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BLOWBACK OF SINTERED-METAL FILTERS: A REVIEW OF TESTS AND OPERATING EXPERIENCE

by

Erwin L. Carls and Norman M. Levitz

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Chemical Engineering Division

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BLOWBACK OF SINTERED-METAL FILTERS: A REVIEW OF TESTS AND OPERATING EXPERIENCE

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SUMMARY

A review has been made of the Chemical Engineering Division's experience with automatic blowback systems, which have been used in fluidization applications to remove accumulated powders from sintered-metal filters. For a wide array of equipment use in process development studies, the blowback systems usually employ 80-100-psig blowback motive gas directed periodically (i.e., in a pulsed manner) into the filter through a 1/32-1/16-in. nozzle in an opposite direction to the normal process-gas flow for pulse durations of 1 sec or less. Through the use of venturis, part of the blowback motive gas is provided by the exiting filtered gas. This has resulted in efficient cleaning of the filters when judged either by the appearance of the filters or by comparison of filter pressure drop before and after a blowback pulse.

A major advantage of pulse blowback is that it reduces the problem of filter plugging that was encountered in continuous reverse-flow blowback systems. With continuous flow, portions of the filter appear to be cleaned too thoroughly; pores that became plugged during subsequent filter use are opened. With pulse blowback, a dust layer remains, which, acting as a pre-filter, does the filtering in place of the sintered metal.

Where possible, two parameters have been calculated to reduce blowback design variables to a more fundamental form. For the operating units examined, it has been found that the ratio of the blowback gas rate to the normal forward-flow filtering gas rate has ranged from 1.3 to 10.0. This can be compared with testing from other sources, which indicate that the optimum ratio is in the range of 0.5-2.0. The second parameter compared has been the ratio of the volume of a blowback pulse to the volume of the internal filter; this ratio had a range of 0.5-8.0 for the various units.

A comparison of the pressure drop versus flow characteristics of installed filters with literature data for sintered-metal filters indicates that, unless special care is given to the placement of pressure-measuring taps, the observed pressure drop is, more often than not, largely due to the geometry of the off-gas lines and associated fittings.

The appendixes of this report contain information on:

- a. Calculated fines concentration in a fluidized bed as a function of blowback interval and elutriation rate constants.
- b. Measurements of the pore size of sintered-metal filter elements.
- c. Measured efficiencies of sintered-metal filters for the retention of particulate fines.

I. INTRODUCTION

Sintered-metal filters* have been used in a wide variety of pilot-plant and laboratory fluid-bed reactors to remove entrained particulate solids from the fluid-bed effluent-gas stream. This is necessary to prevent loss of material from the reactor or contamination of the gas stream.

The particulate solids generally accumulate on these filters as a layer, which requires periodic removal for two basic reasons: First, as the solids loading on the filter increases, the pressure drop across the filter increases, which lowers the gas throughput rate; second, periodic removal of accumulated solids is needed to return incompletely reacted material to the fluid bed so that further reaction with the gases can occur. The second consideration applies when filters are maintained at much lower temperatures than the fluid bed because of corrosion considerations; thus the reaction between the gas and the particulate solid does not proceed on the filters themselves.

The passage of a reverse flow of gas through the filters (i.e., blowback) to dislodge the accumulated layer of solids is a standard practice recommended by filter manufacturers and was used in pilot-plant units at this laboratory as early as 1954.¹ In some cases, filters were blown back whenever the filter pressure drop indicated the accumulation of solids on the filters. In other units using multiple filters, a different scheme was employed. A continuous-blowback gas stream was used on each of the filters in sequence. Solids continued to accumulate on the filters not being blown back, and when the total filter pressure drop increased to a preselected value, the blowback air was switched to another filter and the cleaned filter put back on stream. Loeding et al.² observed that the layer of accumulated solids on the filters was not uniformly removed by this technique. The bulk of the blowback air passed through a relatively small area of the filter, permitting the subsequent buildup of a large amount of filter cake on the rest of the filter. Moreover, the bulk of the gas filtration was done only by the newly cleaned filters, the other filters being relatively ineffective.

*Sintered-metal filters are manufactured in various sizes and shapes from a sintered-metal sheet. The sheet is prepared by passing a uniform layer of metal powder through a furnace just below the melting point of the metal. No bonding agents are used. Pore size is controlled by the size range of particles.

An improved filter-blowback system was designed by Jonke³ and Loeding⁴ in 1957. This system was based on cleaning the filters by impulse from a high-velocity, short-duration, reverse-flow air pulse. The

Fig. 1. Schematic Diagram of Automatic Filter-blowback System

idea of using a short burst of high-pressure gas had been used commercially* to clean bag-type filters. In the commercial units, the impulse would expand the bag slightly, thereby cracking and dislodging the filter cake. Although no filter expansion could be expected with rigid sintered-metal filters, it was expected that the rapid pressure pulse would aid in a more even removal of the filter cake. The system is shown schematically in Fig. 1. Solenoid-actuated air nozzles are directed into venturi fittings surmounting each filter. The solenoids are actuated cyclically by an electric timer. Fractional-second bursts of 100-psig air gave excellent cleaning of the filters.

Because of the venturi and the high-velocity air flow from the nozzle, some of the filtered off-gas is syphoned back to aid in cleaning. Some advantages of this system are:

1. The amount of blowback air required is considerably reduced over that required in the constant-flow scheme.
2. The filters are cleaned more effectively.
3. The filters are on stream for a larger percentage of time.
4. Operation is completely automatic.

This report summarizes experimental testing of automatic filter-blowback systems at the Chemical Engineering Division. Performance data and the effects of variables were investigated on several systems. Following this is a summary of the blowback conditions used in a variety of process development studies where the cited conditions are implicitly favorable for the particular systems. An attempt to reduce a number of design variables to more fundamental parameters is presented in the discussion section (Section IV). The appendixes contain miscellaneous information regarding (1) calculated fines concentrations in a fluidized bed as a

*Pulverizing Machinery Co., Summit, New Jersey.

function of blowback interval and elutriation rate, (2) pore-size testing of sintered-metal filters, and (3) tests of the filtration efficiency of sintered-metal filters.

II. EXPERIENCE WITH TEST UNITS

Automatic pulse-blowback systems have been experimentally tested in glass and plastic units. The feasibility of the technique has been established, and the effects of variables such as pulse duration, interval between pulses, and pressure of blowback gas have been investigated.

A. Feasibility Tests

To test the feasibility of this automatic blowback process, tests² were conducted in 3- and 6-in.-dia glass columns. Each column was equipped with two 18-in.-long bayonet sintered-metal filters having a total surface area of 1.5 sq ft. A bed of aluminum oxide containing a relatively large quantity of -325 mesh particles was used to provide a high solids loading on the filters. (The terminal velocity for a -325 mesh particle, $\sim 40 \mu$, is approximately 1.0 ft/sec, and the following tests were conducted with superficial velocities of 1.5 ft/sec through the columns.)

1. Single-pulse Blowback Tests

To test the effectiveness of a high-pressure gas pulse directed through a nozzle-venturi combination in removing accumulated powders from filters, the alumina bed was first fluidized without blowback. After the formation of powder layers approximately $1/8$ to $1/4$ in. thick on the filters, the fluidizing air was stopped and the filters were blown back by directing a fractional-second pulse of 80-psig air through the nozzle-venturi system. For the 3-in.-dia column, the air pulse removed all but a fine layer of particles and reduced the pressure drop across the filters from 12 in. of water pressure greater than the pressure drop for a clean filter at the same air rate to 2.5 in. greater than the pressure drop for the clean filter. The filter cake disintegrated to a powder, which fell back into the fluid bed. For the 6-in. column, the blowback pulse removed approximately 95% of the accumulated solids and reduced the pressure drop from 112 in. of water pressure to approximately its starting value of 33.5 in. Table I summarizes these tests.

2. Long-term Blowback Test

A longer-duration test was conducted in the 6-in.-dia glass column to determine if the effectiveness noted in the above tests for a single blowback pulse would be achieved in long-term operation. With a gas rate of 11.6 scfm/sq ft filter area and blowback conditions of a fractional-second pulse of 80-psig air per filter every minute, the pressure drop across the

filters rose, over an 8-week period, from a clean filter value of 33.5 in. of water pressure to 40 in. Most of this increase occurred in the first few hours of operation. The short bursts of blowback air removed the bulk of the filter cake but allowed sufficient alumina to remain on the filter to act as a prefilter and thus prevented plugging of the filter.

TABLE I. Feasibility of Automatic-blowback System; Effect of Blowback on Filter-pressure Drop

Superficial gas velocity at column conditions: 1.5 ft/sec
Blowback conditions: 80-psig air, fractional-second pulse

Column Diameter, in.	Gas Flow Rate, scfm/sq ft Filter	Filter Pressure Drop, in. H ₂ O			Filter Cake Thickness before Blowback, in.	Comments
		Original	Before Blowback	After Blowback		
3	3.1	a	12 ^b	2.5 ^c	1/4	Blowback removed all but fine dust layer
6	11.6	~33.5	112	33.5	5/32	Blowback removed ~95% of solids

^aOriginal value not given.

^bRepresents a differential between the operating point and an unspecified original value.

^cRepresents a differential between the observed value and an unspecified original value.

3. Blowback Effectiveness at Various Gas Flows

The effectiveness of filter blowback at various fluidizing-gas flow rates was also determined in the 6-in.-dia glass column. Pressure-

Fig. 2. Feasibility Test of Automatic-blowback System: Pressure Drop vs Flow Rate for 6-in.-dia Column. Column charged with aluminum oxide bed.

drop readings across the filters at various fluidizing-gas rates were determined when the filters could still be considered "clean." These are represented by the "clean filter" curve (Curve 1) on Fig. 2. Following this, the system was allowed to reach a steady-state condition at various gas flow rates under the same blowback conditions as the previously mentioned tests. The new data are shown as the "coated filter" curve (Curve 2) on Fig. 2. Attainment of steady-state conditions required about two days for each flow condition. The differential pressure between the curves represents the increase in filter-pressure drop over a starting filter-pressure drop that would

be experienced at various gas flow rates with automatic blowback. This pressure differential was about 10 in. of water pressure for flows ranging from 4.6 to 12 scfm/sq ft filter area.

At two air rates (10.6 and 8.7 scfm/sq ft filter area), the flow of fluidizing air was momentarily halted and both filters (in the coated filter state) were blown back by one burst through each filter. The results indicated virtually complete cleaning of the filters, as evidenced by the decrease in filter pressure drop to "clean filter" conditions.

B. Effect of Pulse Duration and Frequency

Tests aimed at evaluating the effects of blowback duration and frequency as determined by visual observation and pressure drop across a filter were conducted by Carls,⁵ Vogel,⁶ and Gerard.⁷ Studies by Gabor and Phelps²⁹ concerned with elutriation of fines and frequency of filter blowback are summarized in Appendix A. All three test setups⁵⁻⁷ involved a 3-in.-dia glass or plastic column. Carls used one bayonet filter, 2 $\frac{3}{4}$ in. wide by 9 in. long. The columns were loaded with alumina, and the pressure drop across the filters was measured at various gas flow rates, with and without blowback. The alumina bed for Carls' tests contained 8% -325 mesh particles; the beds for Vogel's and Gerard's tests contained 4% -325 mesh particles. The blowback gas pressure ranged from 40 to 100 psig, and various combinations of pulse duration and frequency were tested. Table II summarizes the various test conditions.

TABLE II. Test Conditions for Evaluation of Blowback Duration and Frequency
(3-in.-dia column)

Reference	No. of Filters	Nominal Filter Porosity, ^a μ	Filter Area, sq ft	Alumina Bed, percent -325 Mesh	Blowback Gas Pressure, psig	Pulse Duration, sec	Gas Flow, scfm/sq ft Filter ^b	Interval between Pulses for Each Filter, min
Carls ⁵	1	10	0.73	8	100	0.5-2.0	2.2, 3.1, 4.2	10, 30
Vogel ⁶	2	20	0.70	4	80	0.1	3.8	2, 14, 30, 60 ^c
Gerard ⁷	2	20	0.70	4	40, 65, 90	0.2-1.4	3.8	2, 60 ^c

^aManufacturer's rating (see Appendix B).

^bAt 4.0 scfm/sq ft filter area, the superficial gas velocity through the columns is approximately 1.0 ft/sec.

^cFor the systems using two filters, the pulses were alternated between filters; i.e., an interval of 60 min/filter would mean a blowback pulse every 30 min alternating between filters.

The results of the test with the single filter, shown in Fig. 3, were typical of subsequent tests on pulse duration and frequency. Blowback durations as short as 0.5 sec reduced the pressure drop across the filter to a value comparable to a "clean filter" value. In this case, the "clean filter" value was the value attained upon blowback. Increasing the duration of blowback to 2.0 sec gave no improvement over the short pulse on either the resultant pressure drop across the filters or the amount of retained fines. Increasing the interval between pulses merely allowed a thicker cake to accumulate on the filters with a higher pressure drop building up across the filters between blowbacks. This is seen in Fig. 3c, showing the

test at 2.2 scfm/sq ft filter area. Visual inspection of the unit during operation showed a cake of powder ranging from 1/16 to 1/4 in. thick building up evenly over the entire filter between pulses. Upon blowback, the entire powder cake was dislodged except for a thin dustlike layer.

Fig. 3. Effect of Blowback Pulse Duration and Frequency on Filter Pressure Drop for Tests with Single $2\frac{3}{4}$ -in.-wide, 18-in.-long Filter. Blowback pressure: 100 psig.

Vogel⁶ obtained similar results in that pulse durations as low as approximately 0.1 sec were effective in removing the layer of solids from the filters. (See Fig. 4 for a schematic diagram of Vogel's equipment.) An interesting effect was noted, however, concerning the interval between blowback pulses. With an interval of 14 min or more, a layer of powder formed on the filters. When a blowback pulse occurred, the filter cake was blown off the filter and dropped almost sheet-like onto the slanted side of the disengaging section. A large fraction of this material continued on into the fluidized bed. A cloud of very fine particles remained in the vicinity of the filter for several minutes after the filter was blown back and dissipated as the fines were redeposited on the filter. With 2-min intervals

Fig. 4. Schematic Diagram of Blowback Test Equipment⁶

between blowback pulses, the time was insufficient for significant cake buildup, and virtually all the material blown off the filters remained in the vicinity of the filters after a blowback pulse and was redeposited.

Gerard's⁷ tests confirmed the above results in that little or no difference in blowback performance was detected when the pulse duration was varied from 0.2 to 1.4 sec. Gerard also observed the effect reported by Vogel relating to longer time intervals (>15 min) allowing a cake to form on the filters, which would drop off the filter as a mass. Short intervals resulted in no appreciable cake formation, and the particles were blown off as a cloud and almost immediately returned to the filters.

C. Effect of Blowback Pressure

Gerard⁷ investigated the effect of blowback pressure by conducting tests at 90, 65, and 40 psig with a pulse duration of 1.2 sec. For blowback pressures of 90 and 65 psig, little detectable difference was noted either for the pressure drop across

the filters after a blowback pulse or for the amount of fines returned to the fluidized bed. However, a pressure of 40 psig was considered inferior with regard to the amount of fines returned to the fluid bed. The measured amount of gas per pulse (1.2 sec) was 0.15 scf at 65 psig and 0.17 scf at 90 psig. Further comment on the significance of blowback gas volume to effectiveness of blowback is included in Section IV of this report.

III. EXPERIENCE WITH OPERATING UNITS

Table III presents the blowback operating conditions for 12 separate pilot-plant and laboratory fluidized-bed units used in a variety of development studies. Studies involved fluorination of uranium alloys or compounds in a fluidized bed of alumina. The data are incomplete in that many variables remain undefined. For instance, the physical and chemical properties of the fine powders and the degree of solids loading in the gas being filtered

differ from process to process and cannot be quantified for each case. The blowback equipment itself varies from unit to unit; the type and size of venturi-nozzle combination and details regarding particular dimensions are not available for all systems. It was assumed that the conditions used were satisfactory for each system. Hence, some generalizations can be made regarding certain blowback variables.

TABLE III. Summary of Filter-blowback Conditions for Various Operating Units

Reference	Unit or Process	Vessel Diameter, in.	No. of Filters	Type and Size of Filter, in.	Nominal Filter Pore Size, μ	Total Filter Area, sq ft	Nominal Gas Flow, scfm/sq ft Filter	Blowback Conditions				
								Gas Pressure, psig	Pulse Duration, sec	Interval between Pulses for Each Filter, min	Nozzle Size, in.	Solenoid Orifice Size, in.
2, 4	Waste calciner	6	10	Bayonet, 3 x 18	10	7.3	1.5	80	0.5	1.0	0.06	-
10, 11	Finned fluorination reactor	3	2	Bayonet, 3 x 18	10	1.5	0.8	80	0.5	20	-	0.03
5, 12	Engineering-scale alpha facility fluorinator	3	2	Bayonet, 3 x 9	20	0.70	1.6	80	1.0	Varied 1-60	0.06 0.06	0.03 0.125
9, 13	U-Zr alloy pyrohydrolyzer	6	4	Bayonet, 3 x 18	10	2.9	1.0	80	0.5	1.5	-	-
8, 9, 14	Bromine inter-halogen fluorination facility	3	4	Bayonet, 3 x 18	10	2.9	0.7	80 80	8.0 1.5	32 24	- -	0.03 0.125
11	Laboratory fluorinator	2	2	Bayonet, 1-3/4 x 12	10	0.44	1.8	50	0.5	1.0-5.0	0.04	0.06
15	Hot-cave fluorinator	1.5	2	Bayonet, 1-3/4 x 6	10	0.22	0.64	40	0.5	3.0	0.04	0.125
16, 17	Aqueous dry fluorination process drying step	6	4	Bayonet, 3 x 18	10	29	4.1	35-80	0.5	1.0	0.06	-
13, 19	UF ₆ -to-UO ₂ converter	3	3	Cylindrical, 3 x 9	10	2.4	-	80	-	1.5	-	-
20	Kinetics of particle growth in calcination	3	2	Bayonet, 3 x 18	-	1.5	-	80-100	0.25	1.0	-	-
21	Small-diameter calciner	2.25	2	-	-	-	-	80	0.1	2.0	-	-
22	Oak Ridge investigation of porous metal filters	-	24	Cylindrical, 2-3/4 x 36	20	52	0.65	15	1.0	15	3/16	-

A. Pulse Duration

For most of the units listed, the pulse duration was 1 sec or less, consistent with the experimental tests discussed earlier. The Bromine Interhalogen Fluorination (BIF) Facility⁹ used an 8-sec pulse initially, but this was later reduced to 1.5 sec.⁹ Modifications to this system also included increasing the size of the solenoid orifice for the blowback gas supply (from 1/32 to 1/8 in.) and locating the solenoids closer to the venturi-nozzle combination. The resultant pressure drop across the filters after a blowback is now less than ~11 in. of water pressure compared with a value of ~25 in. for the old system.

B. Frequency of Filter Blowback

The effect of frequency of filter blowback is difficult to compare for different operating units because of differences in (1) the degree of

solids loading of the gas being filtered, (2) the number and area of filters, and (3) the purpose of filter blowback for a given system, e.g., to return unreacted material to the reaction zone or merely to reduce pressure drop. The processes and units listed in Table III used intervals between blowback bursts ranging from 1 to 60 min. The relative merits of short versus long intervals between blowbacks are discussed in Section IV of this report.

C. Blowback Pressure

As seen in Table III, most of the operating units used a blowback gas pressure of 80-100 psig. Barghusen¹⁷ reported more favorable blowback operation when the pressure was increased from 35 to 80 psig. However, other workers have achieved successful operation at lower pressures. Anastasia¹¹ and Chilenskas¹⁵ used pressures of 40 and 50 psig, and Oak Ridge²² operated one system with a blowback pressure of 15 psig.

D. Nozzle-Venturi Blowback Assemblies

Various designs of nozzle-venturi blowback assemblies have been used to direct a pulse of blowback gas into filters. Figures 5-7 show details of three nozzle-venturi assemblies. The nozzle diameter used for these assemblies was 1/16 in., and the venturi throat diameter ranged

Fig. 5. Cross Section of Nozzle-Venturi Assembly for Waste Calciner

Fig. 6. Cross Section of Nozzle-Venturi Assembly for Uranium Alloy Pilot Plant

Fig. 7. Cross Section of Nozzle-Venturi Assembly for Alpha Facility Fluorinator

from $1/8$ to $9/32$ in. Little information has been reported on the selection of dimensions other than in the early report by Loeding *et al.*² citing the dimensions found optimum (shown in Fig. 5) and stating that the distance between the air-nozzle tip and the venturi throat should be $13/16$ in. The other assemblies, shown in Figs. 6 and 7, were modified designs with consideration given to optimizing the use of filtered off-gas as part of the motive gas during a blowback pulse. However, no measurements have been reported on the quantity of filtered off-gas actually syphoned back through a blowback assembly during a blowback pulse.

Other investigators have tried simpler versions of a blowback device. Lee²⁰ used a nozzle mounted on a commercial steam-jet ejector

Fig. 8. Cross Section of Nozzle Assembly for Hot-cell Fluorinator

which had a venturi throat diameter of $5/16$ in. Chilenskas¹⁵ dispensed with the venturi entirely and used a 0.040-in. nozzle mounted in a standard $3/8$ -in. solder tee above the filters, as shown in Fig. 8. On the basis of the amount of fines retained on the filters after a blowback pulse, both of these units were judged to have operated successfully.

IV. DISCUSSION

On the basis of the experimental tests and the experience with operating units, a relatively wide range of operating conditions and a variety of nozzle-venturi assemblies provide satisfactory blowback performance. However, since the units studied differ in (a) size and configuration, (b) number and area of filters, (c) nozzle-venturi assembly, (d) solids loading in the gas, and (e) properties of the elutriated solids, it is difficult to compare the effects of the variable operating conditions (blowback pressure, pulse duration, and interval between pulses) between the various units.

To better evaluate existing units and to specify the design criteria for future filter-blowback installations, the following discussion considers parameters that take into account some of the differences in unit design and operation. Thus, the quantity and flow rate of blowback air, which depend on the blowback pressure and pulse duration, are related to filter volume and forward gas flow rate, respectively. Also considered are blowback frequency and pressure drop across sintered-metal filters.

A. Ratio of Blowback-pulse Volume to Filter Volume

The ratio of blowback-pulse volume to filter volume is one factor affecting the force applied to dislodge the layer of accumulated powder from the filter. If it can be assumed that a buildup of pressure inside the filter during a blowback pulse in slight excess of the forward-flow pressure drop across the filter will dislodge the powder, then a comparison of internal filter pressure during a blowback pulse with the blowback effectiveness would allow calculation of the volume of blowback gas needed for each pulse. Unfortunately, no pertinent information has been reported relating to internal filter pressures during a blowback pulse. However, if the pulse is assumed to be applied over a short interval, a comparison of the volume of gas in a blowback pulse relative to filter volume may indicate the magnitude of pressure buildup.

The volume of gas introduced during a blowback pulse depends upon the pulse duration, the pressure of the blowback gas, and the smallest restriction in the blowback-gas supply system. Measurements⁵ of the blowback system in the engineering-scale alpha-facility fluorinator¹² indicated that a blowback-pulse volume of 0.015 cu ft was achieved with a pulse duration of 1 sec and 80-psig blowback-gas pressure. This was verified both by pressure-drop tests of a known-volume supply system and by flow tests. Similar blowback-pulse volumes have been calculated for the waste calciner.² From the reported amount of total blowback air used, the quantity of blowback air introduced per 0.5-sec pulse is 0.01 cu ft at 80-psig blowback-gas pressure. Sixfold greater volumes (0.1 cu ft for 1-sec duration) were reported by Gerard⁷ using comparable pressures and a nozzle-venturi assembly similar to that used in the engineering-scale alpha facility. The variation in quantity of blowback gas reported by the various workers can be attributed to different diameters of the smallest restrictions in the blowback-gas supply lines. Gerard's tests used a solenoid with a 1/8-in.-dia orifice and a nozzle of approximately 1/16-in. diameter; the previous tests were made with 1/32-in.-dia orifices.

Table IV summarizes available information regarding the volumes of blowback pulses used for various operating units. The quantities were either measured by the various experimenters or calculated based on the blowback-gas pressure and the smallest opening in the solenoid-nozzle-venturi system.

For each unit this volume was then compared with the volume of the filters as shown in Table IV. The ratio of volume of blowback pulse to volume of filter is seen to vary from 0.5 to 8.0. Sufficiently high internal filter pressures are apparently produced with this range of values to dislodge the filter cakes.

TABLE IV. Blowback-gas Volume and Blowback-gas Flow Rate for Various Operating Units

Reference	Unit or Process	Volume of Blowback Pulse, scf	Blowback-gas Flow Rate, scfm/sq ft Filter	Ratio of Blowback-pulse Volume to Single-filter Volume	Ratio of Blowback-gas Flow Rate to Forward Flow Rate through Filter
2, 4	Waste calciner	0.012 ^a	2.0	0.6	1.3
10, 11	Finned fluorination reactor	0.01 ^a	1.6	0.5	2.0
5, 12	Engineering-scale alpha facility fluorinator	0.015 ^b 0.08 ^a	2.6 13.0	1.5 8.0	1.6 8.0
9, 13	U-Zr alloy pyrohydrolyzer	0.055 ^b	9.0	2.8	9.0
8, 9, 14	Bromine interhalogen fluorination facility	0.07 ^b	3.8	3.5	5.4
11	Laboratory fluorinator	0.007 ^b	3.7	2.0	2.0
15	Hot-cave fluorinator	0.006 ^a	6.5	3.5	10.0
	Oak Ridge investigation of porous metal filters	-	0.12 ^a	-	0.23

^aCalculated.

^bMeasured.

B. Ratio of Blowback-gas Flow Rate to Forward-gas Flow Rate

An additional parameter that can be examined to determine favorable blowback conditions is the blowback-gas flow rate relative to the

Fig. 9. Steady Initial Filter-pressure Drop as a Function of Blowback-gas Flow Rate. Revision of Fig. 6 from Ref. 25. Permission to reprint given by American Chemical Society.

forward-gas flow rate. Figure 9 summarizes results of blowback tests made by a filter manufacturer, Pall,²⁵ for cyclic (not impulse) blowback. He used the term "steady initial pressure drop," which was defined as the sustained value of the pressure drop across the filters after blowback. In plotting steady initial pressure drop as a function of the ratio of blowback-gas flow rate to forward flow rate, he found the optimum ratio to be near 0.5. Values of the ratio less than 0.5 resulted in progressive increases in filter-pressure drop due to inefficient removal of the layer of solids from the filters and progressive increases in thickness of the

solid layer. Values greater than 0.5 also caused progressive increases in filter-pressure drop. The latter apparently anomalous situation was explained as being caused by the flushing of fine particles from the pores of the sintered-metal filters; this allowed successive and deeper penetration of fines throughout the volume of the filter, resulting in filter clogging. Thus, when long-term filter operation is a criterion, high ratios of blowback-gas flow to forward-gas flow rate are to be avoided.

Otero²⁶ suggested a qualification of the above-mentioned optimum ratio of blowback-gas flow rate to forward flow rate of 0.5. He states that the optimum blowback flow rate is 50% of the maximum flow rate through the filter if it can be assumed that, when a filter is undergoing blowback, the remaining filters see all the fluidizing gas as well as the blowback gas. For systems with many filters, the original ratio of 0.5 is not affected much, but for a system with only two filters, optimum ratio of blowback-gas flow rate to forward-stream flow rate for each filter becomes 2.0.

For the impulse-type blowback, the calculation of blowback-gas flow rate through the filter becomes somewhat nebulous. Although the pulse duration is known, the time required for the gas pulse to flow through the filter is not known. If it is assumed that these are equal, then Table IV shows that the ANL operating units used a ratio of blowback-gas flow rate to forward flow rate of 1.3 to 10.0. In each case, the operation of the blowback system was considered satisfactory. Successful blowback operation was also achieved at Oak Ridge (ORNL)^{23,24} with ratios of blowback to forward flow rates less than one. The calculated value of the ratio used by ORNL appears to be 0.23. The effectiveness of this blowback is evidenced in the quantity of powder obtained by brushing the filters after blowback, which yielded a calculated thickness of only 0.02 in. Hence, successful blowback operation is observed over a wide range of ratios if judged only by the criterion of the degree of powder removal. Experience indicates that the short-duration pulsed blowback does not lead to filter clogging even at high ratios of blowback-gas flow rate to forward-gas flow rate.

C. Frequency of Filter Blowback

Frequency of filter blowback is difficult to compare between units because the solids loading of the gas being filtered differs, as do the number and area of filters and the requirements of blowback. For example, if it is desired only to limit the reactor pressure to a certain value, blowback conditions would be chosen that would keep the filter-pressure drop below a predetermined value. There are also cases in which it is desirable to minimize the quantity of powder on the filters or, to be more explicit, to maximize the time that material is in the fluidized-bed reaction zone, where temperatures may be more favorable for chemical reaction. The early testing⁵⁻⁷ showed the expected result--longer intervals between pulses

allowed thicker layers of powder to accumulate on the filters between blowback pulses. This would imply that a need exists for more frequent blowback pulses if the amount of material retained on the filters is to be minimized. Also reported in the earlier testing was the countereffect noted by Vogel⁶ and Gerard⁷ relating to longer intervals aiding in the return of material to the fluid bed by allowing the filter cake to drop as an agglomerate into the fluid bed rather than being blown off as a cloud, which would immediately return to the filter surface. Generally, the length of the interval decided on must be a compromise depending on the goals of the particular process. While short intervals minimize the time the material is out of the fluid bed, some of the smaller particles may never be returned to the reaction zone if intervals between pulses are short. Longer intervals may aid in the intermittent return of some of the smaller particles to the fluid bed by allowing them to drop as part of an agglomerate, but allow more material to remain out of the reaction zone during the intervals between blowback.

D. Pressure Drop across Sintered-metal Filters

The pressure drop across sintered-metal filters in any unit is a function of the gas flow rate per square foot of filter area and the degree of solids loading in the gas. Pressure drops at various flow rates of actual operating units have been compared with the manufacturer's data for sintered metal in order to judge the effectiveness of a filter-blowback system. This information may also serve as an aid in the selection of future filtering systems.

Figure 10 contains data points from pressure-drop readings immediately after a blowback pulse, i.e., when the filters were considered clean. The curves for actual operation are considerably higher than the manufacturer's

Fig. 10. Pressure Drop across Sintered-metal Filters as a Function of Gas Flow Rate

reported pressure-drop data. The reason for this is probably a combination of two effects. First, the measured pressure drop, because of the placement of the pressure-sensing points, included not only the resistance of the filter elements but also that of the nozzle-venturi assembly and any fitting and line resistance between pressure taps. Second, although the filters were considered "clean" after a blowback pulse, the presence of small quantities of particulate solids in the pores could have altered the pressure drop considerably. To isolate these effects, readings of pressure drop versus flow should be obtained in future installations before the filters have seen any solids. It would also be desirable to locate the low-pressure tap of the filter-pressure-drop measuring system immediately upstream from the nozzle-venturi assembly to exclude this unit from the measurement.

Although each system used a filter area based on a desired allowable pressure drop for the particular flow rate and solids loading, most of the units surveyed used considerably less gas per unit filter surface area than the manufacturer states²⁷ to be normal practice (6-60 scfm/sq ft filter area).

V. CONCLUSIONS AND RECOMMENDATIONS

1. Periodic fractional-second pulses of approximately 100-psig gas directed from a nozzle-venturi assembly in a reverse direction to the normal gas flow path have been successful in removing accumulated powder from sintered-metal filters.
2. A major advantage of pulse blowback is that it reduces the problem of filter plugging encountered in continuous reverse-flow blowback systems. With continuous flow, portions of the filter appear to be cleaned too thoroughly; pores are opened that become plugged during subsequent filter use. With pulse blowback, a dust layer remains, which, acting as a pre-filter, does the filtering in place of the sintered metal.
3. For a wide variety of laboratory and pilot-plant units, successful operation was achieved at Argonne with a ratio of blowback-pulse volume to single-filter volume of 0.5-8.0 and a ratio of blowback-gas flow rate to forward flow rate ranging from 1.3 to 10.0.
4. Since successful blowback operations have been achieved at other sites at lower ratios of blowback-gas flow rate to forward flow rate than the ratios used at Argonne, the effect of a reduced blowback-air flow rate on performance and on filter life should be investigated.
5. More quantitative measurements of solids removal by filter blowback are desirable. Perhaps the weight gain of the filter or the

pressure drop could be measured more carefully in a study to evaluate the effects of the controlled variables.

6. Internal filter pressure during a blowback pulse should be measured to help define additional criteria for successful blowback operation.

7. Existing venturi-nozzle devices should be comparatively evaluated to define the design requirements more explicitly since successful operation appears to have been achieved with a variety of systems. Measurements should also be made to evaluate the syphon effect of these units with the aim of reducing the amount of overall blowback-gas requirements.

8. Care should be taken to ensure that the gas flow rate through the nozzle of the blowback system is not reduced below the design flow rate by restrictions (e.g., small-size lines and solenoid orifices) in the gas supply system.

APPENDIX A

Fines Elutriation and Filter-blowback Frequency²⁹

Studies were conducted to determine the elutriation rate of fines from fluidized beds and to determine the filter-blowback conditions that would maximize the residence time of fine particles in a fluidized bed.

The tests were conducted using a 6-ft-long, 3-in.-dia brass column. Alumina (-80 +170 mesh) was used as the fluidized-bed material, and various amounts of -500 mesh nickel shot were added as a fines fraction. The fines that were elutriated from the fluidized bed were collected in an external chamber containing a 9-in.-long by $1\frac{3}{4}$ -in.-wide sintered Inconel bayonet filter, which had a nominal pore size of $10\ \mu$. Elutriation rates were calculated from the weight of fines collected periodically.

Fig. 11. Elutriation Rate as a Function of Initial Fines Concentration. Gas velocity: 1.52 ft/sec, -80 +170 mesh alumina, 3-in.-ID brass column, and 13-in. static-bed height.

The elutriation rate, defined as the rate of change of the ratio of the concentration of fines C in the bed at any time to the initial concentration of fines C_0 , decreased with increasing initial fines concentration in the bed (as plotted in Fig. 11). It was also determined that the average particle diameter of the elutriated fines increased with time. The description of the particle-size distribution of the elutriated fines by the logarithmic normal distribution (i.e., the logarithm of the particle diameter follows a normal distribution) appears to be suitable.

The average concentration of fines in the reactor was calculated as a function of blowback frequency and elutriation rate. It was assumed that elutriation can be described by a first-order rate law and that all elutriated fines are collected on the filter and are returned to the bed by blowback. Depletion of fines by chemical reaction was neglected. From the first-order rate law, the change in fines concentration with time t in the bed is described by

$$-\frac{dC}{dt} = kC,$$

where k is the elutriation rate constant, min^{-1} .

Integrating with the boundary condition of $C = C_0$ at $t = 0$ yields

$$\frac{C}{C_0} = e^{-kt}$$

At any time, t , the average fines concentration in the bed is found from

$$\bar{C} = \frac{\int_0^t C dt}{\int_0^t dt} = \frac{\int_0^t C_0 e^{-kt} dt}{t} = \frac{C_0}{kt} (1 - e^{-kt})$$

Figure 12 shows the average fines concentration in the fluidized bed as a function of blowback interval and elutriation rate constants. It is seen, for example, that for low rate constants ($<0.02 \text{ min}^{-1}$), the average fines concentration in the bed would be $>87\%$ of the original amount with blowback once every 15 min.

Fig. 12. Dependence of Average Concentration of Fines in the Fluidized Bed on Blowback Interval

APPENDIX B

Pore Testing of Sintered-metal Filters

The pore sizes of sintered-metal filters have been compared both as received and after use in a fluorination pilot-plant facility.³⁰ The pore-size test is based on measurements of the surface tension of a bubble of air forming under a liquid.³¹ In these tests, the filter was submerged 0.25 in. in isopropyl alcohol, and the air pressure required to form a bubble was measured with a manometer. The net pressure inside the bubble required to oppose the surface tension is found by subtracting the hydrostatic head of the liquid at the (outside) top surface of the bubble. The net pressure P (dynes/sq cm) is related to the bubble diameter D (cm) and to the surface tension γ (dynes/cm) by the relation

$$P = \frac{4\gamma}{D}$$

When a filter is tested, the pressure inside the filter is gradually increased and bubbles form one by one, starting at the largest pore. Thus the size of individual pores is determined. The largest 20 pores were measured for each filter tested.

Two filters from the fluorination pilot plant each had approximately 200-hr exposure to fluorination conditions. The filters were nickel, 10 μ nominal porosity, 3 in. wide by 18 in. long. The temperature of exposure was less than 150°C. Before the pore test, the filters were cleaned by brushing off any dust and washing with water and acetone. In addition to these two exposed filters, other filters were measured for comparison. One was a nickel filter that had been subjected to only a few hours of fluorination at a low temperature. Two others were similar, but made of Monel that had never been exposed to fluorine. Another was a cylindrical filter of nickel. Table V summarizes the results of these pore-size measurements.

TABLE V. Pore-size Measurements of Porous-metal Filters

(Bubble-surface tension method)

Filter: Type 1. Bayonet, 10 μ nominal porosity
Type 2. Cylindrical

Test	Filter	Process History	Largest Pore Diameter, μ		15th Largest Pore Diameter, μ
			At Weld	Not at Weld	Not at Weld
1	Nickel, Type 1	Extensive fluorination (~200 hr)	181 129 ^a 70 ^b	42	38
2	Nickel, Type 1	Extensive fluorination (~200 hr)	891 166 ^a 78 ^c	46	30
3	Nickel, Type 1	Little fluorination (<10 hr)	73	54	49
4	Monel, Type 1	No fluorination	63	62	43
5	Monel, Type 1	No fluorination	86	64	52
6	Nickel, Type 2	No fluorination	65	55	49

^aSecond largest pore.^bFifth largest pore.^cThird largest pore.

As can be seen from the table, new filters with a nominal 10 μ rating have pores as large as 40-80 μ in diameter. The largest pores are close to welds, where the sintered metal is joined to the inner support members of the filter.

For the two nickel bayonet filters with long exposure to fluorine, a pronounced pore enlargement appears to have occurred near the welds. Four pores were particularly enlarged in one case, and two in the other. Most of the pores not near welds remained unchanged or may even have decreased slightly in size with use.

The pore enlargement observed is believed to be associated with the susceptibility of sintered metal to weaken in the neighborhood of a weld. Sintered metal has been known to crack near welds. Cracking is associated with the low tensile strength of this material and the likelihood of failure under high thermal stresses.

APPENDIX C

Filtration Efficiency of Sintered-metal Filters

In two runs involving the oxidation of UO_2 pellets to U_3O_8 fines,¹¹ attempts were made to evaluate the filtration efficiency of sintered-metal filters. The equipment was a 3-in.-dia fluorinator that used two 3-in.-wide by 18-in.-long bayonet filters mounted in the disengaging section above the fluidized bed.

Data were obtained by passing a sidestream of the filter off-gas through a high-efficiency paper filter. Solids collected on the paper were leached and the solutions analyzed by fluorophotometric techniques. Table VI summarizes the results of these tests. The rather high initial (blank) value of uranium before the start of oxidation, which is before the start of U_3O_8 fines production, may indicate contamination of the lines with uranium, which would prevent a precise determination of filter efficiency. However, assuming that uranium pickup is all due to the passage of the U_3O_8 fines, about 1-100 μg of oxide fines pass through the metal bayonet filters in every cubic foot of gas. The filters used were rated at 10 μ average pore size with 98% removal of 0.1 μ particles. The material contacting the filters was apparently all -325 mesh. By Coulter counter analysis, the average particle size for the fines was determined to be 12 μ , with less than 1% of the material outside the range 2.0-35 μ .

TABLE VI. Detection of Particulate Uranium in Off-gas Passed through Monel Bayonet Filters during Uranium Dioxide Pellet-oxidation Runs

Uranium Detected in 1 cu ft Gas, mg U		Uranium Detected in 1 cu ft Gas, mg U	
<u>Run UOF-43</u>		<u>Run UOF-45</u>	
Before O_2 introduction	6.4×10^{-2}	Before O_2 introduction	3.4×10^{-2}
End of 500°C period	4.5×10^{-3}	End of 300°C period	3.2×10^{-2}
End of 600°C period	2.0×10^{-3}	End of 400°C period	7.0×10^{-3}
		End of 500°C period	1.7×10^{-1}
		End of 600°C period	1.5×10^{-1}

Earlier tests performed by Loeding *et al.*² on the waste calciner equipment were performed in a similar fashion, but results indicated higher filtration efficiencies. Spectrographic analyses of the collected sample and a blank sample were identical, indicating little if any passage of oxide dust through the porous-metal filters.

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