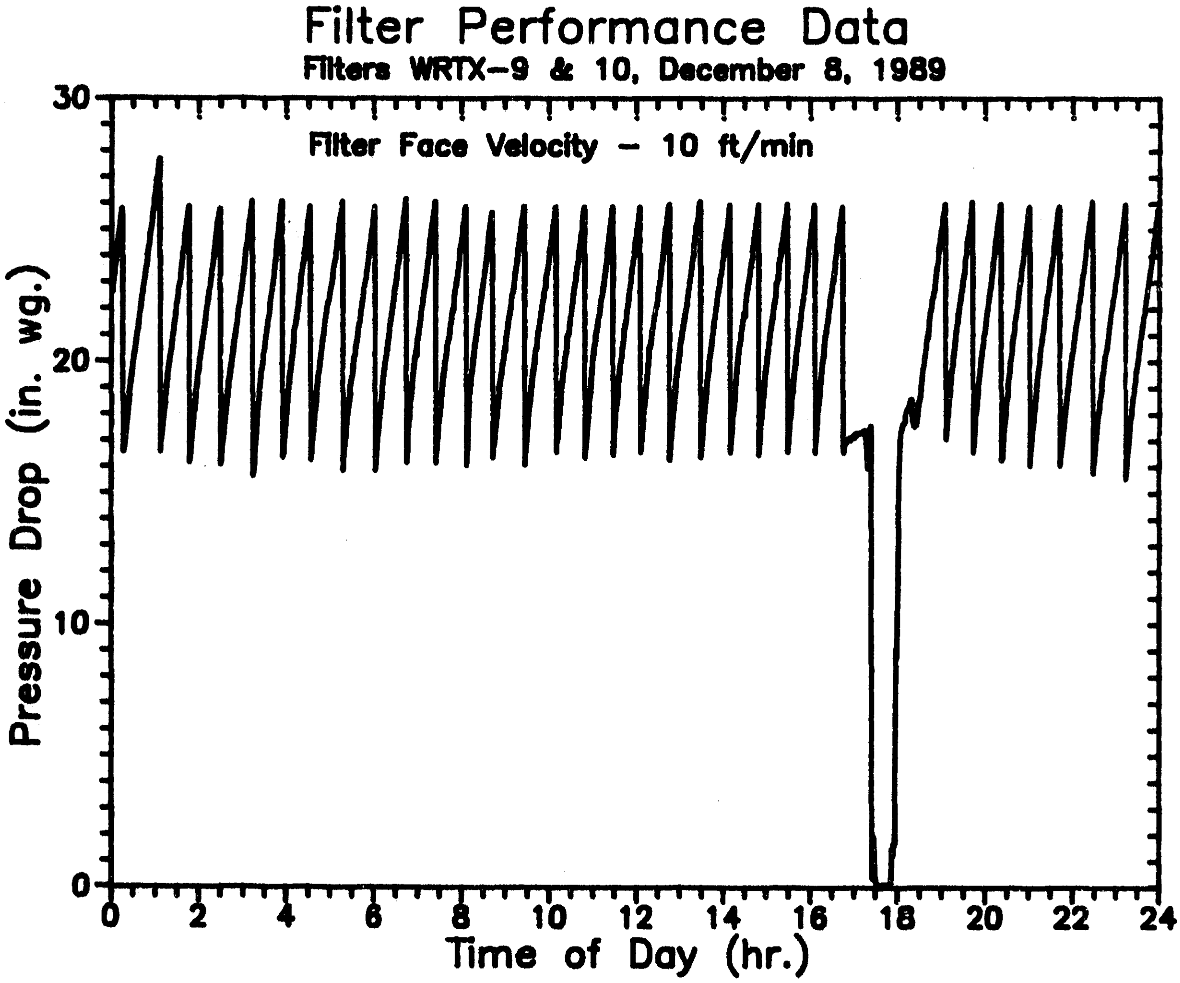


Operation Notes for December 6, 1989:

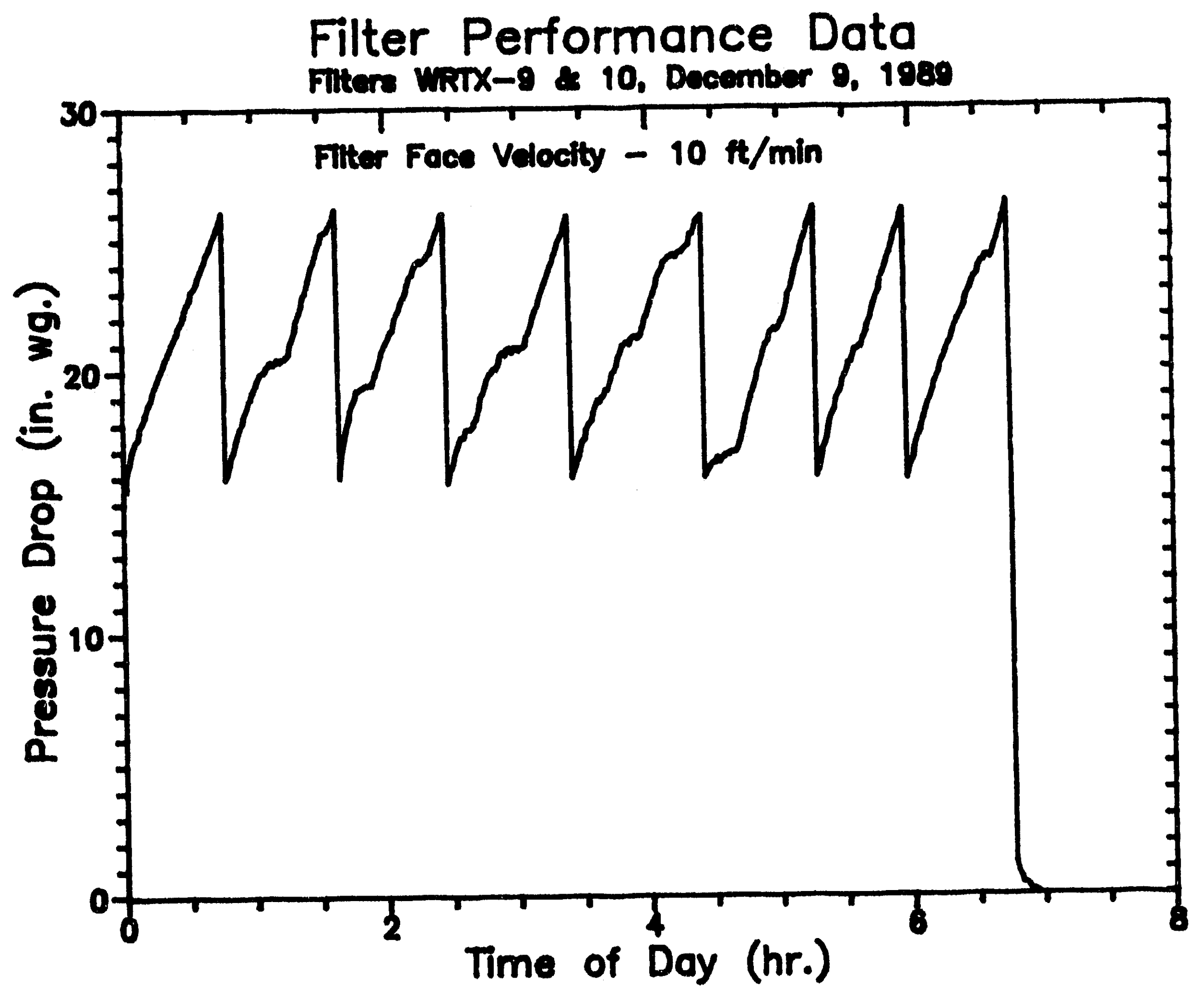
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
2023 - dust off, dust added to vessel
2105 - dust on



Operation Notes for December 7, 1989:
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

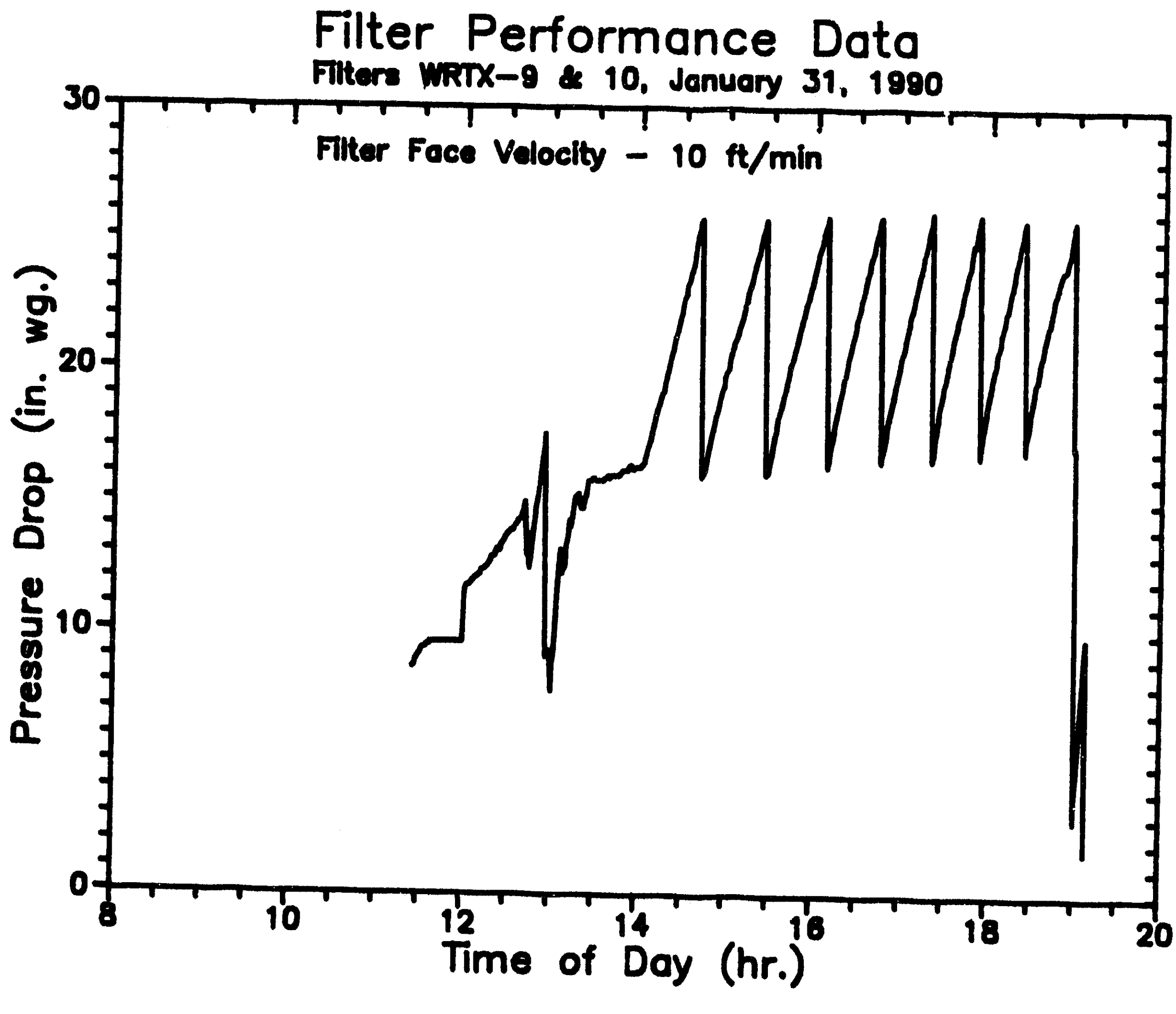


Operation Notes for December 8, 1989:
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec
1644 - Dust off, dust added to vessel
1725 - Unscheduled shutdown - repair dust feed line
1753 - Retart



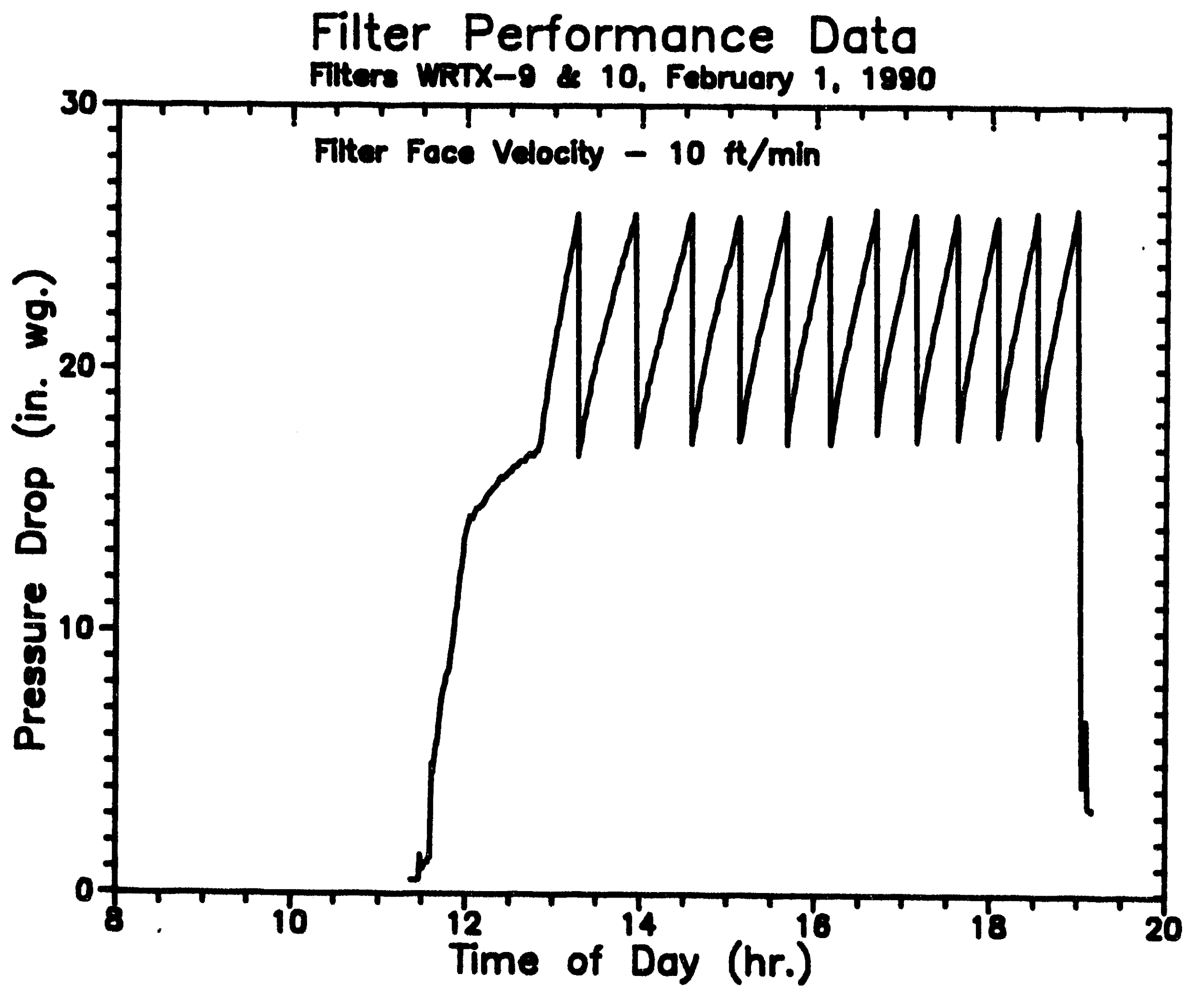
Operation Notes for December 9, 1989:

End week long test
Scheduled shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

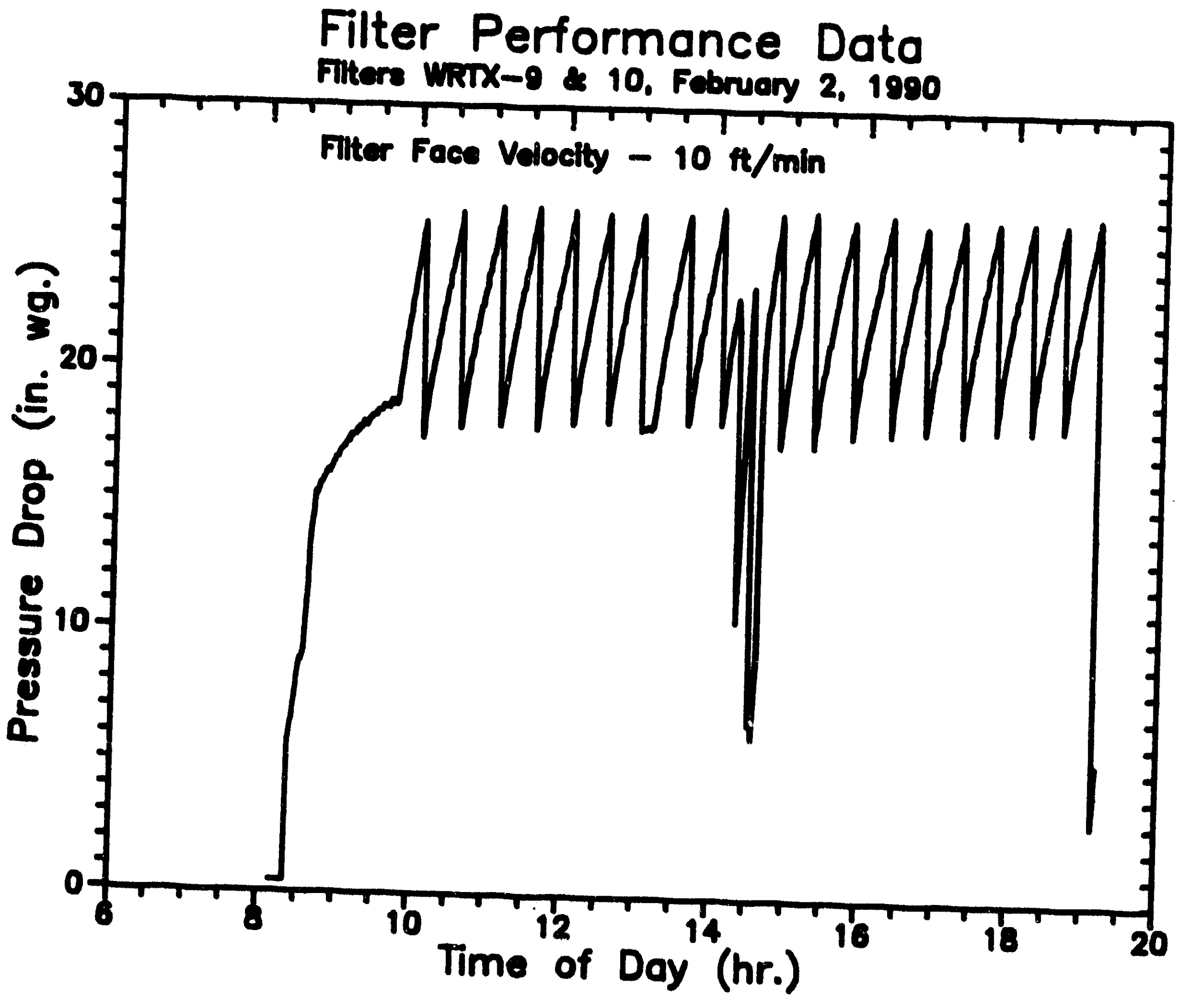


Operation Notes for January 31, 1990:

12 hour test, includes startup and shutdown
1300 - Lost house air supply
Shut down
Restarted
ΔP Trigger = 26.0" WC
Pulse Cleaning 290 psig/0.1 sec

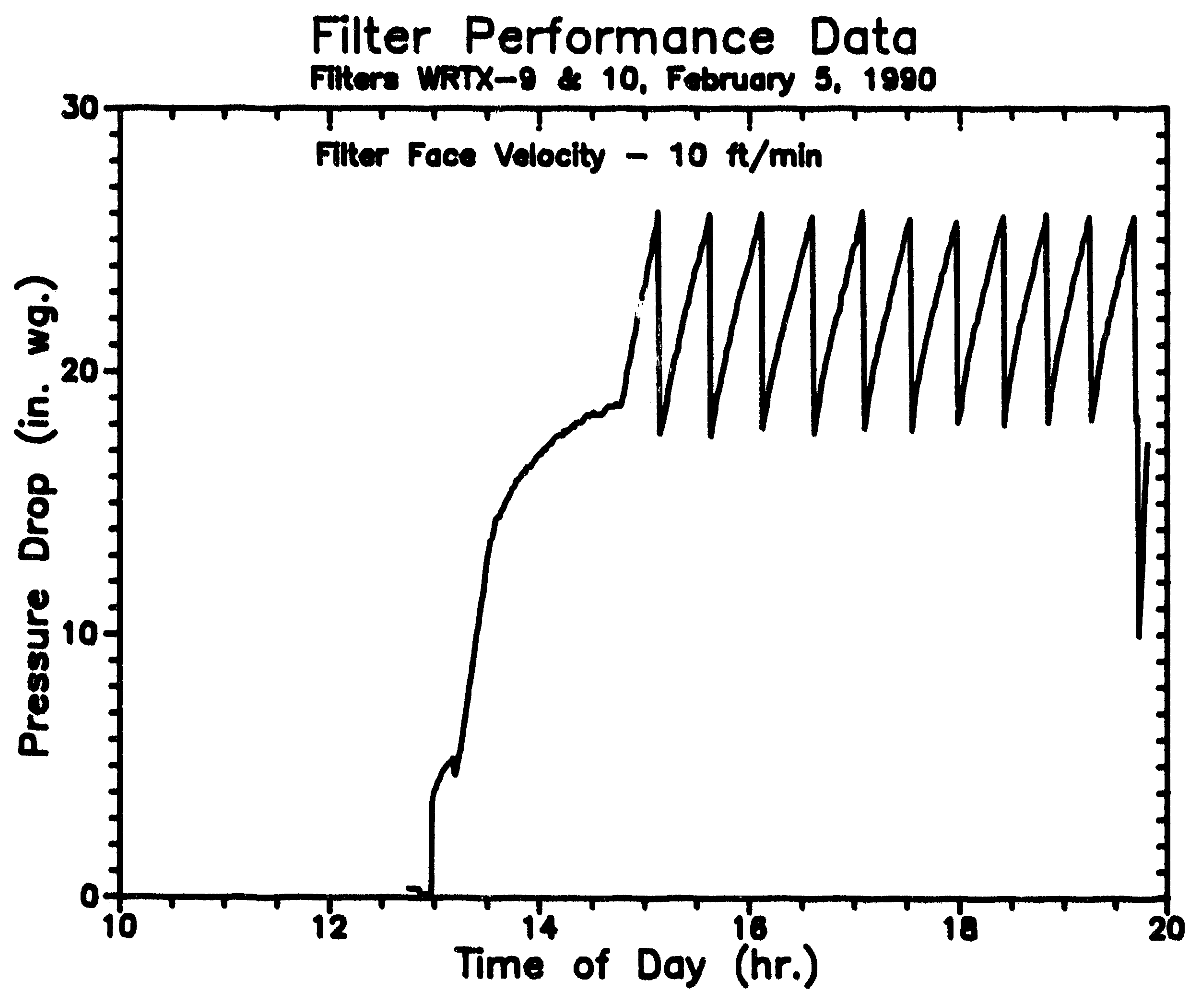


Operation Notes for February 1, 1990:
12 hour test, includes startup and shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for February 2, 1990:

12 hour test, includes startup and shutdown
1430 Lost cooling water to air compressor
Shutdown & restart
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

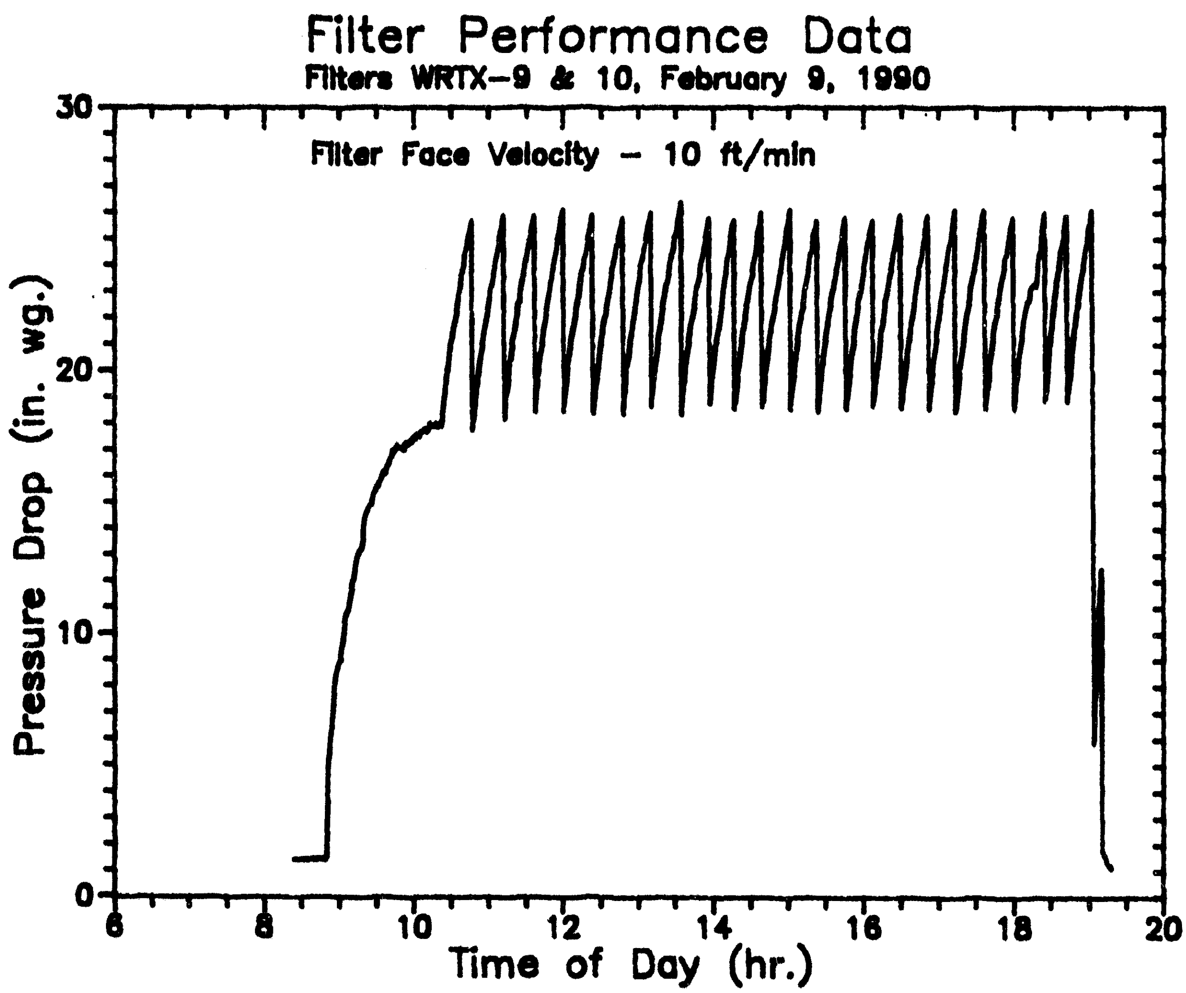


Operation Notes for February 5, 1990:

8 hour test, includes startup and shutdown

ΔP Trigger = 26.0" WC

Pulse Cleaning - 290 psig/0.1 sec

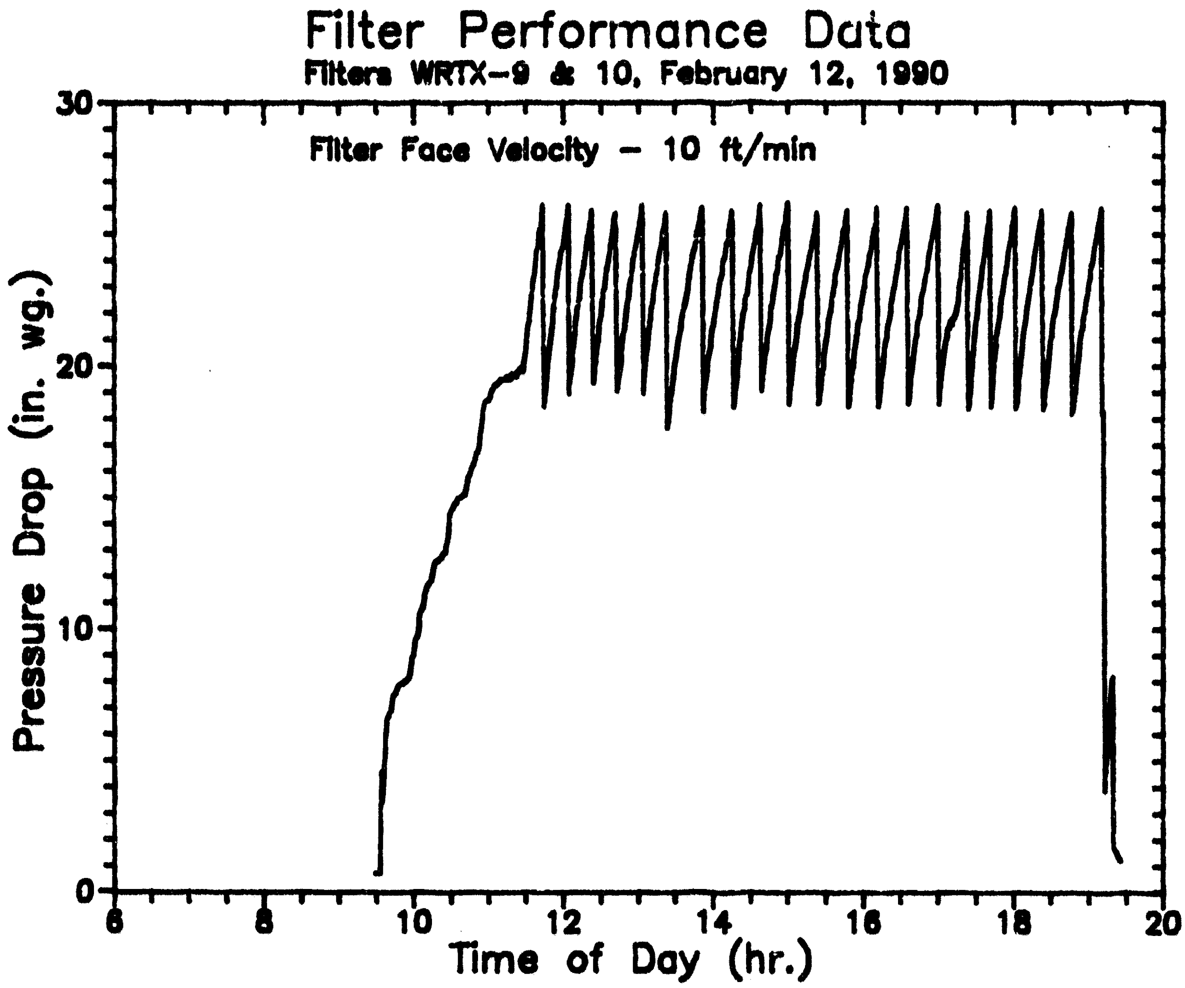


Operation Notes for February 9, 1990:

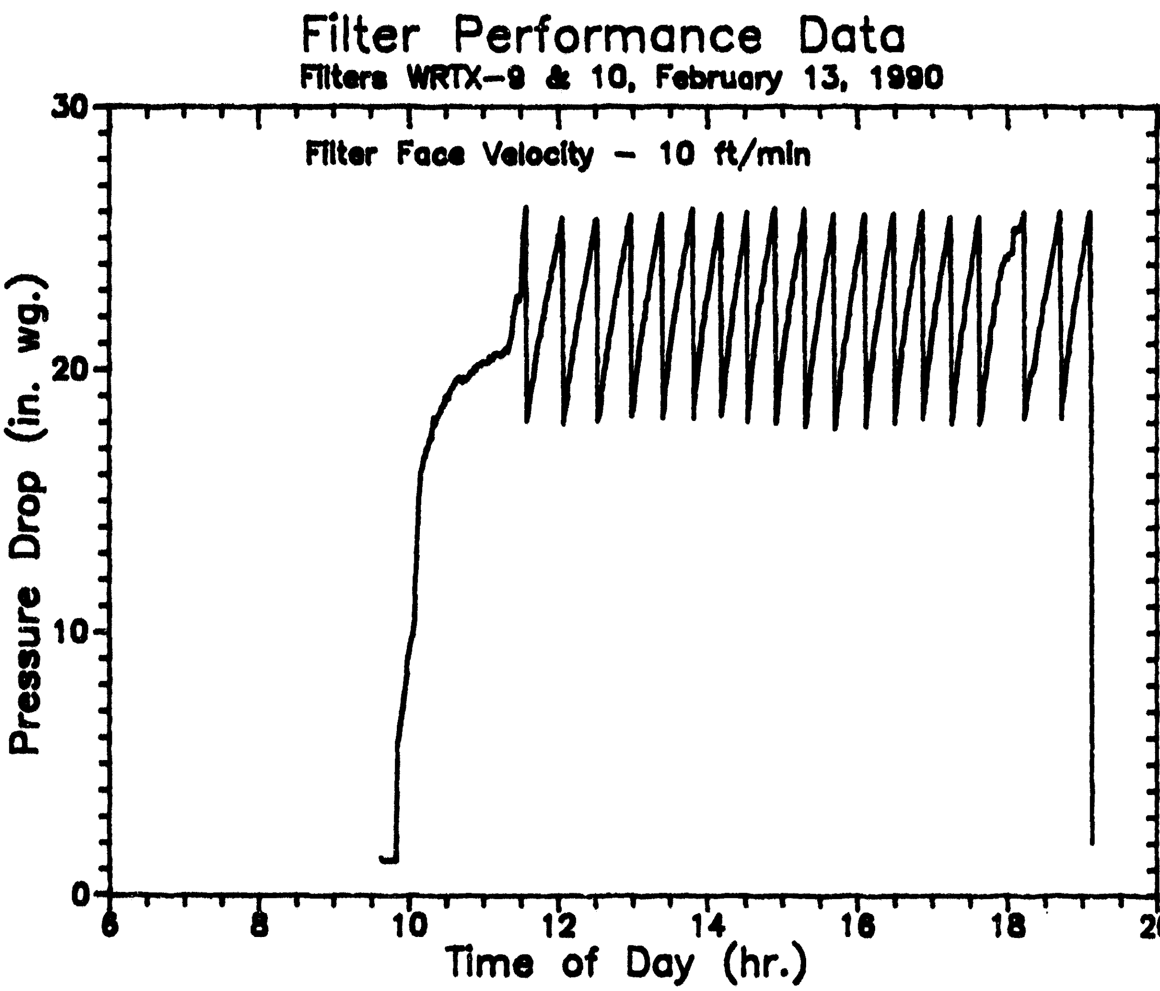
12 hour test, includes startup and shutdown

ΔP Trigger = 26.0" WC

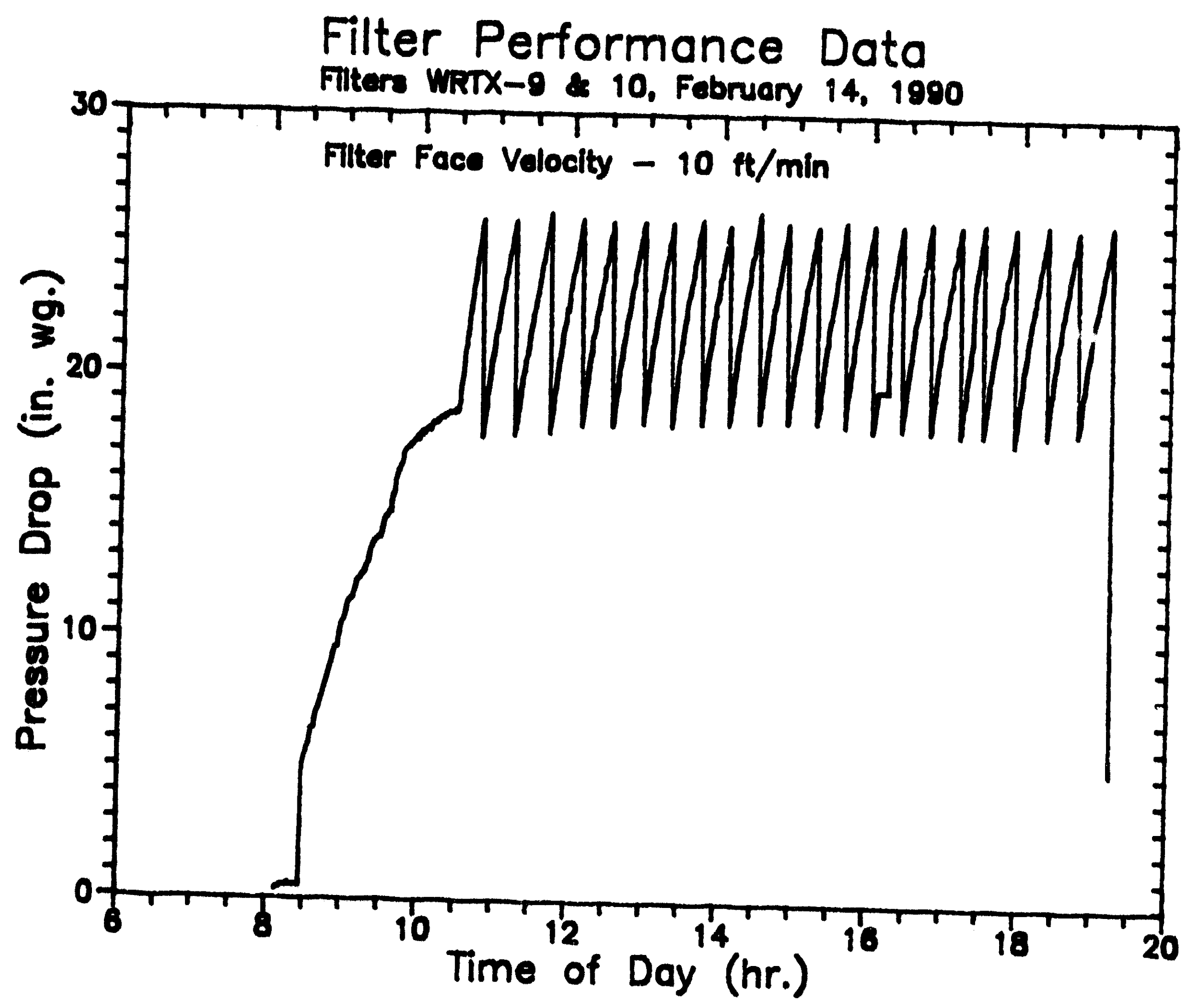
Pulse Cleaning - 290 psig/0.1 sec



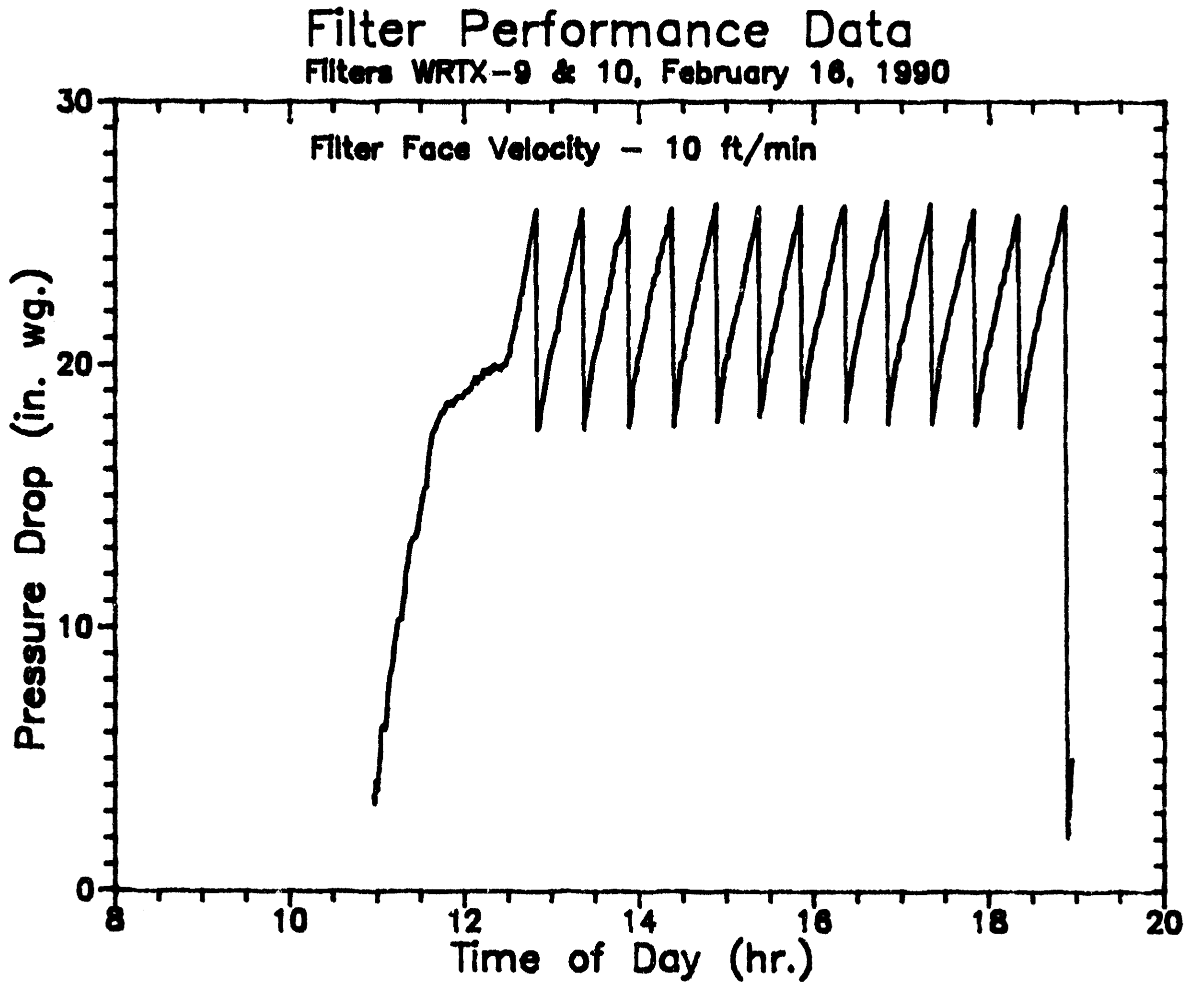
Operation Notes for February 12, 1990:
12 hour test, includes startup and shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for February 13, 1990:
12 hour test, includes startup and shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for February 14, 1990:
12 hour test, includes startup and shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

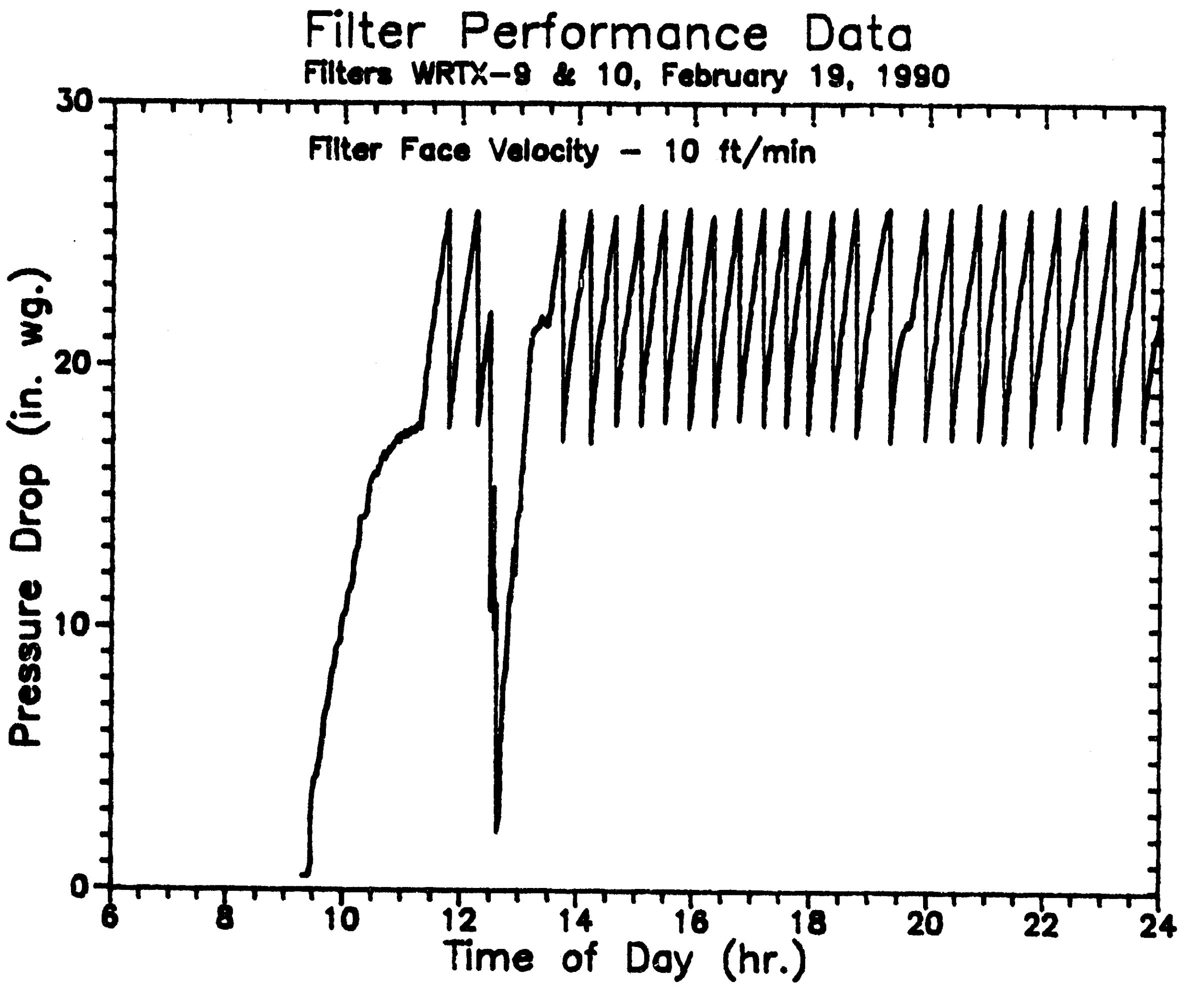


Operation Notes for February 16, 1990:

12 hour test, includes startup and shutdown

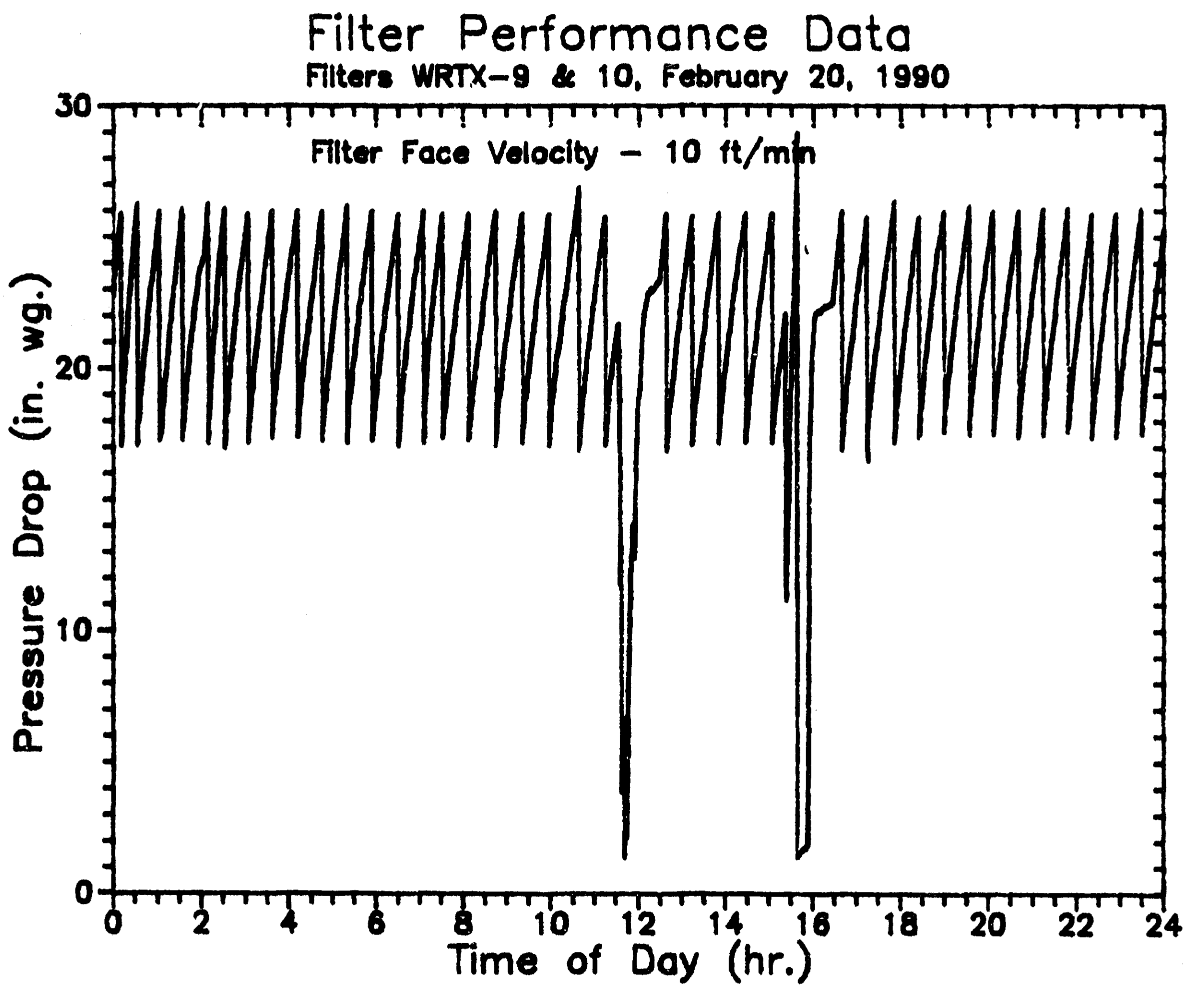
ΔP Trigger = 26.0" WC

Pulse Cleaning - 290 psig/0.1 sec

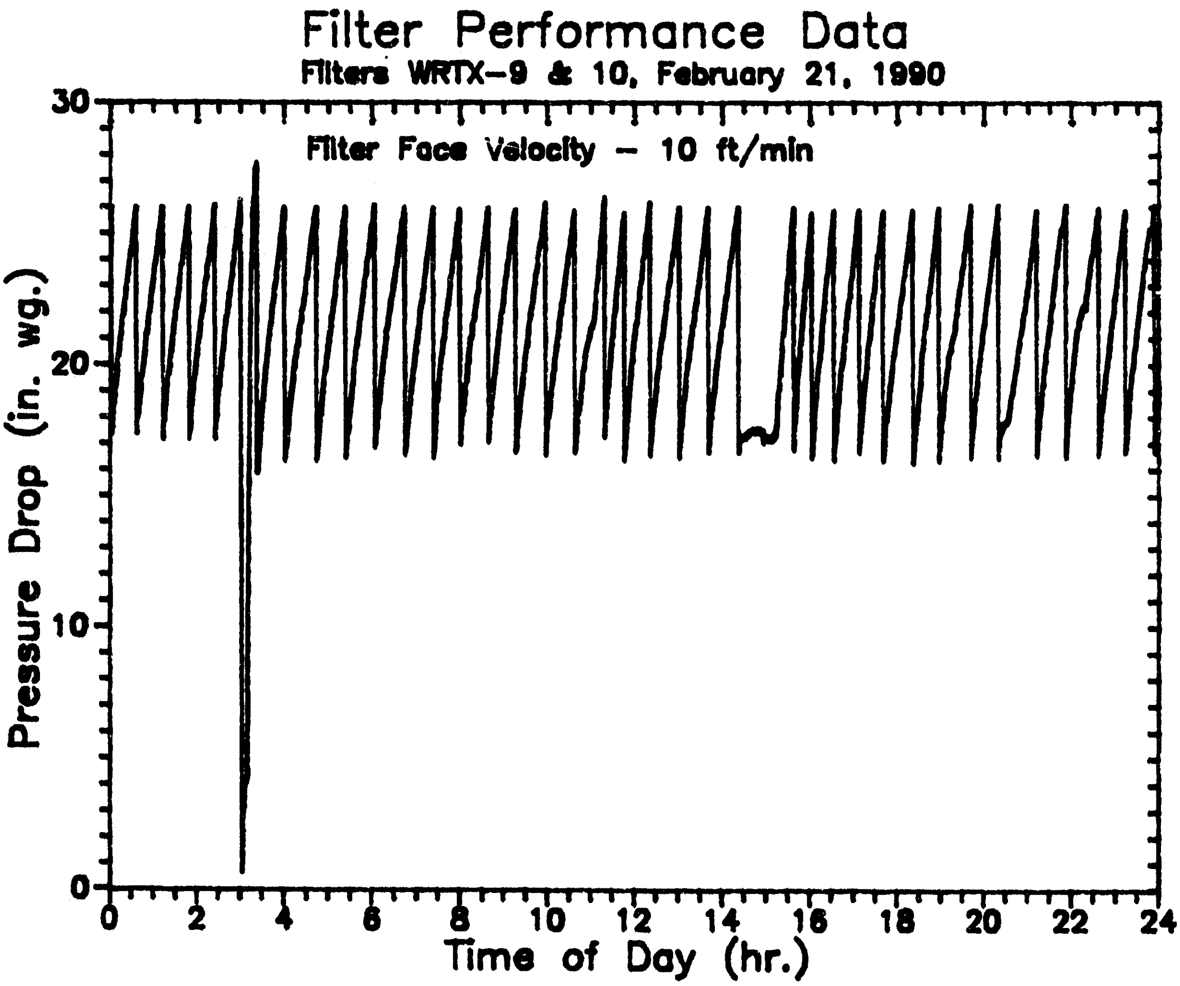


Operation Notes for February 19, 1990:

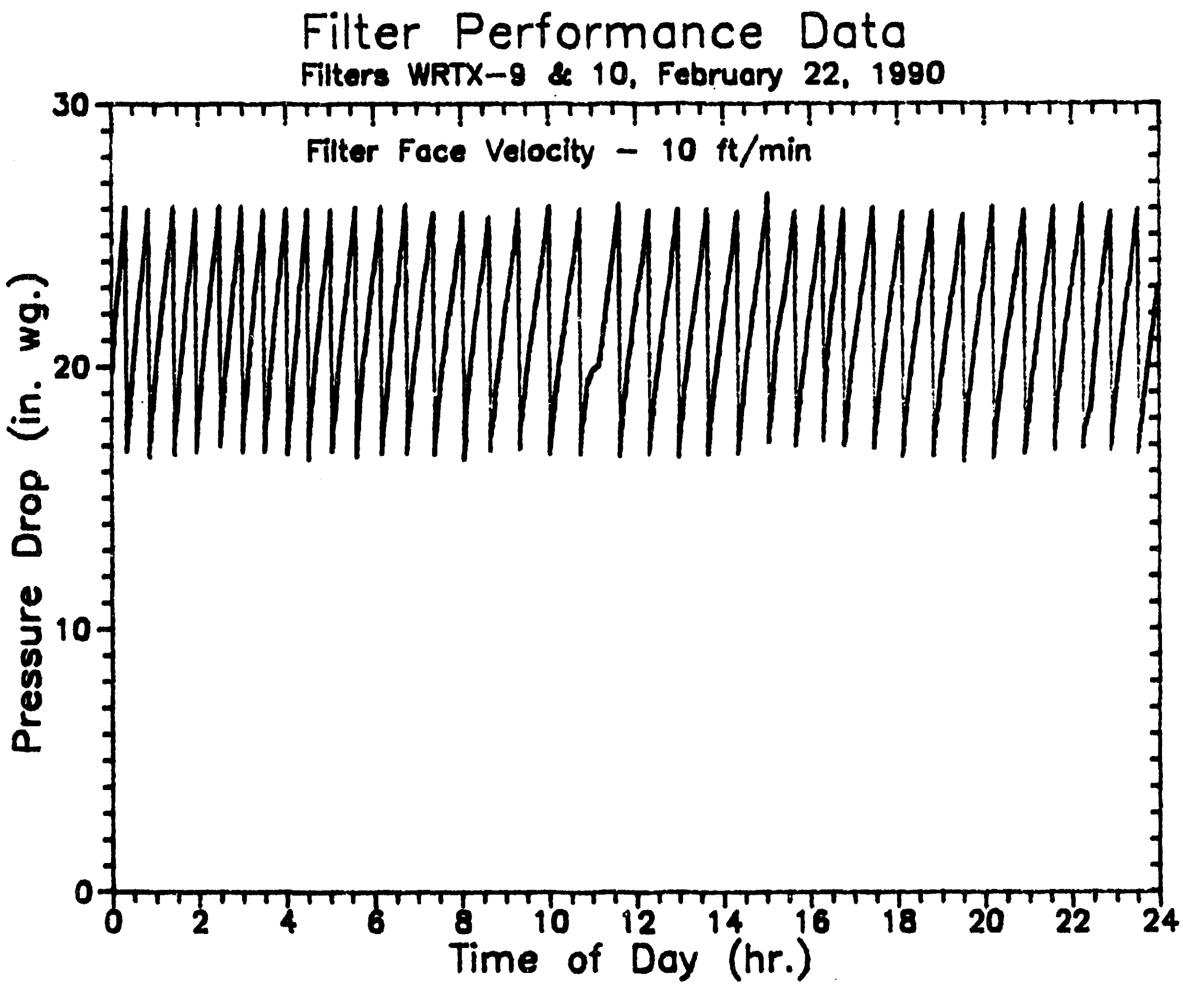
Start of week long test
1230 Flame out - unscheduled
Restarted
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



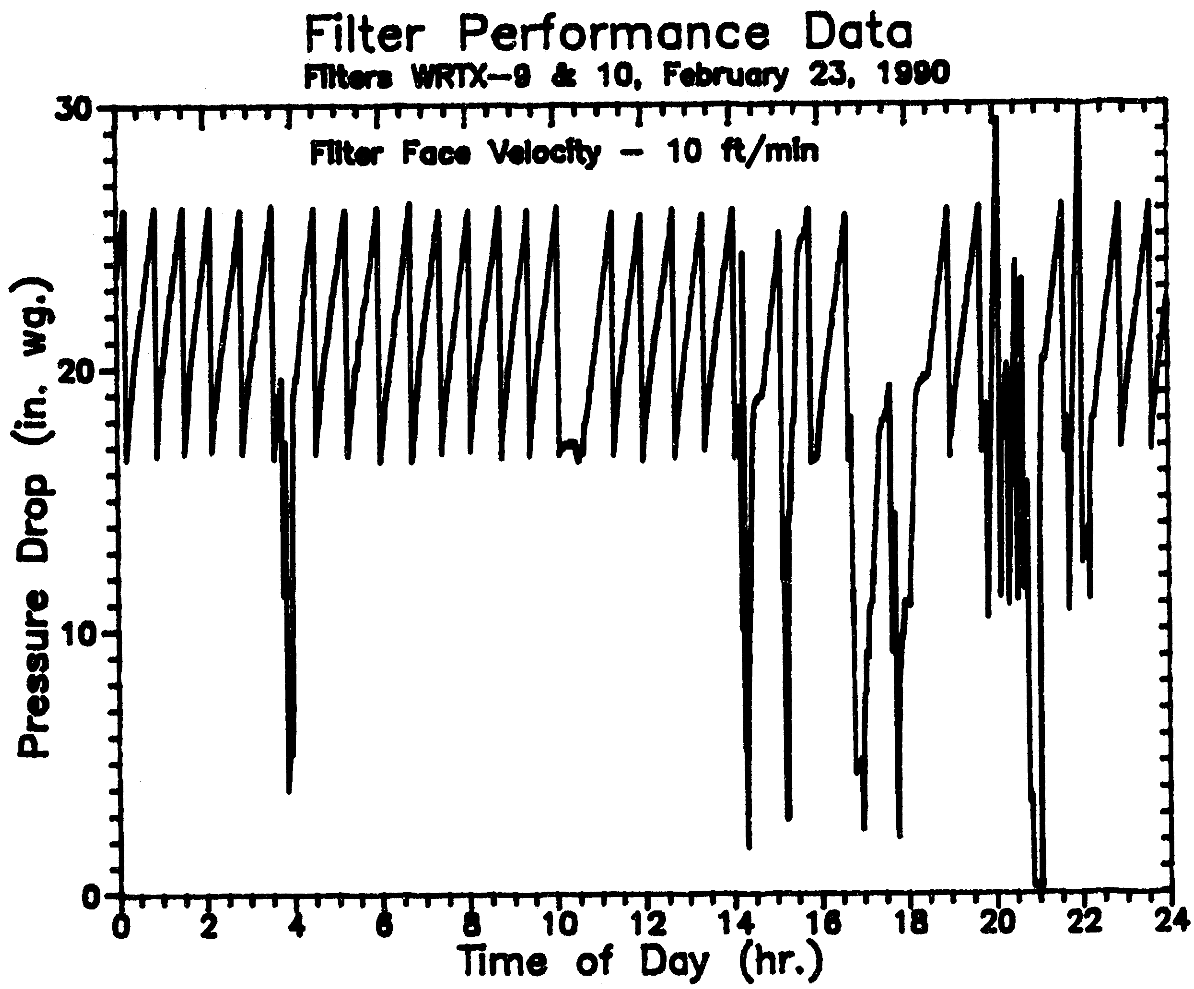
Operation Notes for February 20, 1990:
1130 Flame out - unscheduled
1520 Flame out - unscheduled
Restarted
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for February 21, 1990:
0300 Flame out - unscheduled
Restart
1430 Dust Added
Pulse Cleaning - 290 psig/0.1 sec



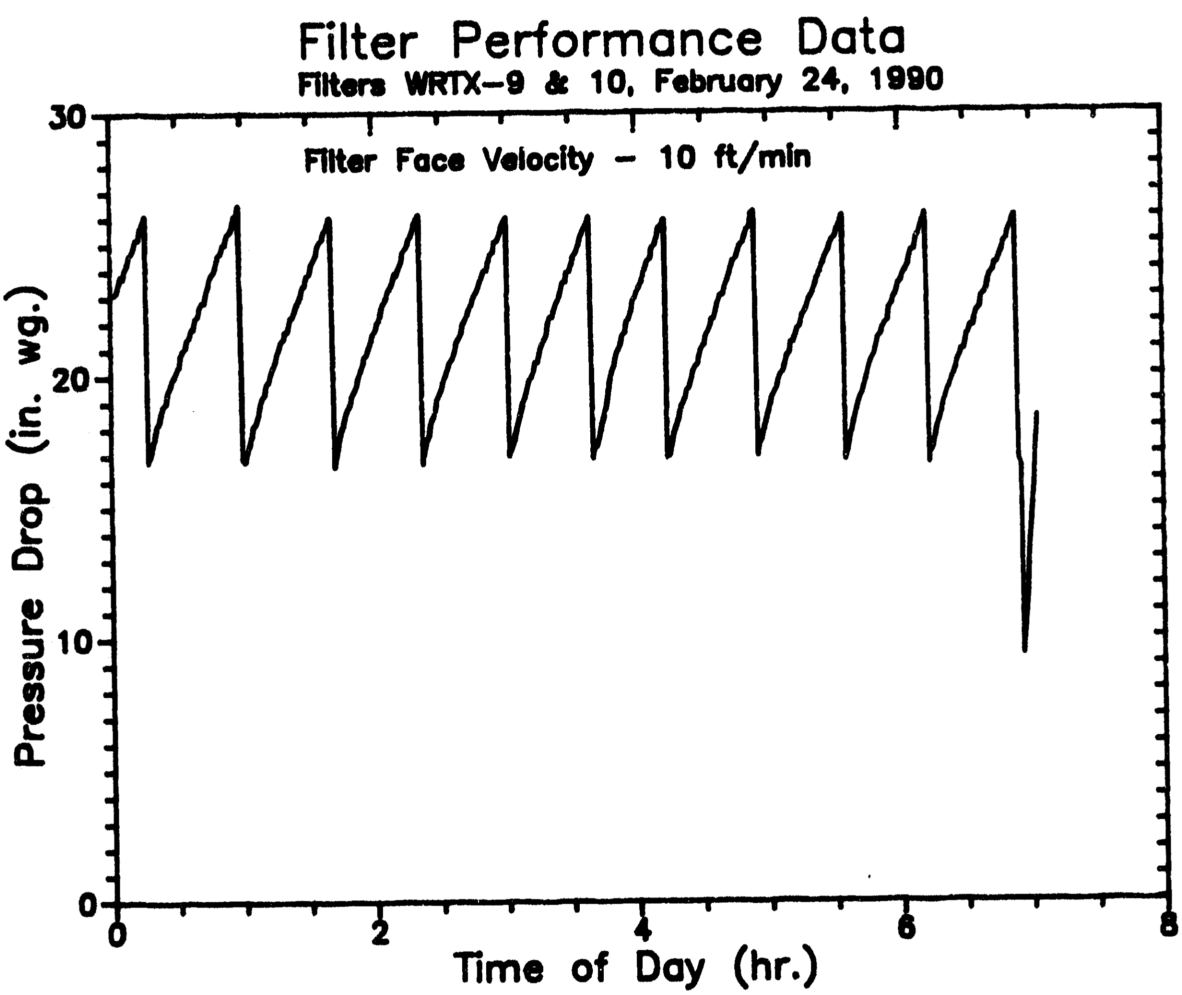
Operation Notes for February 22, 1990:
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



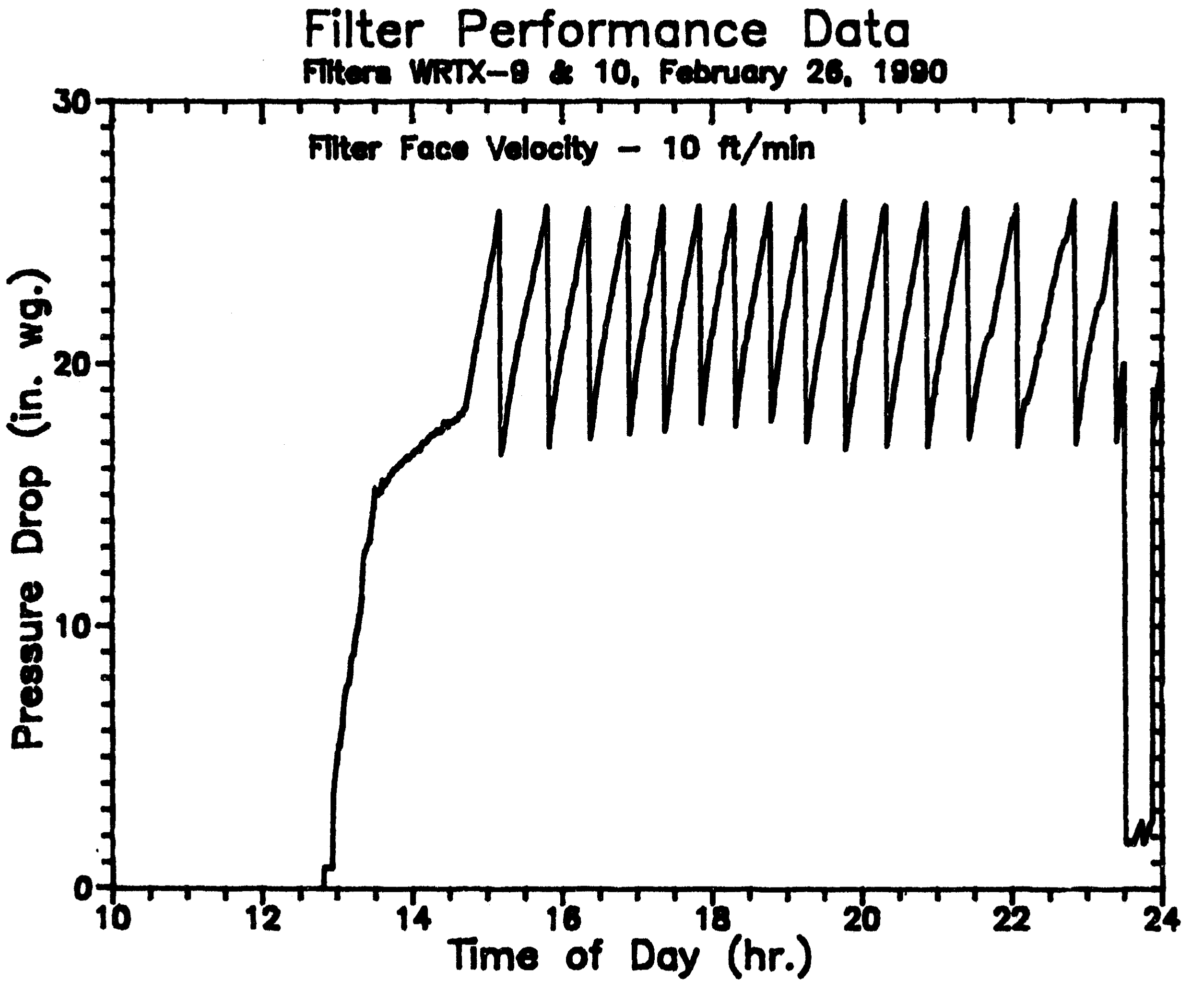
Operation Notes for February 23, 1990:

0345 Flame out - unscheduled
Restart
1000 Dust Added
1415 - 2200 Multiple Flame outs - unscheduled
Restarted each time
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

Filter Performance Data

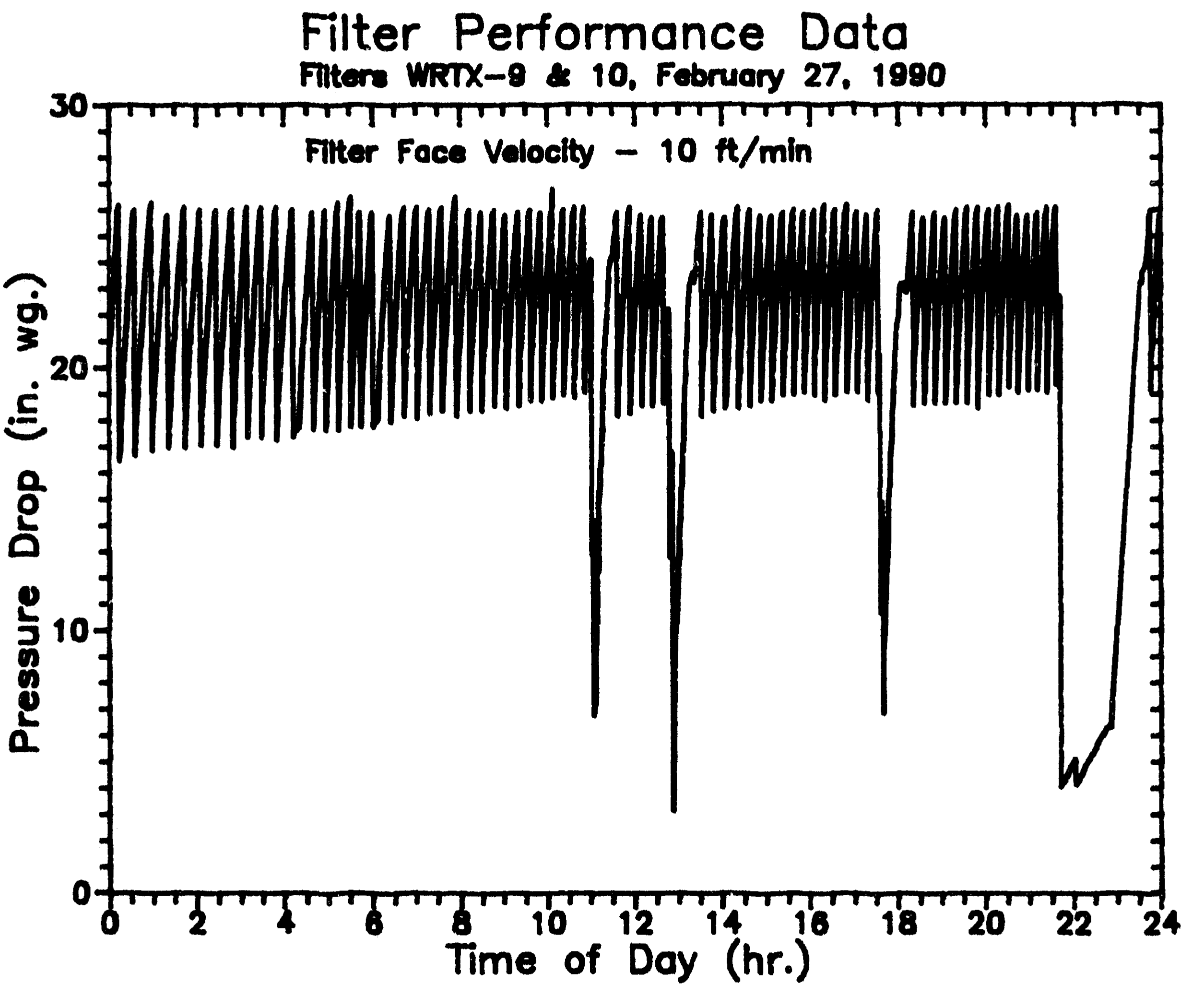


Operation Notes for February 24, 1990:
End of week long test
0700 scheduled shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

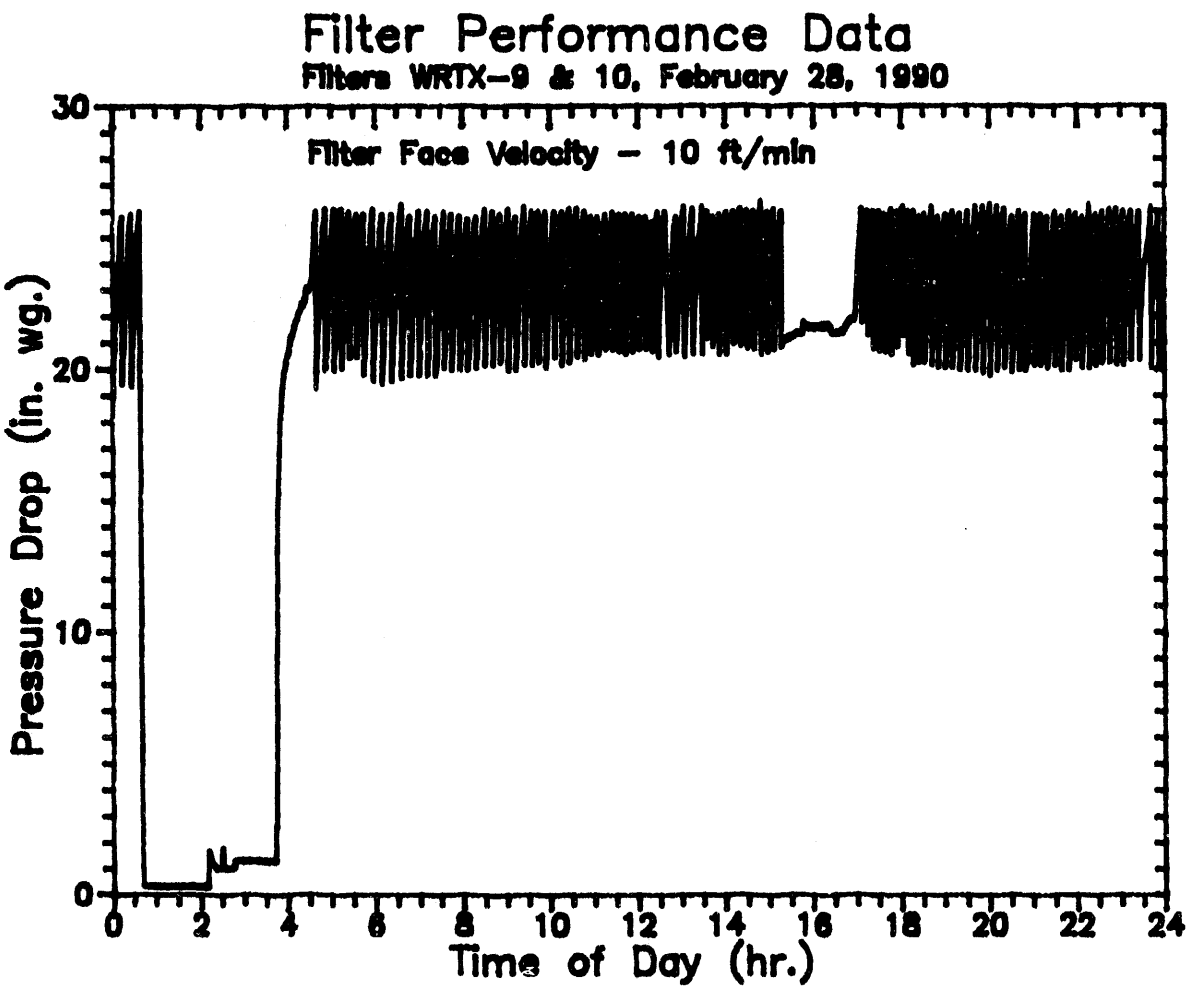


Operation Notes for February 26, 1990:

Start of week long test
Changed to Grimethorpe PFBC flyash for dust injection
2330 Flame out - unscheduled
Restart
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec

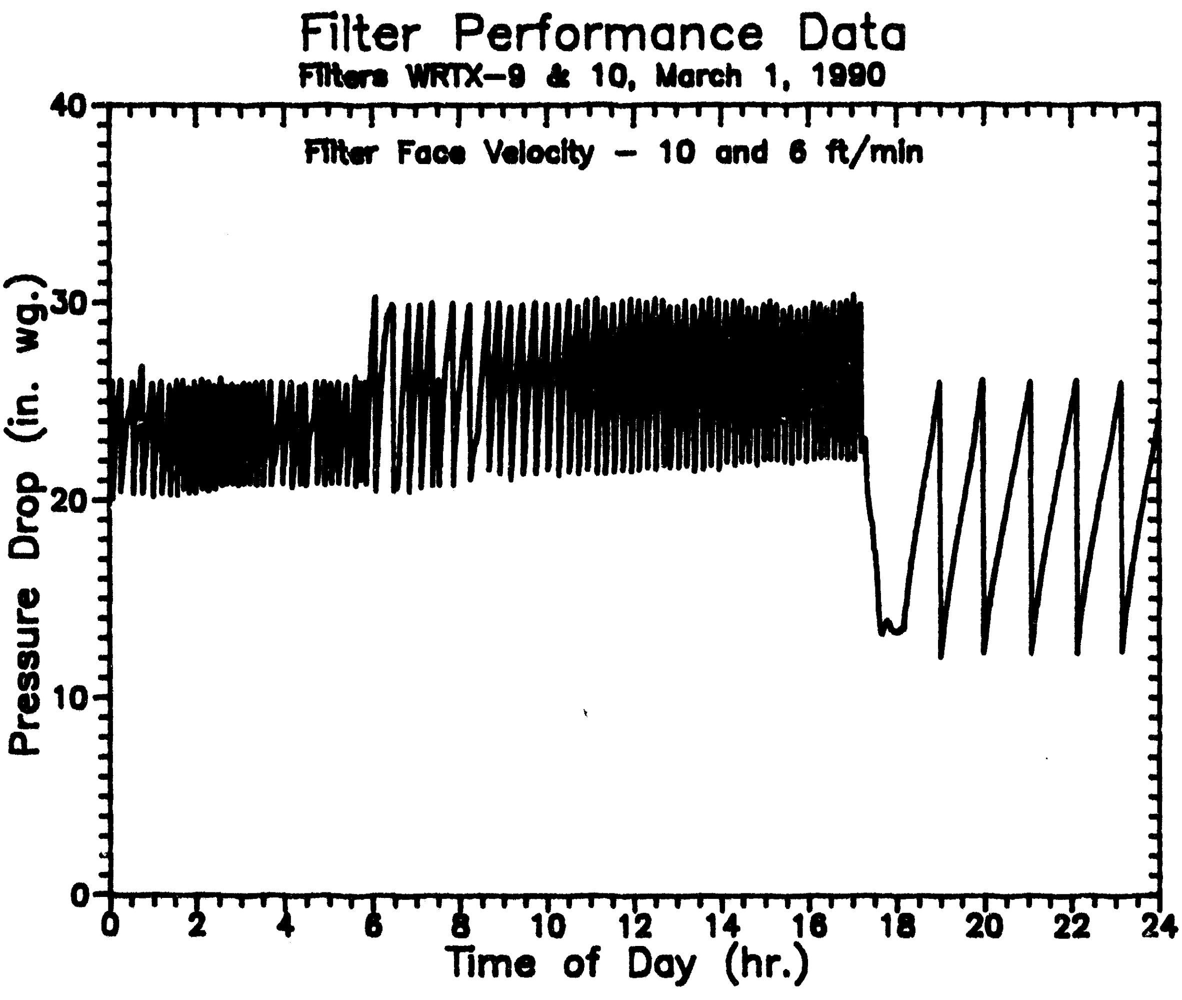


Operation Notes for February 27, 1990:
1100-2145 Multiple Flame outs - unscheduled
Restarted each time
ΔP Trigger = 26.0" WC
Pulse Cleaning - 290 psig/0.1 sec



Operation Notes for February 28, 1990:

0040 Flame out - unscheduled
Temperature controller malfunction - repaired
Restarted
1515 Dust Added
ΔP Trigger = 26.0" WC
Pulse Cleaning - 305 psig/0.1 sec

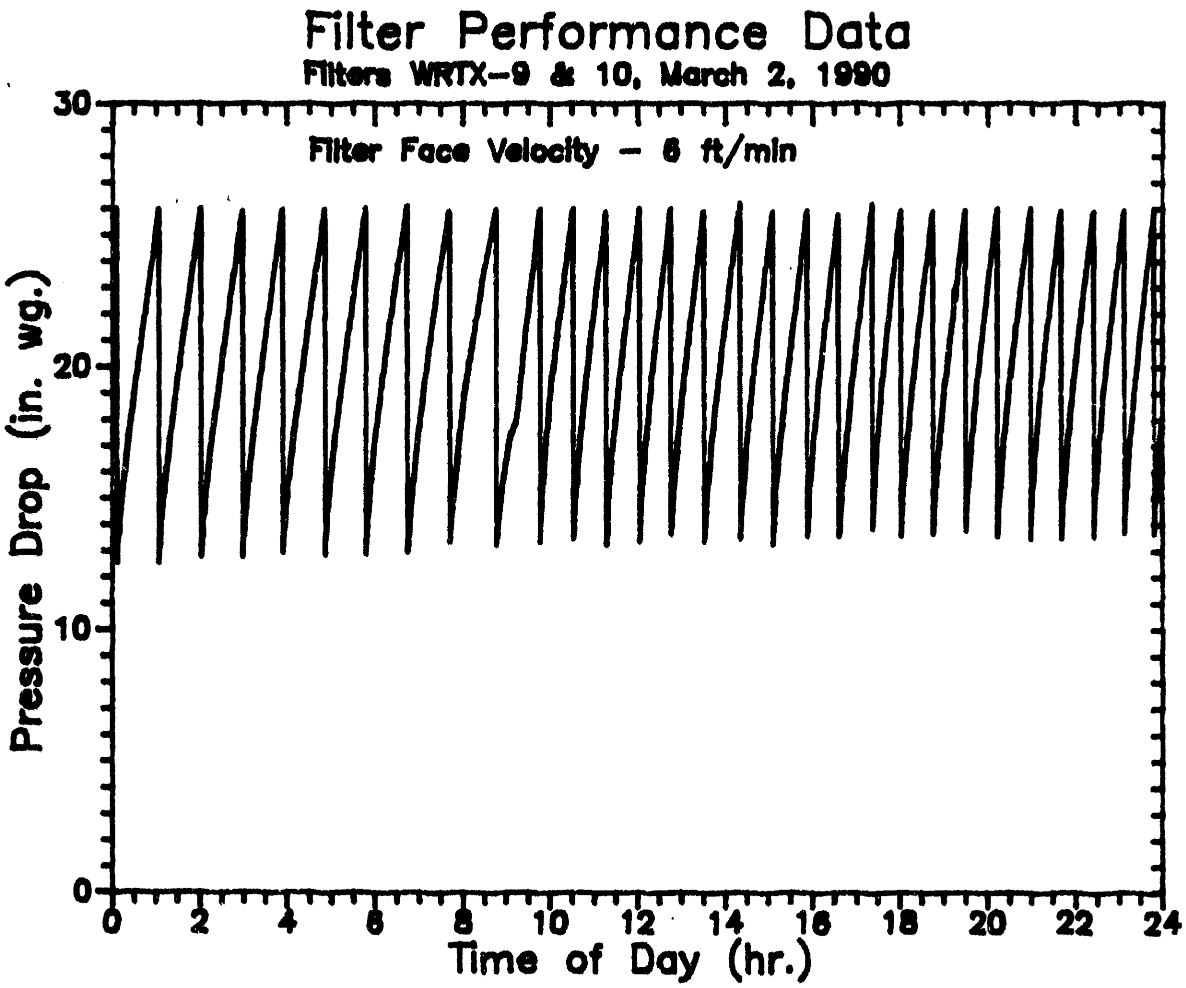


Operation Notes for March 1, 1990:

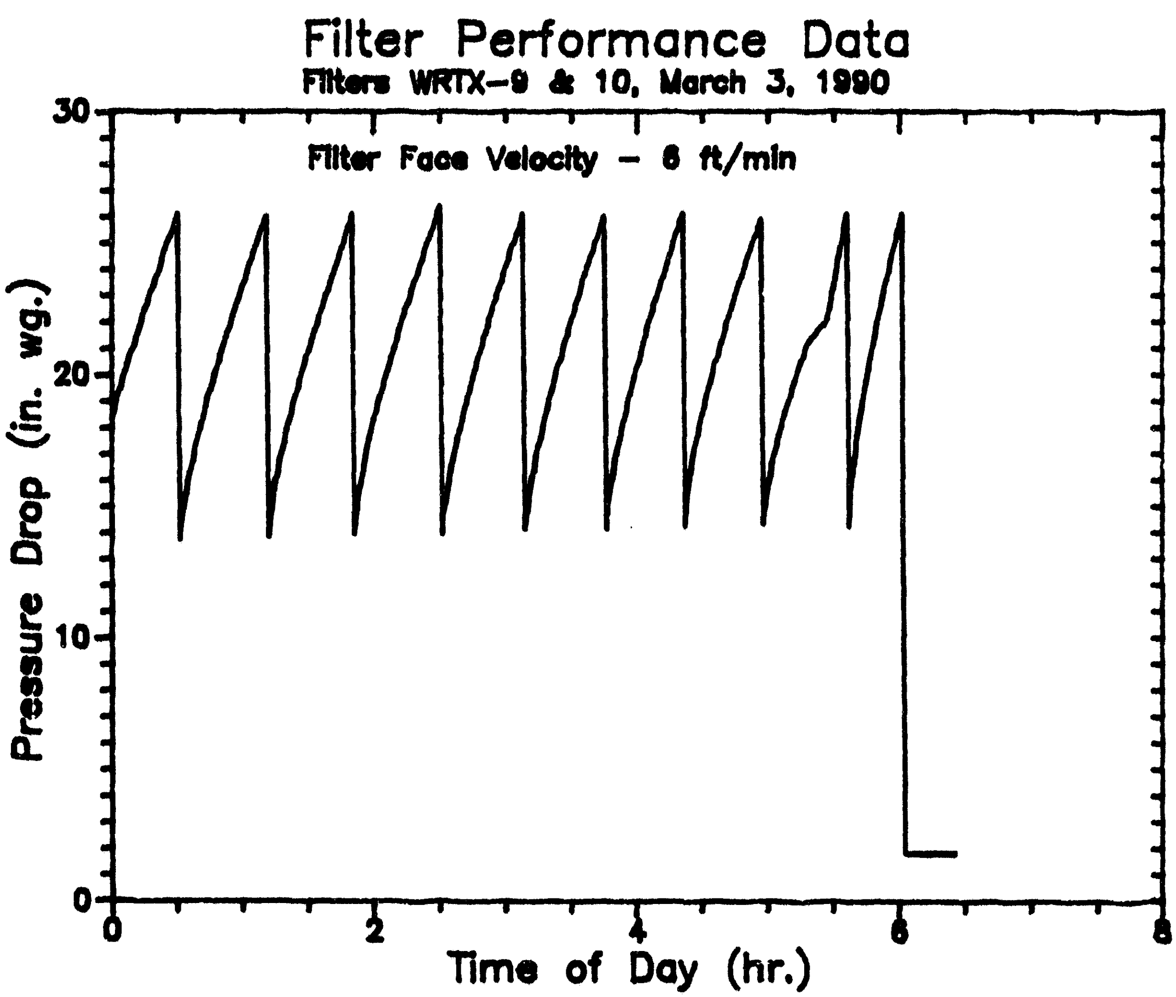
0600 Changed ΔP Trigger to 30.0 "WC

1800 Conditions changed from 10 ft/min to 6 ft/min face velocity, ΔP Trigger changed back to 26.0" WC

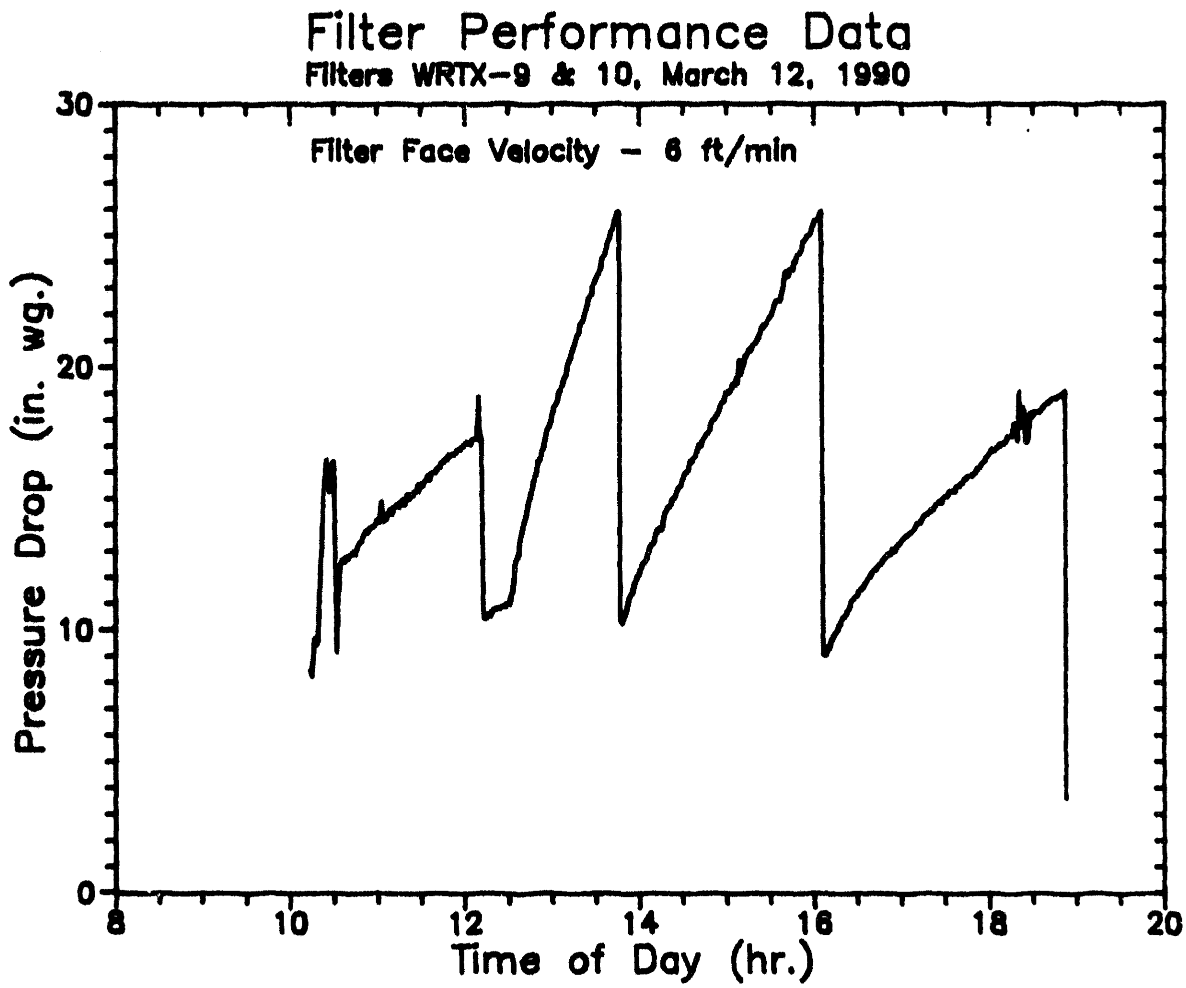
Pulse Cleaning - 315 psig/0.1 sec



Operation Notes for March 2, 1990:
ΔP Trigger = 26.0" WC
Pulse Cleaning - 315 psig/0.1 sec



Operation Notes for March 3, 1990:
End of week long test
0600 scheduled shutdown
ΔP Trigger = 26.0" WC
Pulse Cleaning - 315 psig/0.1 sec



Operation Notes for March 12, 1990:
Dust out concentration higher than usual
Shutdown for inspection
ΔP Trigger = 26.0" WC
Pulse Cleaning - 315 psig/0.1 sec

APPENDIX E

ASSESSMENT OF CROSS FLOW FILTER MOUNTING DESIGN

FILTER SYSTEM STATUS

1.0 SUMMARY

Two cross flow filter elements were successfully tested under simulated PFBC conditions for over 1300 hours, thus representing the longest successful test campaign on this barrier filter technology. The filter operation was terminated when the dust loading on the filter outlet increased up to 100 ppm and the system permeability profiles suggested that a breach had developed on at least one of the elements. Post test inspection of the filter system revealed that one of the elements had developed a longitudinal crack on the ceramic flange, and the flange corners of both elements were crushed by the metal clamping plates. Neither filter showed any signs of delamination failure which had historically plagued the first generation of cross flow filters.

A comprehensive fractographic evaluation and a mechanical design analysis were undertaken to investigate and correct the cause of this failure. The flange failure [illegible]ttributed to three principal deficiencies in the current [illegible]g apparatus, namely,

- Non-uniform loading of the ceramic flange imparting point or line stresses which ultimately lead to brittle fracture failure,

- Relaxation of the filter clamping bolts causing up to 90% reduction of the seating forces on the filter and gasket after about 1000 hours of hot testing such that the element could either vibrate, or in the extreme, levitate during reverse pulse cleaning,

- Imposition of differential contraction stresses on the ceramic flange during shutdown periods caused by the accumulation of dust in the cavities outside the element seating area.

A retrofit design has been proposed to eliminate the deficiencies in the current mounting apparatus. It is recommended that this retrofit be implemented on the PFBC simulator facility and other cross flow filter prototypical test facilities to ensure long term operational reliability of this cleanup system.

2.0 DESCRIPTION OF CURRENT SYSTEM

The PFBC long term durability test rig can accommodate up to four commercial scale cross flow filter elements which are distributed on two metal plenum pipes suspended from an uncooled metal tubesheet. During the 1304 hours of simulated PFBC testing only one active plenum with two filter elements was used. The second plenum was installed with blank metal plates covering the filter seating areas of the plenum fixtures. The following discussion provides background information on the filter elements and the current assembly procedure.

2.1 Element Geometry

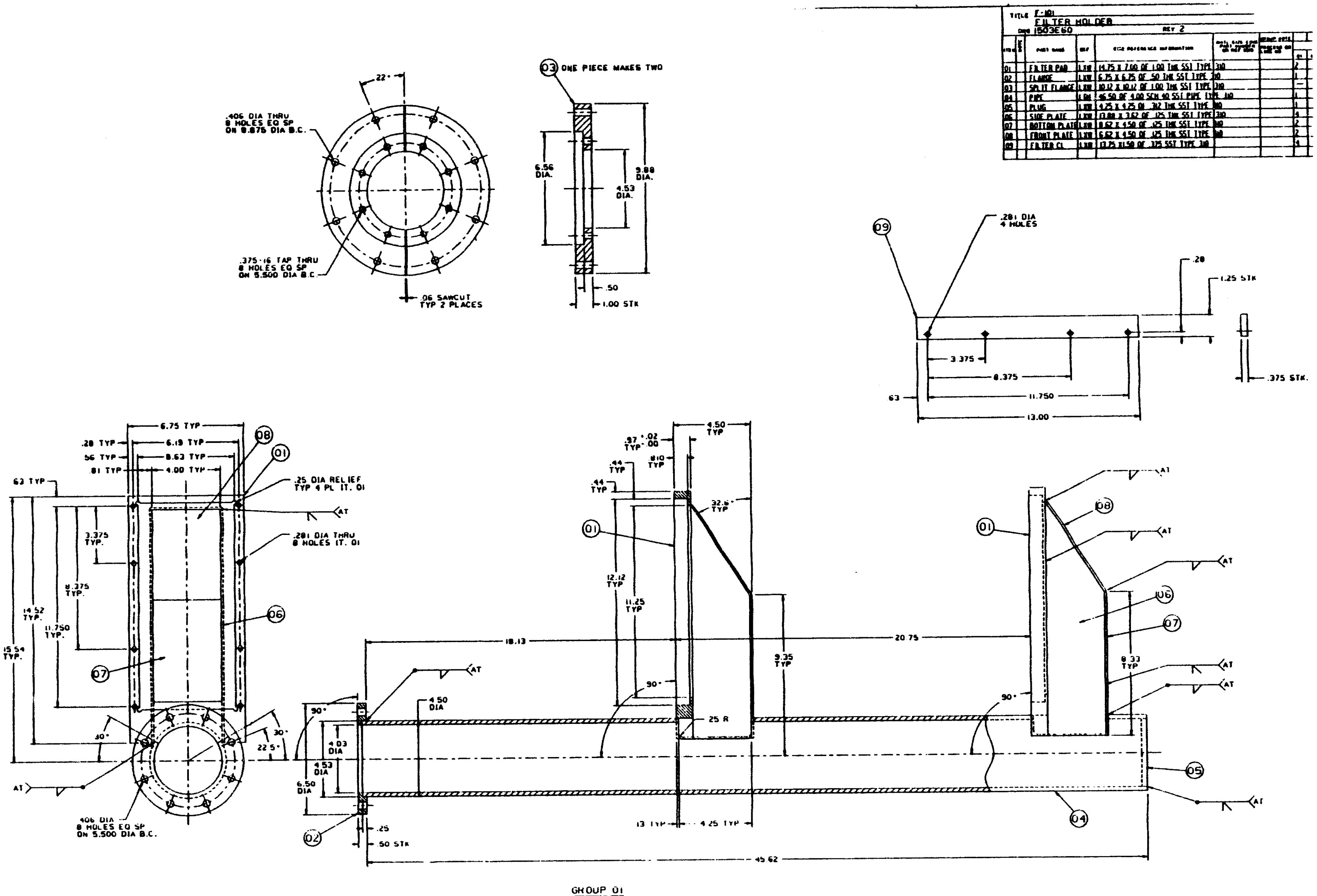
The two filter elements tested in the PFBC rig, labelled WRTX-9 and WRTX-10, featured the use of the mid rib bond and radiused flanges for enhancing the mechanical strength of the ceramic flange and filter body. Prior to installation these elements were characterized for their permeability at ambient conditions and found to be within the Westinghouse acceptance criteria for pressure drop, namely less than 5 in. wc. at a face velocity of 10 fpm. The elements were dimensionally checked to verify fitup inside the metal fixture. During this inspection one of the elements was found to be oversized along the length, causing an interference with the fixture. Therefore a small section of the end plate 5 inches wide by 0.5 inch high and 0.2 inch deep was cut using a diamond saw. Per normal practice the seams between the individual plates were painted with a ceramic glue as a precautionary measure against dust infiltration through any gaps left in the manufacturing process. In addition the clean side channel rows on the two outer edges of the element (near the 12x4 end plates) were filled with the ceramic cement because these channels are otherwise blocked by the gasket material.

The flanges of the two elements were inspected to verify that the radiused fillet on each flange met the Westinghouse specification and that there were no residual sharp edges or corners on the flange and fillet surface.

2.2 Element Mount Configuration

Figure E.1 is an engineering drawing of a typical element mount configuration. The element rests on a stainless steel ledge which is welded to the support fixture. After installation the ceramic flanges on the element are nearly flush with the upper surface of the fixture. The filter flanges are clamped to the fixture by means of stainless steel plates, 13 inches long by 1.25 inches wide and 0.375 inch thick. Each plate is held by four 0.25 inch 316 stainless steel bolts.

Figure E.2 shows an end view of a fully assembled "ideal" filter element (i.e., an element that meets all dimensional tolerances). The clamping plate would rest flat and parallel with the top surface of the flange with a compliant layer of gasketing material between the metal and the ceramic. Note also the position of the compressed gasket under the filter which functions as a dust seal during filtration (forward flow) periods and a partial gas seal during any pulse cleaning event (reverse flow).



01		FILTER PAD	LXW	14.75 X 7.00 OF 1.00 THK SST TYPE 310			2
02		FLANGE	LXW	6.75 X 6.75 OF .50 THK SST TYPE 310			1
03		SPLIT FLANGE	LXW	10.12 X 10.12 OF 1.00 THK SST TYPE 310			—
04		PIPE	LGH	46.50 OF 4.00 SCH 40 SST PIPE TYPE 310			1
05		PLUG	LXW	4.25 X 4.25 OF .312 THK SST TYPE 310			1
06		SIDE PLATE	LXW	13.88 X 3.62 OF .125 THK SST TYPE 310			4
07		BOTTOM PLATE	LXW	8.62 X 4.50 OF .125 THK SST TYPE 310			2
08		FRONT PLATE	LXW	6.62 X 4.50 OF .125 THK SST TYPE 310			2
09		FILTER CL	LXW	13.75 X 1.50 OF .375 SST TYPE 310			4

TITLE F-101 FILTER HOLDER, DWG 1503E60, REV 2

Figure E.1 - Typical Element Mount Configuration

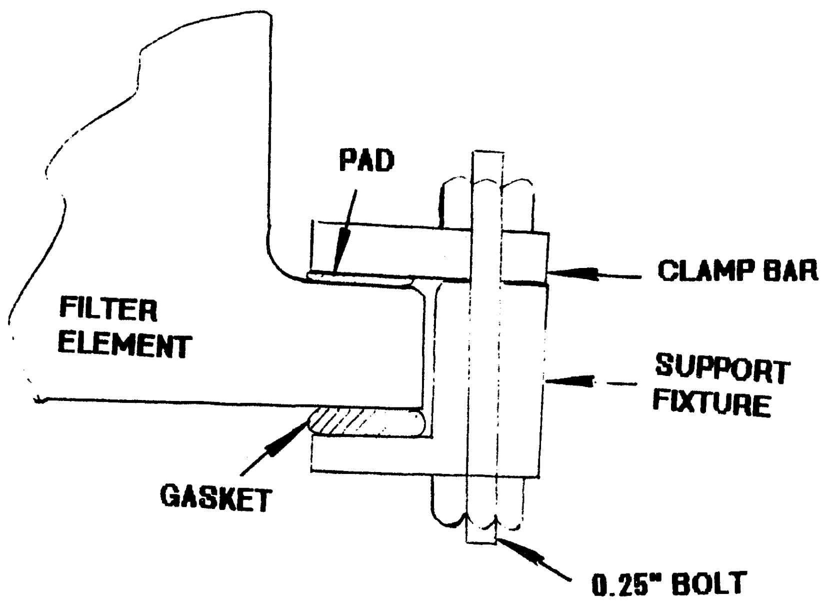


Figure E.2 - End View of an "Ideal" Assembled Filter Element

2.3 Gasketing Materials

As shown above there are two gasketing materials used for fixing the ceramic element inside the metal fixture. The top layer is essentially a compliant pad to fill the asperities on the ceramic flange surface. The material used for this purpose on the PFBC test rig was a 0.15 inch thick layer of Interam Brand Mat Mount made by the 3M Company. This material is made of alumina silicate fibers interspersed with an intumescent or heat expandable layer of vermiculite. While this material has found commercial use as a gasket on catalytic converters, the upper temperature limit is only 1300°F. Figure E.3 shows a photograph of an Interam pad after exposure to a temperature of 1600°F for 8 hours. Note that the pad completely disintegrates into powder after exposure to PFBC type conditions, which indicates that the material has marginal resilient properties and, at best, only provides a residual granular layer sandwiched between the clamping plate and the ceramic flange.

The bottom gasket, on which the element rests and which actually functions as the dust seal, is a Westinghouse assembled pad made of 3M's commercially available Nextel fabric and a silica-boria-alumina fiber blanket, shown in Figure E.4. After exposure to the PFBC simulator conditions for 1304 hours and 2068 pulse cleaning cycles, there was virtually no damage or distortion sustained by this gasket. The load-deflection characteristics for the unused and the exposed gasket, as measured on a standard testing machine, were found to be identical; thus indicating that the gasket does not experience any long term deterioration in its resiliency properties.

2.4 Assembly Methods

During assembly the dust seal gasket is first installed on the metal ledge inside the fixture. The filter is then seated on the dust seal and loaded with a 400 lbs. weight placed on top of the element,

Figure E.3 - Interam Gasket After Exposure to 1600°F for 8 Hours.

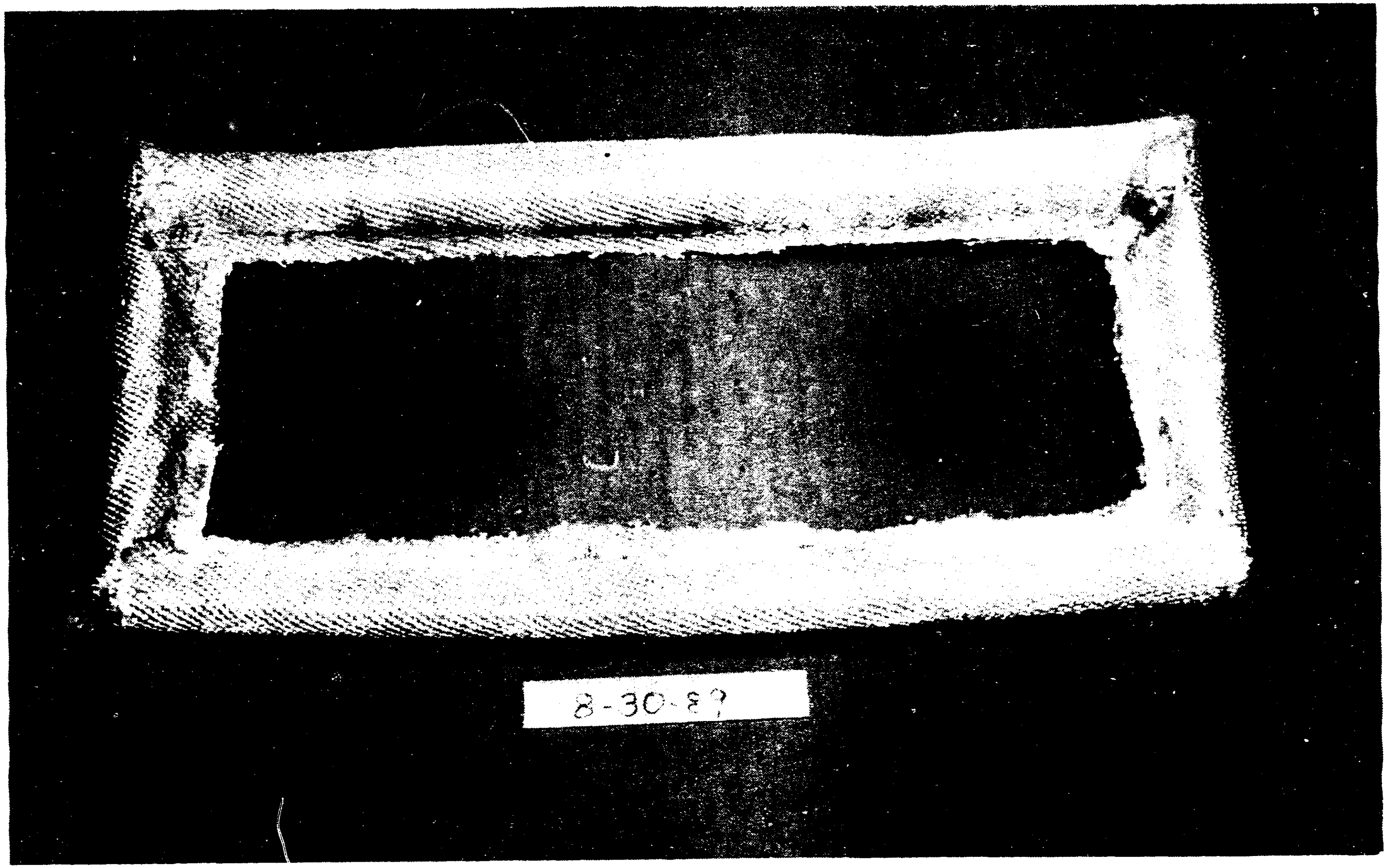


Figure E.4 - Photograph of Nextel Reinforced Fiber Blanket Pad Used as Dust Seal.

thereby uniformly compressing the gasket. Two strips of Interam pads are then placed on the ceramic flanges which are then covered by the clamping plates. The eight bolts are assembled finger-tight and subsequently torqued to 15 in-lbs. The weights are now removed thus providing a total nominal gasket seating force of 2430 lbs.

Each element is then mounted with side compression plates to provide precautionary reinforcement against element delamination. These plates are made of 4 inch by 12 inch by 0.25 inch thick 316 stainless steel plates, which are assembled using metal tie-rods to provide a compressive force of approximately 1400 lbs. Six ceramic rods are then fitted into corresponding slots on the sides of the parallel plates, these rods are held in place by compression collars. After assembling the ceramic rods the metal rods are removed. Interam pads are used as cushioning material between the metal end plates and the ceramic side walls of the filter. Figure E.5 shows a photograph of a typical fully assembled filter element.

3.0 ASSESSMENT OF SYSTEM RELIABILITY

The PFBC simulator rig containing the two ceramic filter elements was operated for a total of 1304 hours. The system was subjected to 43 warm standby to startup cycles and 6 cold shutdown to startup cycles. The filter pressure vessel was first disassembled at the end of the 1304 hours when the dust mass loadings at the exit of the filter showed a dramatic increase from a nominal 3 ppm to over 100 ppm. This excursion was diagnosed as a serious breach in at least one of the filters, hence the testing was thereafter discontinued. The results of the operational analysis, system inspection and failure analysis are reported below.

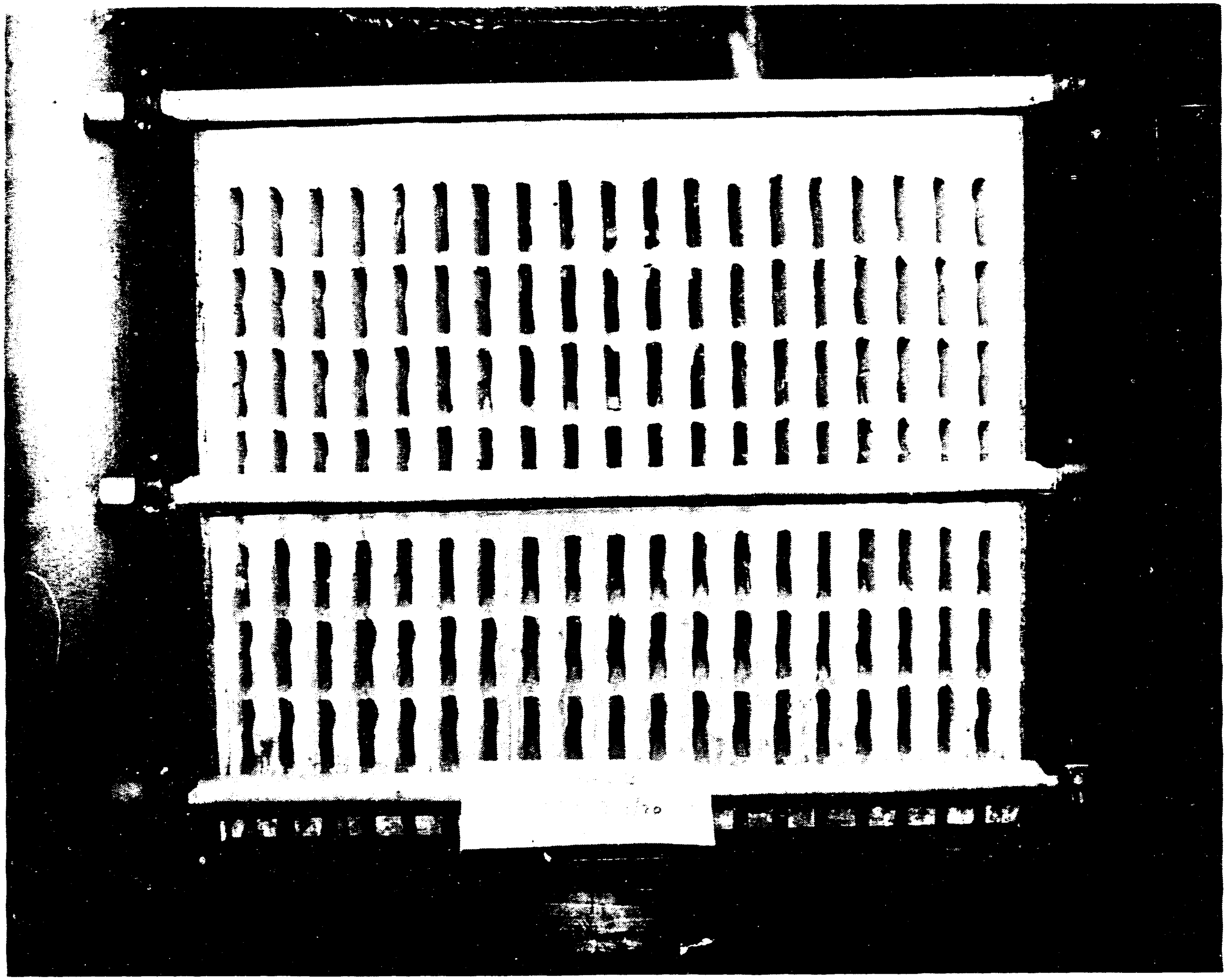


Figure E.5 - Photograph of an Assembled Filter Element

3.1 Operational Analysis

The test campaign of 1304 hours represented the longest successful test exposure of cross flow filters to the high temperature and high pressure PFBC conditions. During the first 1300 hours of testing the system operated as a barrier filter releasing trace quantities of PFBC dust. The system pressure drop profiles showed consistent recovery after each pulse cleaning action, indicating efficient removal of dust cake. As discussed elsewhere in this report, the residual or baseline pressure drop showed a normal stabilization behavior at a value approaching 20% of the unused filter permeability. In an attempt to identify the sequence of operational events that may have triggered the filter failures, the operational behavior of the filter system was closely examined.

The outlet dust loading profiles for the entire test campaign are shown in Figure E.6, wherein the test interruptions are marked by the "S" and "C" symbols designating the warm startups (from a warm standby condition at 600°F temperature) and cold startups (from ambient temperature conditions) respectively. It is interesting to note in this chart that, with the exception of C7, all other startups were marked by a 10 ppm spike in the outlet loading (not necessarily dust) which subsides to less than 1 ppm within a few hours of hot operation. Figure E.7 shows a typical sequence of dust samples extracted by the sample probe following an interim shutdown. The initial samples consistently show a black patch on the filter paper, the samples subsequently become lighter and after about 10 hours show a faint smearing of the beige color which is characteristic of the PFBC ash. This trend in the dust profile indicates that the internal 316 stainless steel components develop corrosion scale from exposure to the damp shutdown conditions. After the system has been reheated the black scale is released. It is concluded that the 10 ppm spikes occurring over the

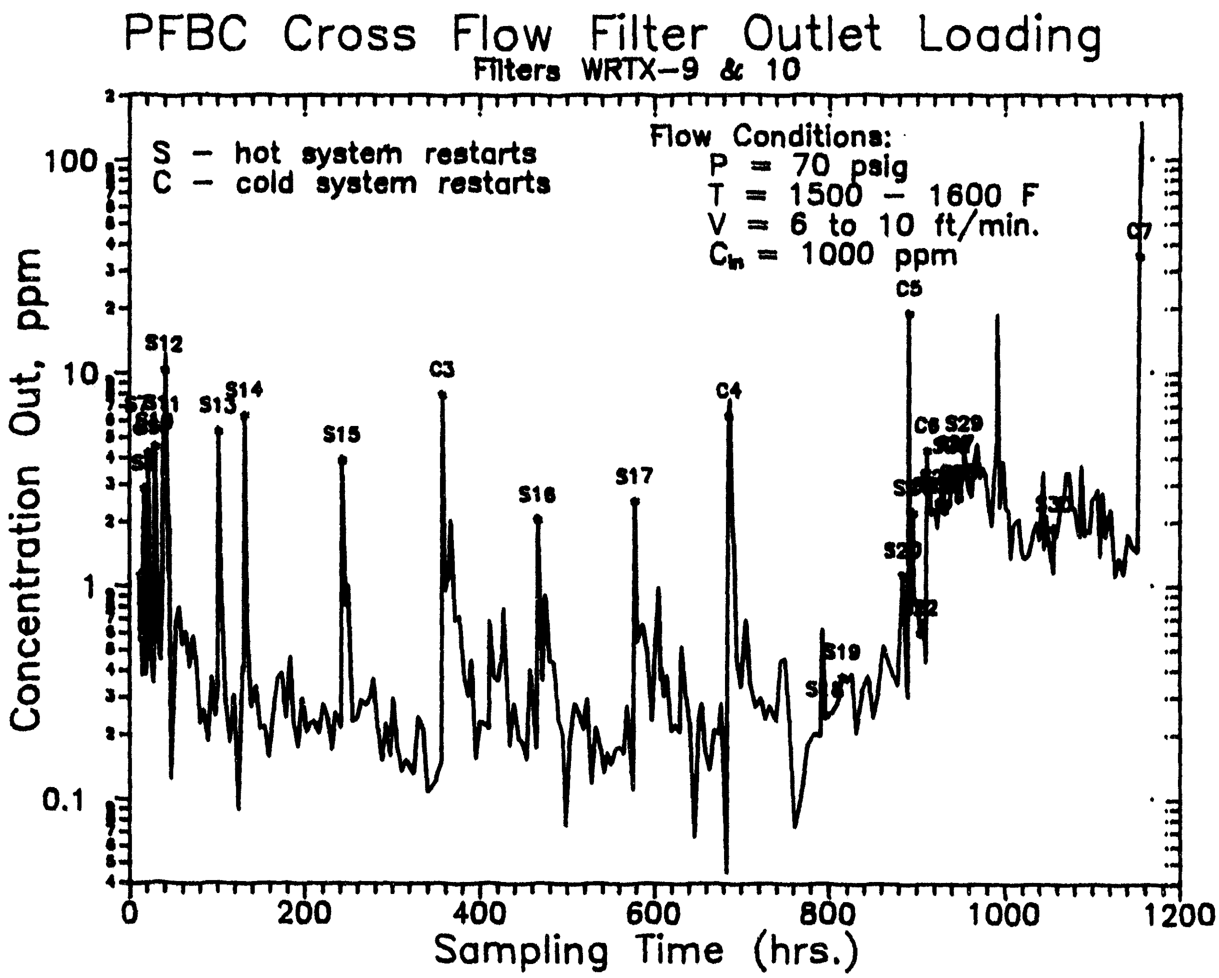


Figure E.6 - Filter Outlet Loading Profiles During PFBC Simulator Test

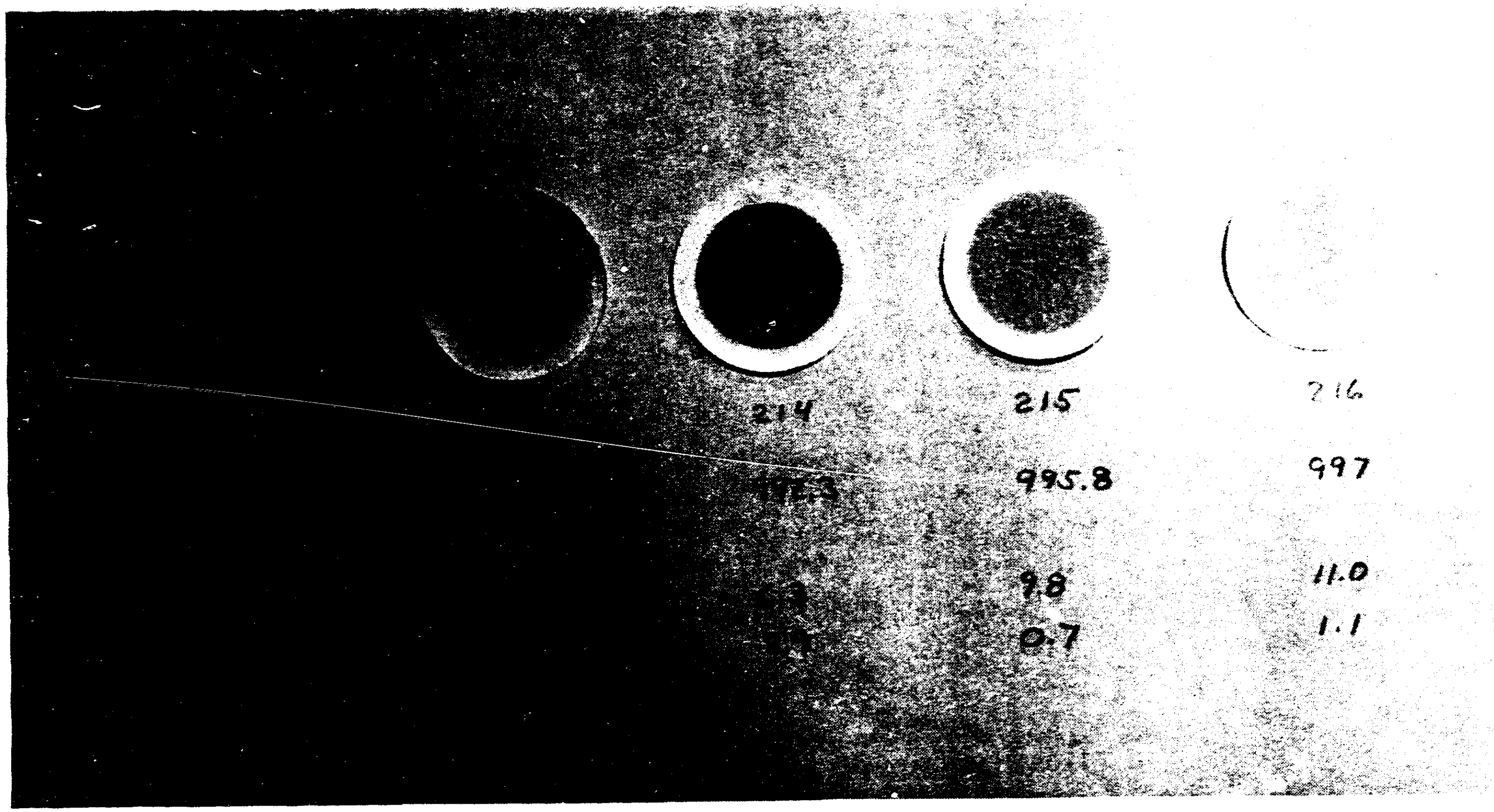


Figure E.7 - Progression of Outlet Dust Samples Following Interim Shutdown.

first 1300 hours of testing are, in fact, the corrosion scale released by the internal steel lining, and the actual PFBC dust penetration throughout the bulk of the test campaign was less than 1 ppm.

From the dust loading traces in Figure E.6 it appears that the filter elements developed an initial breach after shutdown C6 (increase from less than 1 ppm to about 4 ppm) which increased in severity after shutdown C7 when the loadings exceeded 100 ppm. The overall system permeability, defined as the reciprocal of the normalized pressure drop, was analyzed for the post C6 shutdown test periods. As shown in Figure E.8 the permeability did not show an increase until after shutdown C7 suggesting that the first stage of failure after C6 was a small crack which only allowed seepage of dust cake, whereas the second stage of failure was a large crack which permitted significant bypassing of dust laden gases into the clean side of the system.

3.2 Inspection and Fractographic Examination

The tubesheet and plenums were removed from the vessel and first inspected with a borescope inserted from the top open end of the plenum pipe. The internal cavities of the two fixtures showed some accumulation of the beige colored PFBC dust; it appeared that the top fixture with element WRTX-10 contained more dust than the lower fixture with WRTX-9. The compression braces on both elements were found to be loosely connected, and one of the end plates had actually become detached from the ceramic rods. The elements were securely seated in their respective fixture cavities and did not show any outward indication of breakage or cracking.

The clamping plates on both filters appeared to be tilted such that the inside edges of the plates actually impinged on the ceramic flange surface. Cracks emanated from the contact point and appeared to have propagated into the fillet of the flange.

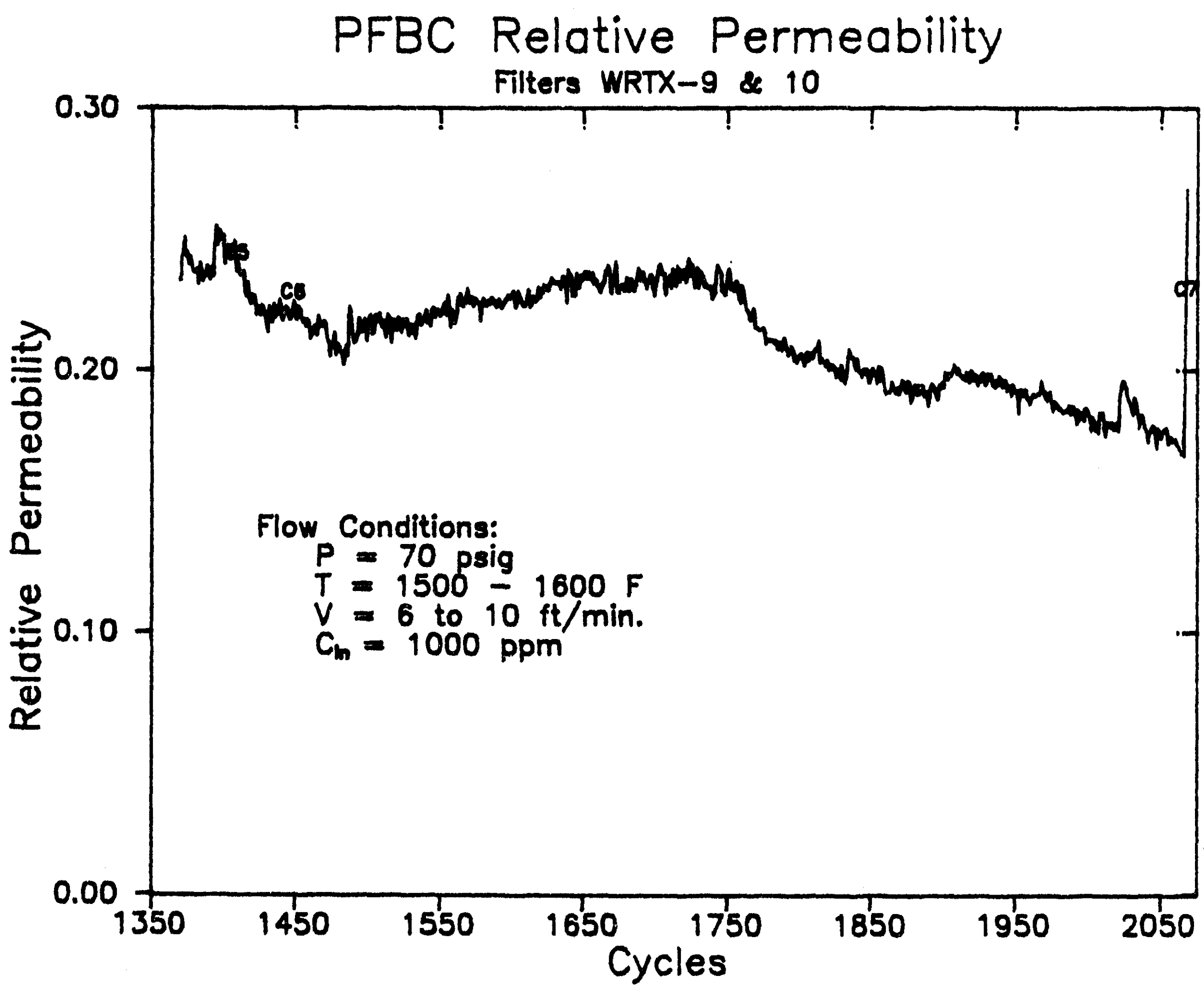


Figure E.8 - Filter Permeability Trends During PFBC Simulator Test

The side plate of filter WRTX-10 (which was machined prior to installation) showed cracking and spalling along the bottom face as shown in Figure E.9. The cracking and spalling may have been caused by the thinning of the end plate during the machining process.

The flange surfaces were examined after removal of all four clamping plates. The flange corners of both filters showed severe crushing and/or cracking damage, as typified in Figure E.10. The gaps between the flanges and the metal fixture were completely filled with fly ash.

The most significant failure was a longitudinal crack along one of the flanges on filter WRTX-10, as shown in Figure E.11. The crack appeared to have started at the corners and propagated through the fillet and caused a separation of the filter body from the flange.

The bottom filter WRTX-9 was wedged firmly into the fixture by the fly ash and, during disassembly, a part of the flange was sheared off. Figure E.12 shows a remnant of this flange and the gasket after removal of the element. The fly ash present on the corners of the gasket indicates that the corners of the flanges were crushed during operation, allowing dust penetration.

Figure E.13 describes, in schematic form, the shapes of the various fractures formed on these filters during operation.

3.3 Failure Mechanisms

- The clamping bars rested partly on the fillets between the flanges and the body of each filter, and partly on the edges of the flanges. This caused concentrated pressures on the filters and bending of the flanges, as well as bending of the bolts.

Figure E.9 - End View of Filter WRTX-10, Shows Cracking and Spalling in the Area Which Was Machined Prior to Installation

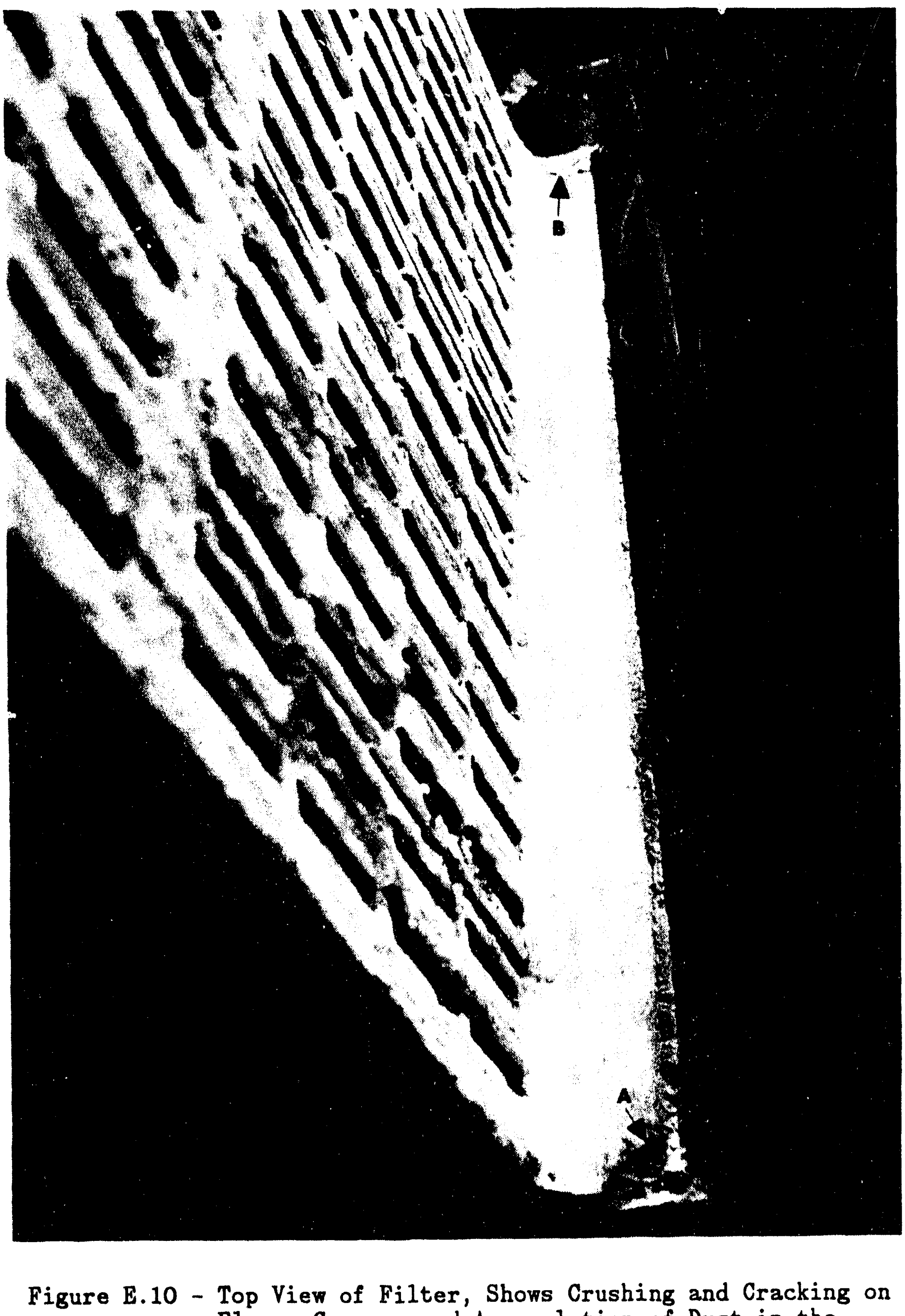


Figure E.10 - Top View of Filter, Shows Crushing and Cracking on Flange Corners and Accumulation of Dust in the Fixture Cavity

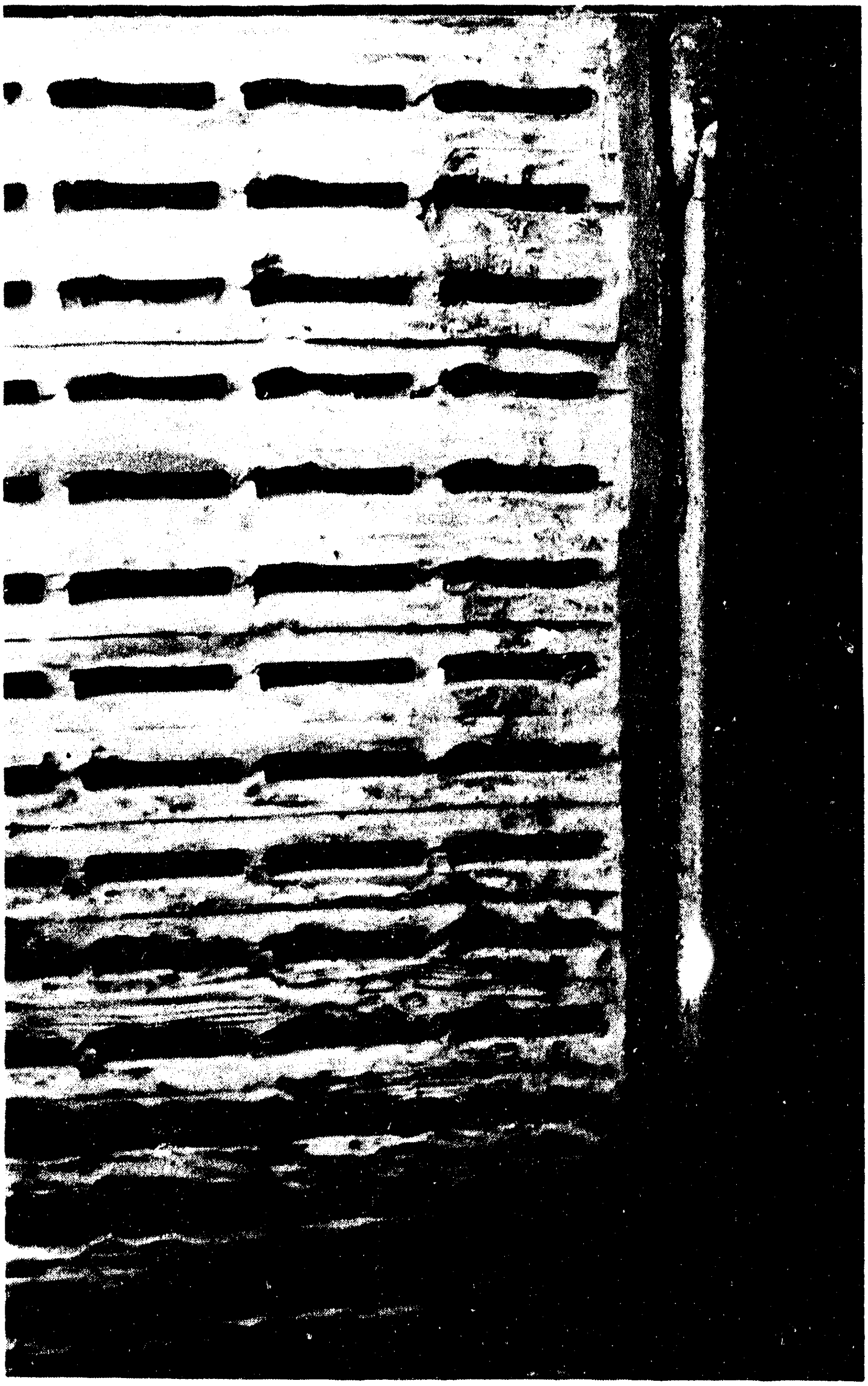


Figure E.11 - Frontal View of Filter WRTX-10, Shows Longitudinal Crack Along the Fillet of the Flange

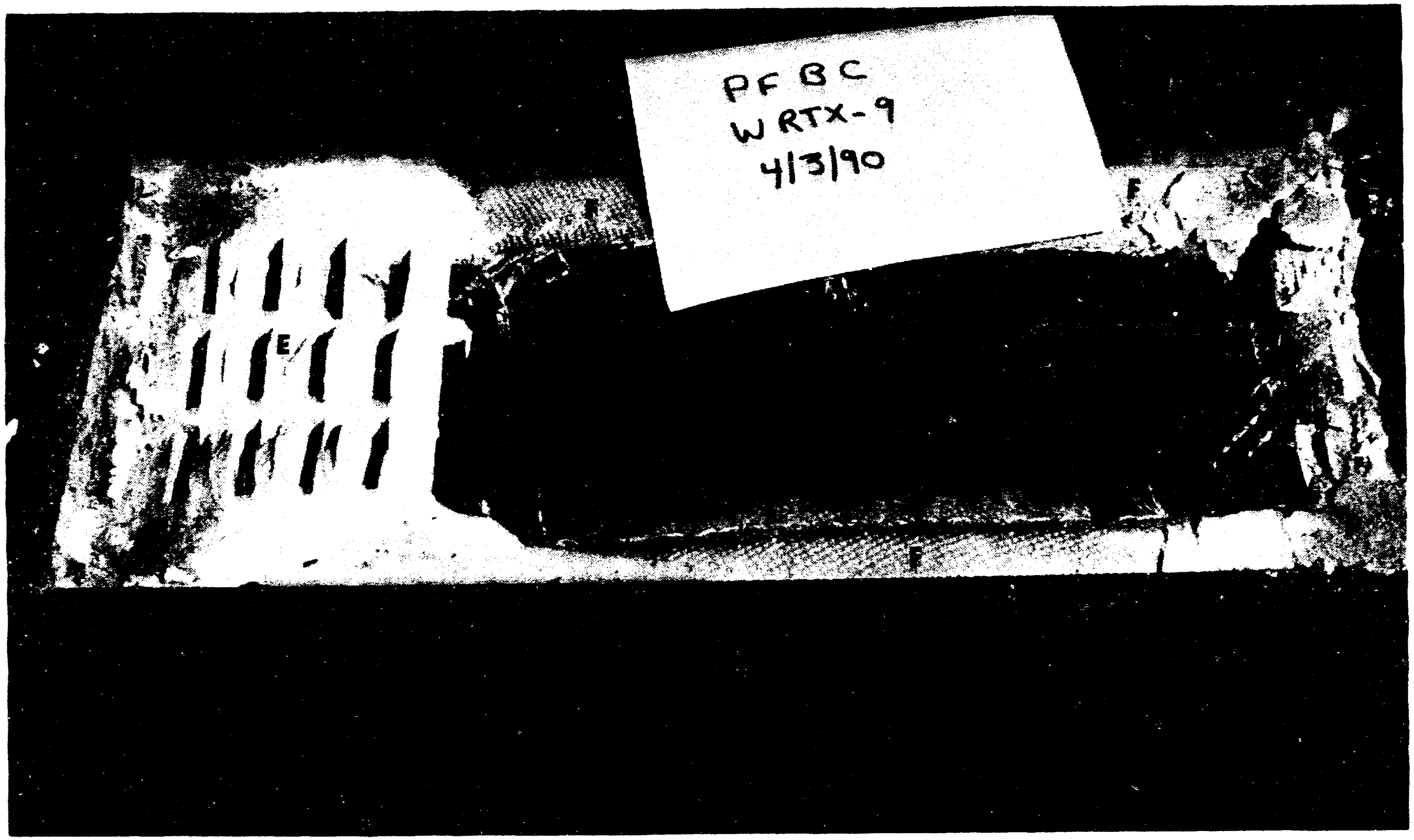


Figure E.12 - Remnant of Filter WRTX-9 Which Broke During the Element Removal; Note the Collection of Dust on Corners of Mount Indicating Flange Cracks During Service

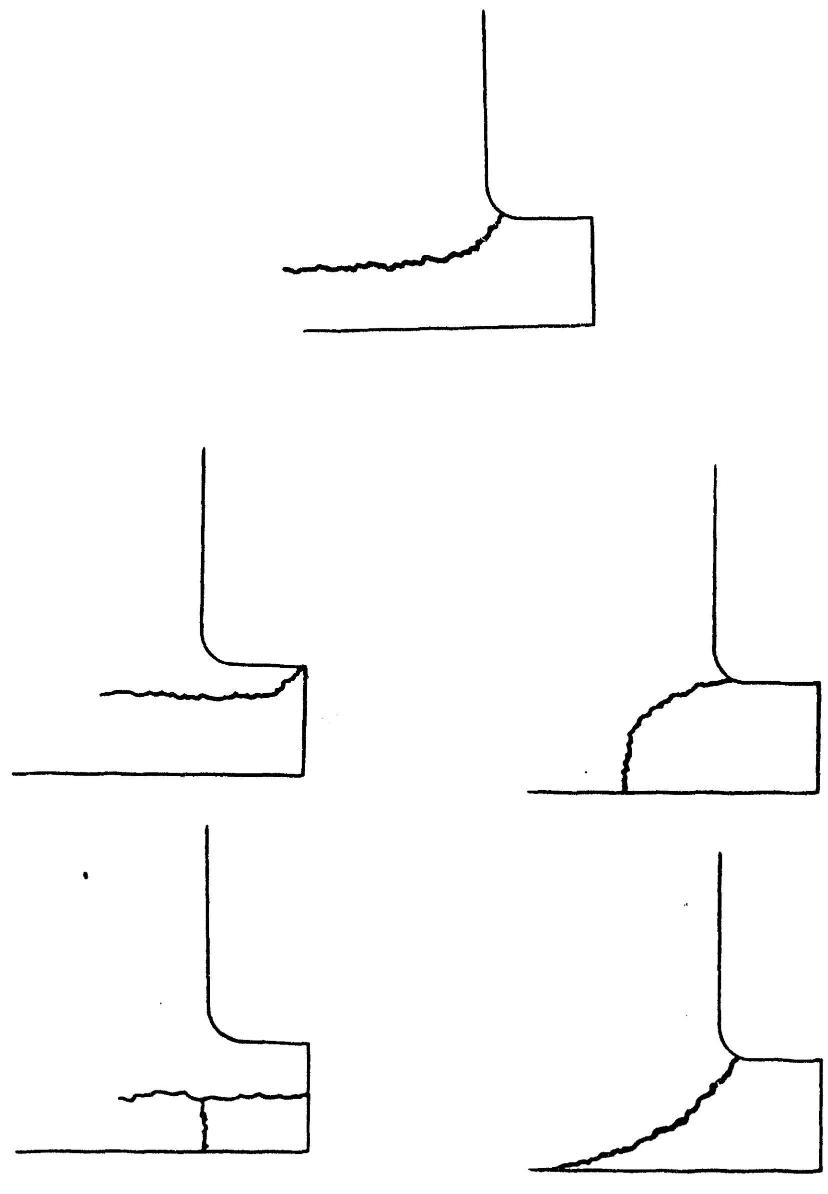


Figure E.13 - Fracture Profiles on WRTX-9 and WRTX-10 Filters

- Grinding of the end walls of the filters prior to the installation may have contributed to the cracking and spalling of the lower portions of the end walls.

- The location of the end bolts of the clamping bars next to the end corners of the flanges may have contributed to the crushing of the surface of the corners.

- The fractures in the flanges and in the bases of the filters appear to have always started in the regions of the end corners of the flanges.

- The holder appears to have exerted considerable loads on each filter by "pinching" tight its base via fly-ash compressed between the vertical walls of the holder and the sides of the filter.

- In general, the cracking of the filters appears to have been caused by concentrated stresses, some constant, some cyclic (including thermal fatigue), resulting from the methods of supporting and clamping the filters. Grinding of the filters prior to the installation might have been a contributing factor to some additional spalling.

3.4 Drawbacks of Current Design

Judging from the results of the operational analysis and the fractographic evaluation, the primary cause of the filter failure appears to be the design of the filter mounting apparatus and the assembly procedure. The characteristics of the flange fractures indicate that the crack initiation occurred primarily on the flange edges and that the crack growth was accelerated by the imposition of point and/or line stresses on the interface between the ceramic flange and the metal clamping plates. Notably, these fractures did not result in any filter delaminations, as previously experienced on the first generation of cross flow filters. The absence of delamination in the second generation elements is attributed to the use of the radiused fillet between the flange and the filter body, the mid-rib bond structure and the overall improvement made by Coors in the element fabrication and sintering procedures. Once initiated, these cracks did not propagate laterally into the filter body as a delamination, but instead proceeded longitudinally across the flange.

Specific deficiencies in the current mount design are discussed below.

A. Non-uniform Loading of Filter Flanges

The filter support ledge is recessed inside the metal fixture so that the clamping plates are normally flat and horizontal in the assembled state. Such a perfect fitup of the element is seldom achieved in practice because the flange dimensions vary by 150 mils in thickness and 30 mils in flatness. Therefore, after installation, the clamp becomes tilted and imposes a direct crushing load on the longitudinal edges and corners of the flanges as shown in Figure E.14(a). Alternatively, shims are used to raise the outboard side of the clamping plates to achieve a horizontal fitup as shown in Figure E.14(b). The end result is that when the bolts are torqued the compression force only acts on the shim; the clamp transfers marginal compression to the ceramic flange again in the form of an edge load or moment. It is virtually impossible to (a) achieve uniform distribution of load along the flat surface of the flange, (b) to preclude any interference of the flange corners and

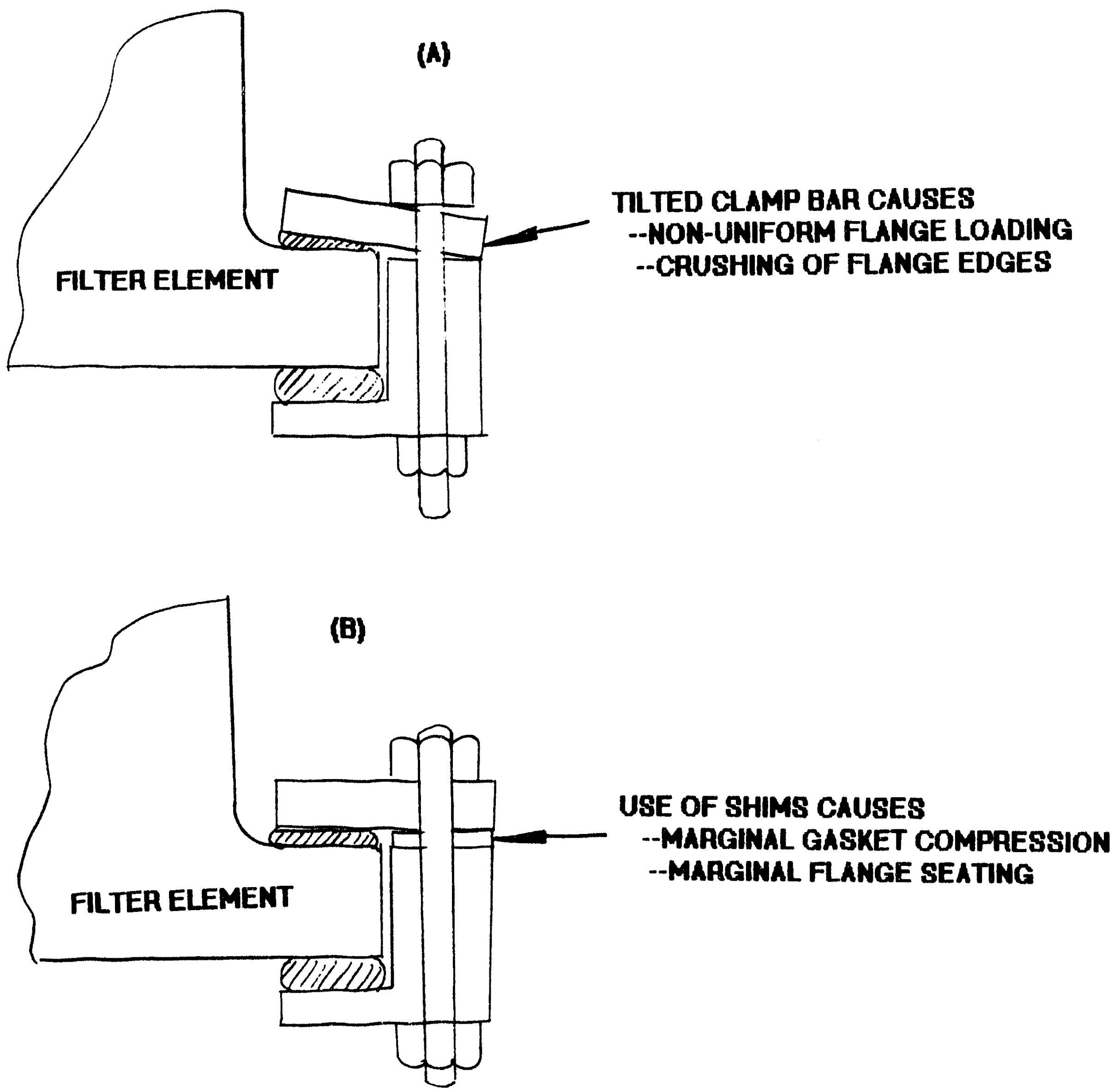


Figure E.14 - Typical Element Installation Problems with Current Mount Design edges with the clamp plates, and, (c) to reliably translate the bolt loads into an equivalent seating force on the filter.

B. <u>Bolt Relaxation due to Creep Effects</u>

As described previously, the filter gasket is preloaded with an initial seating force of 2430 lbs. The 0.25 inch 316 stainless steel bolts, however, relax at high temperature causing a reduction in the effective seating force on the gasket. Using the isochronous stress-strain curves for 316 stainless steel the gasket seating force was calculated for various exposure times at 1500°F temperature. As shown in Figure E.15, the actual seating force deteriorates to about 10% of the initial value after 1000 hours or about 260 lbs. Given the non uniform loading characteristics of the clamp discussed above and the closeness of the residual seating force to the reverse hydrostatic force generated during pulse cleaning, it is probable that the elements are partially lifted and/or severely vibrated during each pulse. Because the Interam pad placed between the clamp and the flange crumbles to powder at high temperature there is virtually no resilient layer to absorb any impact of the ceramic flange with the metal plate.

C. <u>Lateral Loads due to Dust Accumulation</u>

Because of the differential thermal expansion between the ceramic flange and the metal ledge, the 0.125 inch gap is opened during high temperature operation. After 1000 hours the creep relaxation behavior of the bolts substantially reduces the gas sealing characteristics of the gaskets allowing dust laden gas to permeate through the gasket and

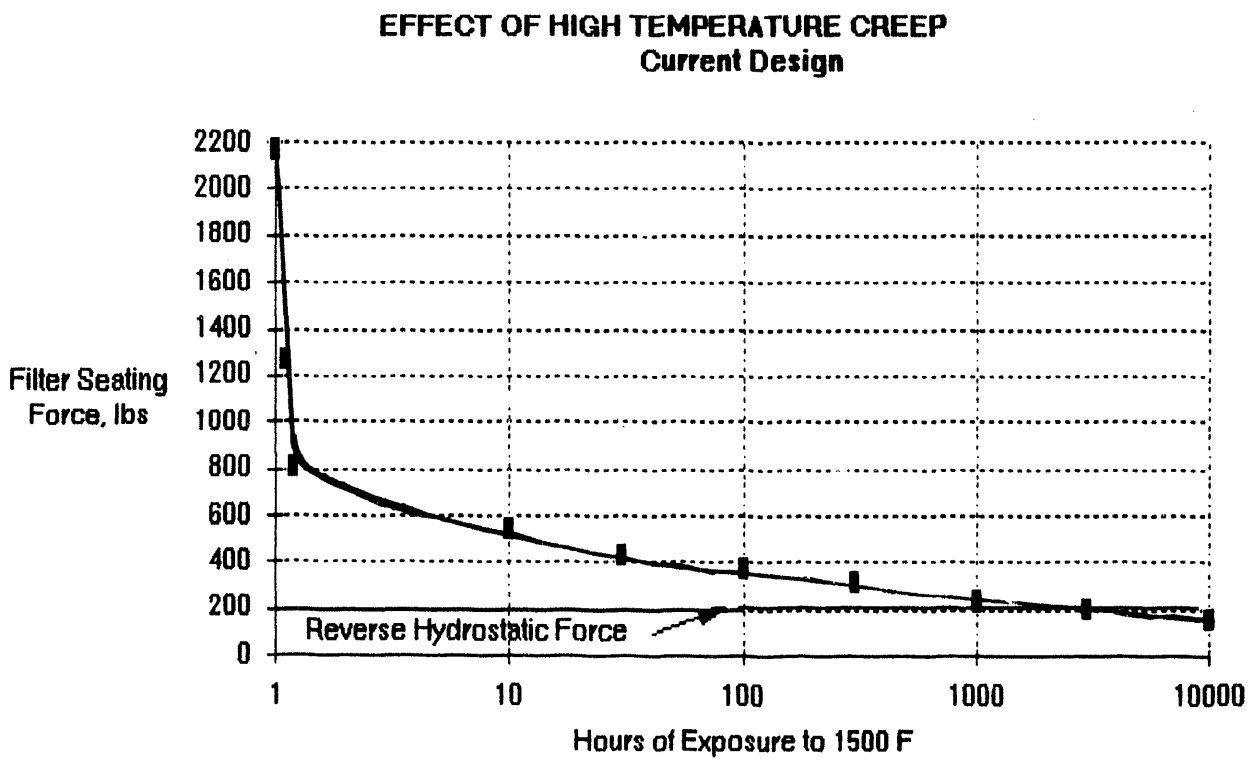


Figure E.15 - Effect of Bolt Relaxation on Filter Seating (Current Design) form a dust cake in the cavities outside the gasket and in the gaps between the flanges and the metal fixture. Because this cake is normally thicker than the cake depositing on the filter walls, it is unlikely to be removed during on-line pulse cleaning. Upon shutdown when the metal cavity contracts a residual stress is exerted laterally into the flange body. The wedging effect of the fines was particularly visible on the bottom element which had to be forcibly ejected out of the metal fixture causing a cleavage of the flange during disassembly. The lateral forces would principally be manifested during the cold shutdown periods after about 1000 hours of hot operation when the seating forces on the gasket have substantially relaxed allowing the buildup of dust in the cavities.

3.5 Proposed System Retrofit

In an effort to eliminate the deficiencies in the current filter mounting apparatus a retrofit design has been developed as shown in Figure E.16. The salient features of this retrofit are now outlined.

1. The Nextel reinforced gaskets are used on the upper and lower surfaces of the ceramic flange. Note that the upper gasket after compression now provides a compliant layer to smooth out the seating forces imposed by the flange loading plate and also ensures a resilient shock-absorbing layer to cushion the vibrational forces generated during pulse cleaning.

2. The single clamp plate is now substituted by a flange loading plate and a separate loading bar with a swivel action. This type of clamping arrangement ensures that,

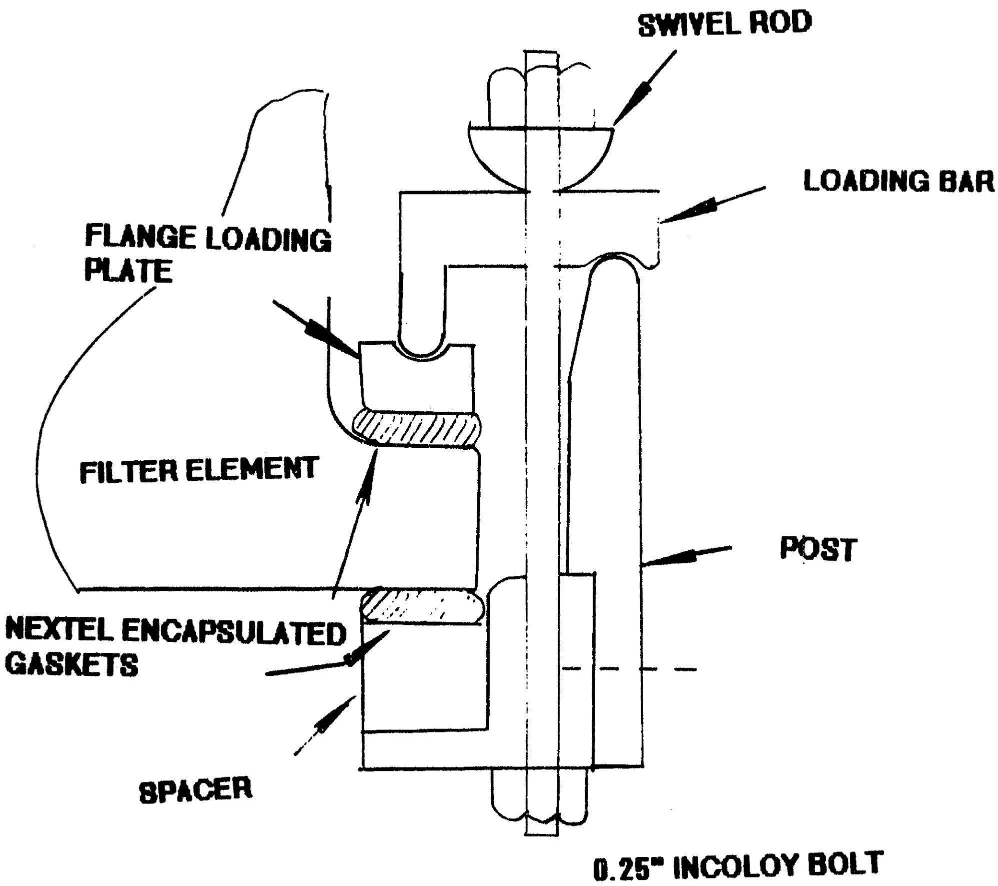


Figure E.16 - End View of Retrofitted Element Mount Fixture regardless of the ceramic flange geometric variations, the loading plate will remain parallel and horizontal whereas the loading bar can rotate as necessary without actually interfering with the edge of the ceramic flange.

3. A metal post is attached to the outside of the existing fixture such that the loading bar is simply supported on either side of the bolting axis. Thus the bolting forces are directly transferred into an equivalent seating force on the filter, without the use of shims.

4. The eight 316 stainless steel bolts are substituted by 14 bolts made of creep resistant Incoloy 800 alloy. During the assembly procedure a 270 lbs weight is placed on the element to pre-compress the bottom gasket. The clamping device is now mounted and the 14 bolts are sequentially torqued up to 10 in-lbs. After removal of the 270 lbs weight, the two gaskets will be loaded in series to approximately 2700 lbs of seating force. For the retrofit design Figure E.17 shows the effect of long duration bolt creep on the seating forces acting on the filter. Comparing with Figure E.15 it is clear that the seating forces are held to a relatively steady value with a substantial margin over the hydrostatic reverse forces generated during pulse cleaning. Note also that this high seating force is calculated to prevail over at least a 4 year operating period.

5. The filter seating area is elevated by the use of a spacer such that no dust can accumulate between the flange and the metal fixture. Notwithstanding the rugged gasket seating properties of the modified design, this feature ensures that no residual transverse stresses can act on the flange during shutdown conditions.

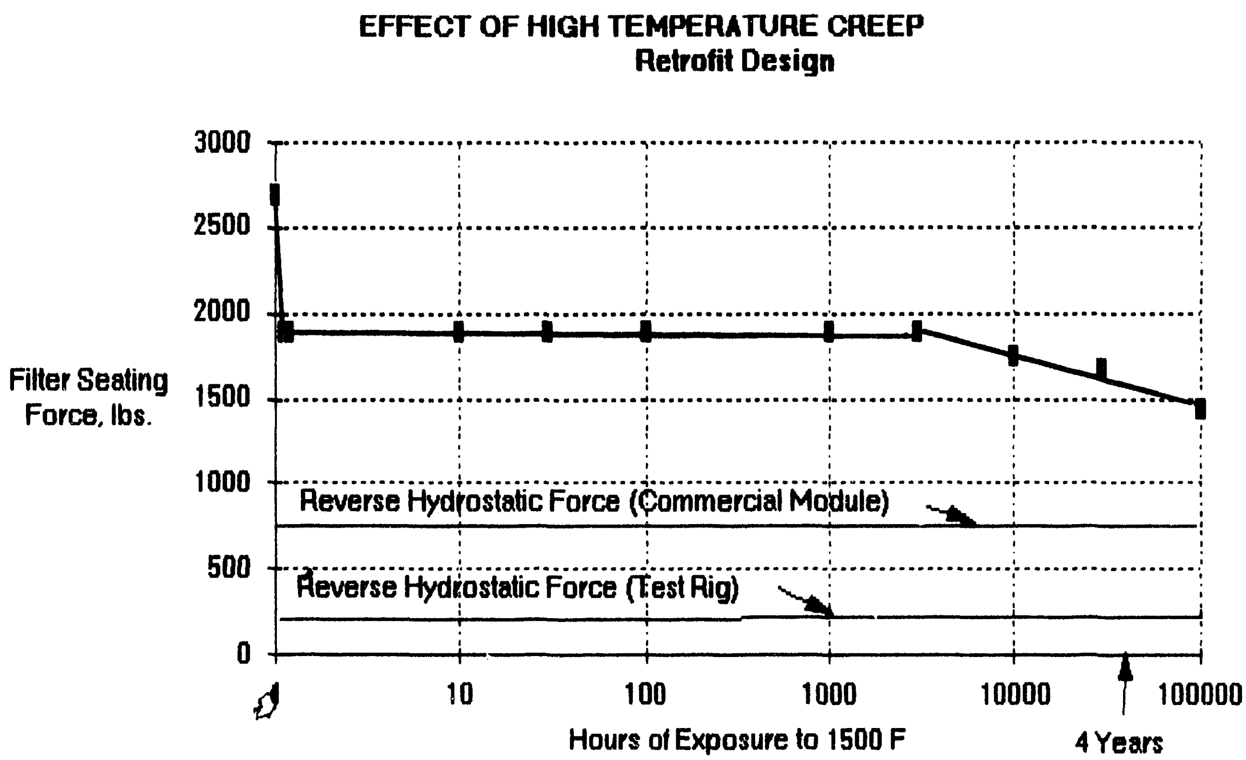


Figure E.17 - Filter Seating Characteristics of Retrofit Mount Design

Whereas, these modifications can be easily implemented in the current filter support structure, the retrofit mount blocks off the bottom two rows of filtering surface, thus reducing the overall filtration area from 8.4 to approximately 7.0 ft^2. This penalty, however, can be easily eliminated in a "clean sheet" mount design which incorporates all of the improved features associated with the retrofit design.

It is recommended that the element mount modifications be implemented on the long term durability test rigs as well as on pilot scale filter systems integrated with the Texaco gasifier and the Foster Wheeler second generation PFBC system. Additionally, it is recommended that the filter compression braces, which were hitherto used to guard against delamination, be omitted in future testing. The results of the 1300 hour test campaign have shown significantly improved resistance to delamination and that delamination may no longer be an operational issue with cross flow filter elements. It is also clear that these braces become easily detached during high temperature operation and provide negligible compressive forces on the element.