CHAPTER 4
FILTRATION

Filtration is one of the most common applications of the flow of fluids through packed beds. As carried out industrially, it is exactly analogous to the filtrations carried out in the chemical laboratory using a filter paper in a funnel. The object of filter is the separation of a solid from the fluid in which it is carried. In every case, the separation is accomplished by forcing the fluid through a porous membrane. The solid particles are trapped within the pores of the membrane and build up as a layer on the surface of this membrane. The fluid, which may be either gas or liquid, passes through the bed of solids and through the retaining membrane.

Industrial filtration differs from laboratory filtration only in the bulk of material handled and in the necessity that it be handled at low cost. Thus, to attain a reasonable throughput with a moderate-sized filter, the pressure drop for flow may be increased, or the resistance to flow may be decreased. Most industrial equipment decreases the flow resistance by making the filtering area as large as possible without increasing the over-all size of the filter apparatus. The choice of filter equipment depends largely on economics, but the economic advantages will vary depending on:

a. Fluid viscosity, density, and chemical reactivity.
b. Solid particle size, size distribution, shape, flocculation tendencies, and deformability.
c. Feed slurry concentration
d. Amount of material to be handled
e. Absolute and relative values of liquid and solid products.
f. Completeness of separation required
g. Relative costs of labor, capital, and power.

4.1 Sand Filters

The simplest of industrial filters is the sand filter, consisting of layers of rock, gravel, and sand supported by a grating, as shown in figure 4.1. The feed is pumped onto the top of the sand layer and trickles through the bed by gravity. Sand filters are used only when large flows of very dilute slurry are to be treated, when neither liquid nor solid product has high unit value, and when the solid product is not to be recovered. After a period of operation, the bed is cleaned by back flushing with wash water. Typical applications are found in water-and sewage-treatment plants.

Sand filters may be built from concrete with open tops as is that of Figure 4.1 or may be enclosed to permit pressure operation. Backwashing rates are usually made high enough to fluidize the uniformly sized sand that makes up the actual filter medium.

Flow rate through a sand filter may be calculated using equations in flow through packed beds for the condition immediately after backwashing when the bed is clean. As solids build up between the sand particles, the porosity decreases and the flow rate drops.

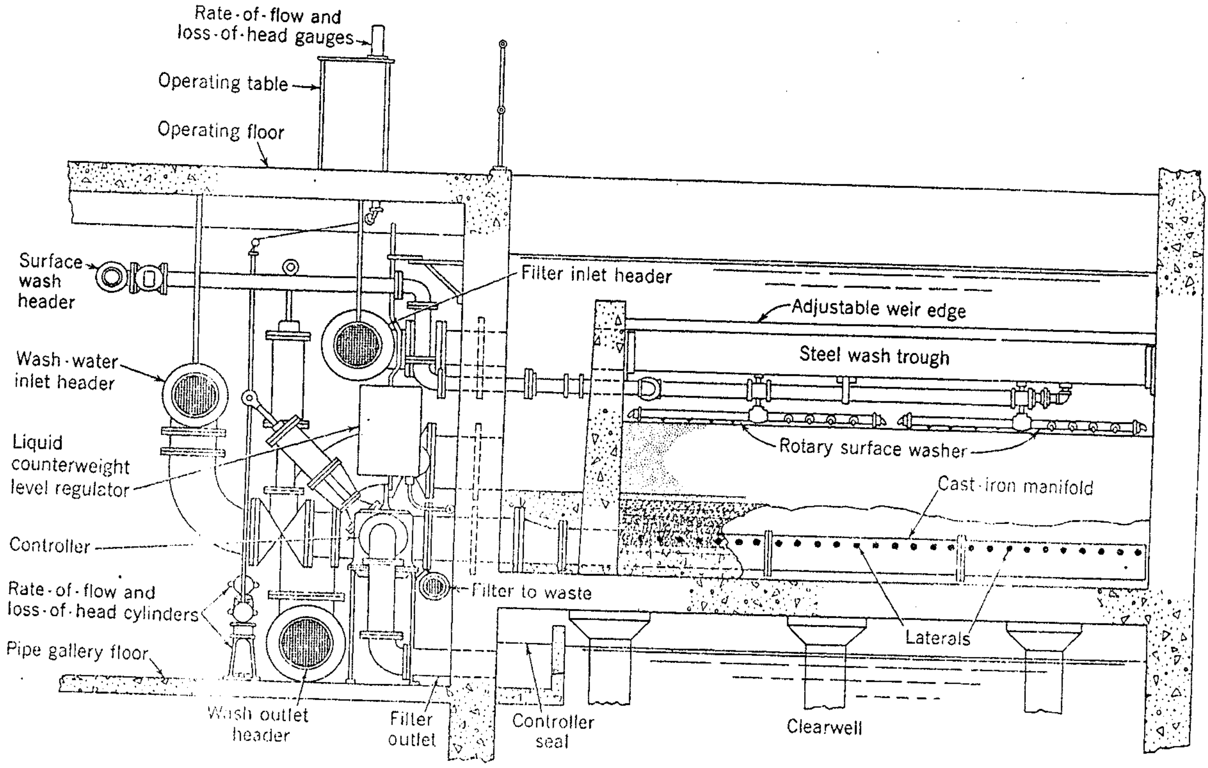


Figure 4.1 . Sectional diagram of gravity sand filter showing feed and wash piping systems, graded sand and gravel bed, and clearwell. (Courtesy The Permutit Co.)

Example 4.1

An open sand filter uses a 3-ft-deep bed of -20 +28 mesh sand as primary filter bed. The sand particles used have an estimated spheroid of 0.9. If the slurry being filtered is essentially water and stands 2 ft deep over the top of the sand, determine the maximum flow rate through the bed which occurs immediately after backwashing.

Solution

The average particle size, as determined from the screen openings, is 0.0280 in. Since the particle area and volume are not known, the particle diameter (D_p) cannot be precisely determined. One method would be to take D_p as equal to 0.0280. An alternate approach is to assume the particles have a volume equal to that of a sphere of D = 0.0280 in. Then

$$\text{Surface of sphere} = \frac{\pi \times \overline{0}.0280^2}{144} \text{ sq ft}$$

$$S_p = \frac{S_{sphere}}{\psi} = \frac{\pi \times 0.0280^2}{0.9 \times 144} \text{ and } V_p = \frac{\pi \times 0.0280^3}{6 \times 1728} \text{ cu ft}$$

$$\text{This gives } D_p = \frac{\dfrac{\pi \times \overline{0.028}^3}{1728}}{\dfrac{\pi \times \overline{0.028}^2}{0.9 \times 144}} = 0.0021 \text{ ft}$$

Applying Equation

$$\frac{(-\Delta P)_f}{L} \cdot g_c = 180 \frac{(1-\epsilon)^2}{\epsilon^3} \frac{\mu v_s}{D_p^2}$$

From Appendix B, Figure B – 10, the porosity is estimated at 0.40 Then,

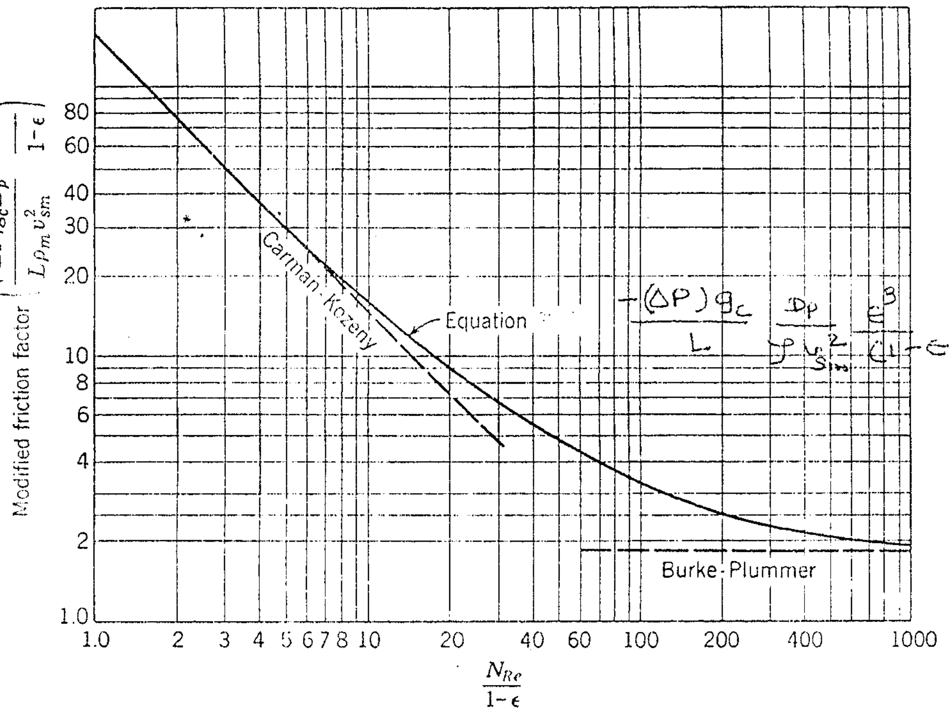
$$\frac{5 \times 62.4}{3} \times 32.2 = 180 \frac{\overline{0.6}^2}{\overline{0.4}^3} \times \frac{(1 \times 0.000672) \times v_s}{\overline{0.0021}^2}$$

$$v_s = 0.0218 \text{ ft/sec}$$

Note that in this solution $p\Delta z\, g/gc$ has been substituted for ΔP. The carman-Kozeny equation is correct only at low N_{Re}. Checking the N_{Re},

$$N_{Re} = \frac{0.0021 \times 0.0218 \times 62.4}{1 \times 0.000672} = 4.25$$

From the following Figure, it is apparent that at this N_{Re} the Carman-Kozeny equation is in error by 36.5/35.0 in terms of $1/v_{sm}2$. Thus, the corrected V_{sm} is



$$\frac{-(\Delta P) g_c}{L} \frac{D_p}{\rho v_{sm}^2} \frac{\epsilon^3}{(1-\epsilon)} = 150 \frac{(1-\epsilon)}{N_{Re}} + 1.75$$

Figure . . Pressure drop for flow through packed beds.

$$V_{sm} = 0.0218 \sqrt{\frac{35}{36.5}} = 0.0214 \text{ ft/sec}$$

The volumetric flow is 0.0214 x 60 x 7.48 = 9.6 gal/sq ft min. This applies immediately after backwashing. The average rate for the entire filter cycle may be less than half this figure.

For filtering a gas-solid material, the bag, or hat, filter is often used. This filter consists of large felt or canvas bags stretched across the openings in a framework built across the gas-flow passageway. Several hundred of these bags may be placed in parallel in this way. The gas passing through the bags deposits the entrained solids on the inside of the bags. Periodically the bags are cleaned by shaking the rack to which they are fastened. The household vacuum cleaner operates on this same principle.

4.2 Plate-and-Frame Filter Press

The filter press has long been the most common filtering device throughout the chemical industry. Although it is now being replaced in large installations by continuous filter devices it has the advantages of low first cost, very low maintenance, and extreme flexibility. On the other hand, the need for periodic manual disassembly represents a large labor requirement that is often excessive.

The filter press is designed to accomplish a variety of functions, the sequence of which is controlled manually. During filtration the press (a) permits the delivery of feed slurry to the filter surfaces through its own duct, (b) permits the forcing of feed slurry against the filter surfaces, (c) permits filtrate which has passed through the filter surfaces to exit through its own duct, while it (d) retains the solids that were originally in the slurry. During the wash sequence the press (a) permits delivery of wash water to the filtered solids through its own duct, (b) permits the forcing of wash water through the solids retained in the filter, and (c) permits wash water and impurities to leave through a separate duct. Filter design can include four separate ducts as indicated above or can allow for only twoducts where the contamination of the liquid products is not important. After the wash sequence the press is disassembled, and the solids may be collected manually or merely removed and discarded.

The most common filter-press design consists of alternate plates and frames hung on a rack and forced tightly together with a screw – or hydraulic-closing mechanism. Figure 4.2 shows a plate-and-frame pair; Figure 4.3 is a diagram of a filter press in operation, and Figure 4.4 is a photograph of a typical filter press. To set up this press, the plates and frames are hung alternately on the side rails of the press using the side lugs on the plates and frame. The filter medium is then hung over the plates extending over both faces of the plate. The filter medium may be canvas or synthetic cloth, filter paper, or woven wire. Holes are cut in the cloth to match the channel holes in the plates and frames. If cloth is used, it may be necessary to preshrink the medium so that the holes will continue to match. When the filter cloths are aligned with the plates and frames, the press is closed with a hand screw or in large sizes by hydraulic - or electric - closing devices. When the press is

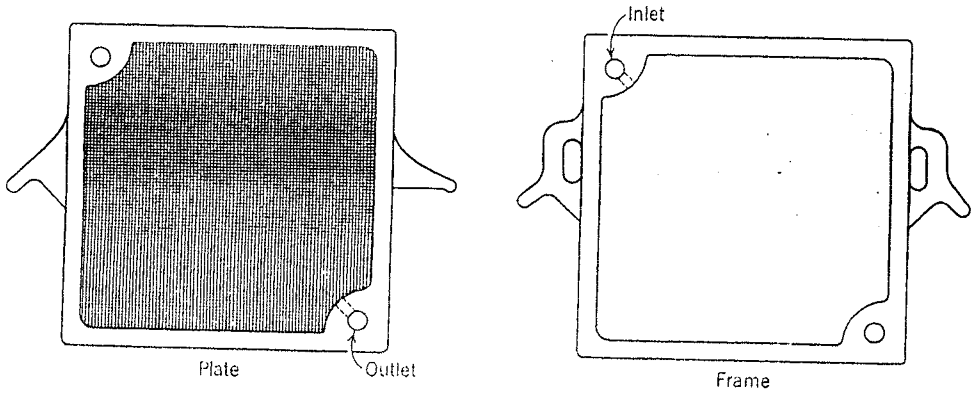


Figure 4.2 Plate-and-frame pair of simple corner-hole nonwashing design with closed discharge and waffle-grid surface. (Courtesy T. Shriver and Company.)

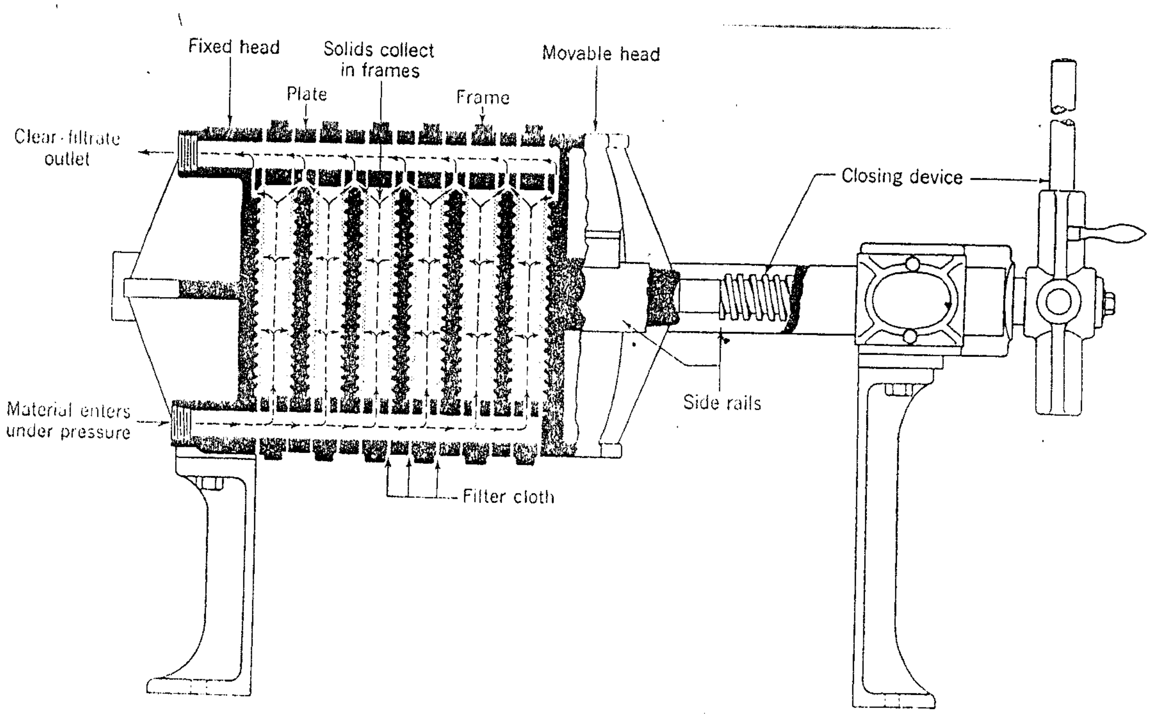


Figure 4.3 Schematic Diagram of Filter Press in Operation

closed the filter medium acts as a gasket, sealing the plates and frames and forming a continuous flow channel from the holes in the plates and frames as shown in Figure 4.3. Feed slurry is then pumped to the press under pressure and flows in the press of Figures 4.2 and 4.3 into the bottom-corner duct. This duct has outlets into each of the frames, so the slurry fills the frames in parallel. The solvent, or filtrate, then flows through the filter media while the solids build up in a layer on the frame side of the media. The filtrate flows between the filter cloth and the face of the plate to an outlet duct. As filtration proceeds, the cakes build up on the filter cloths until the cakes being formed on each face of the frame meet in the center. When this happens, the flow of filtrate, which has been decreasing continuously as the cakes build up, drops off abruptly to a trickle. Usually filtration is stopped well before this occurs.

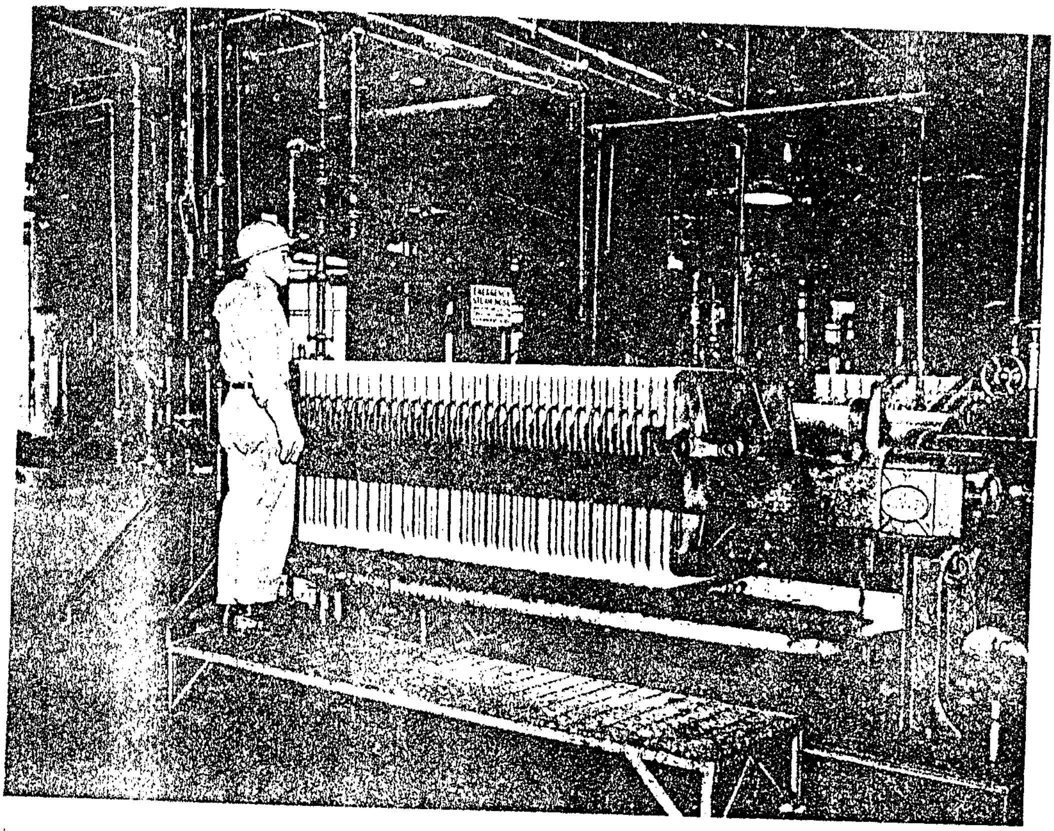


Figure [illegible] A filter press operating in a chemical plant separating neutralizing salts from 1,2,6-hexanetriol before distillation. (T. Shriver and Company, Courtesy Am. Chem. Soc.)

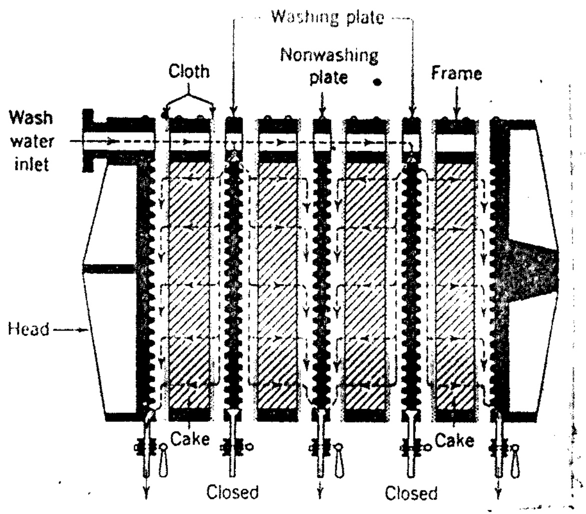


Figure 4.5 Schematic diagram of through-washing in a plate-and-frame filter press with open delivery. Note one button, two-button, three-button coding on the top edge of the plates and frames. (Courtesy T. Shriver & Co.)

In many cases, it is desirable to wash the filter cake in order to remove the solvent trapped in the cake or dissolve impurities from the cake. In a filter using the plates of Figure 4.2, the washing could be done by feeding wash water into the feed opening, but, if the cake nearly fills the frames, the wash water may be blocked from passage just as is the feed slurry. A better system is afforded by the through-washing plate-and-frame press. In this press, a separate channel is supplied for the wash-water inlet; in closed-delivery presses, a separate exit channel is also supplied. Wash water enters the channel which has ports opening behind the cloths at every other plate. The wash water then flows through the filter cloths, through the cake built up in an entire frame, through the filter media at the other side of the frames, and out the discharge channel. The flow path is shown in Figure 4.5. In this figure, an open-discharge filter press is pictured. In this figure, an open-discharge filter press is pictured. In the closed-discharge press shown in Figure 4.3, the outlet streams would be collected into a common duct like the inlet duct. Note that in this press there are two kinds of plates: those with ducts to admit wash water behind the filter media alternating with those without such ducts. In closed-delivery presses, the alternate plates often have ducts to permit the withdrawal of wash through a channel separate from the [illegible]. [illegible] plates and frames are coded with buttons on the top edge: one button [illegible] plate, two buttons a frame, [illegible] a washing plate. Figure 4.6 shows the plates and frame for a **through-washing open-delivery** filter press.

Filter presses can be made of any construction material desired such as wood, cast iron, rubber, and stainless steel. They can be built for slurry pressures up to 1000 psia. They can handle the filtration of heavy slurries or the polishing of a liquid containing only a faint haze of precipitate. For these reasons, they are used widely throughout the process industries, but, in operations involving a large, continuous throughput, the requirement of manual cleaning and assembling becomes prohibitively expensive.

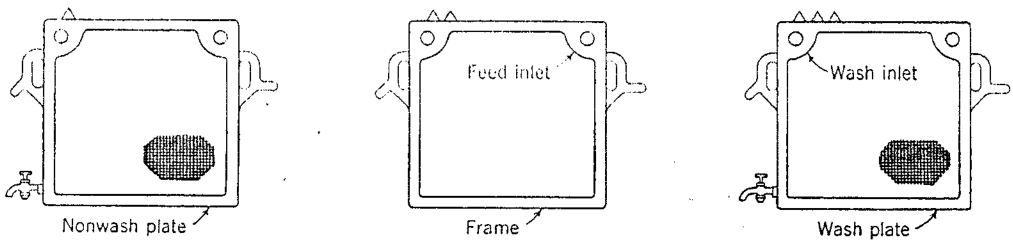


Figure 4.6 Plates and Frame for a Through-Washing Open-Delivery Filter Press

4.3 Other Batch Filters

A large variety of filters is made which, though still batch filters, do not require the complete disassembly for cleaning that is necessary with a plate-and-frame filter press. A few of these are shown in Figures 4.7, 4.8, 4.9 and 4.10. All these filters use varieties of filter leaves. The filter leaf is a hollow, internally supported plate as shown in Figure 4.8, which is permanently covered with filter medium. The slurry to be filtered fills the space around the leaf and is forced by pressure on the slurry or vacuum within the leaf to flow through the leaf. Filter cake is built upon the outside of the leaf and filtrate passes from within the leaf to the filtrate discharge system. When a cake of the desired thickness is built up on the leaves, the filter is opened, and the leaves are either removed for cleaning or are cleaned in place manually or by sluicing away the solids. Of the filters shown the horizontal-plate filter, Figure 4.7 is particularly well adapted for the final clarifying of solutions containing minute quantities of solids because of the ease of applying a filter aid precoat. Filter aids are open-structured incompressible solids that may be deposited on the filter cloths to serve as a high-efficiency filter medium. They are further discussed below. The horizontal leaf filter (Figure 4.9) is built in very large sizes and can be opened particularly rapidly for cleaning. The Sweetland filter, (Figure 4.7) is made in two half-cylinders. The bottom half opens downward by releasing the quick-opening cam locks to expose vertical disk-shaped leaves which are cleaned in place.

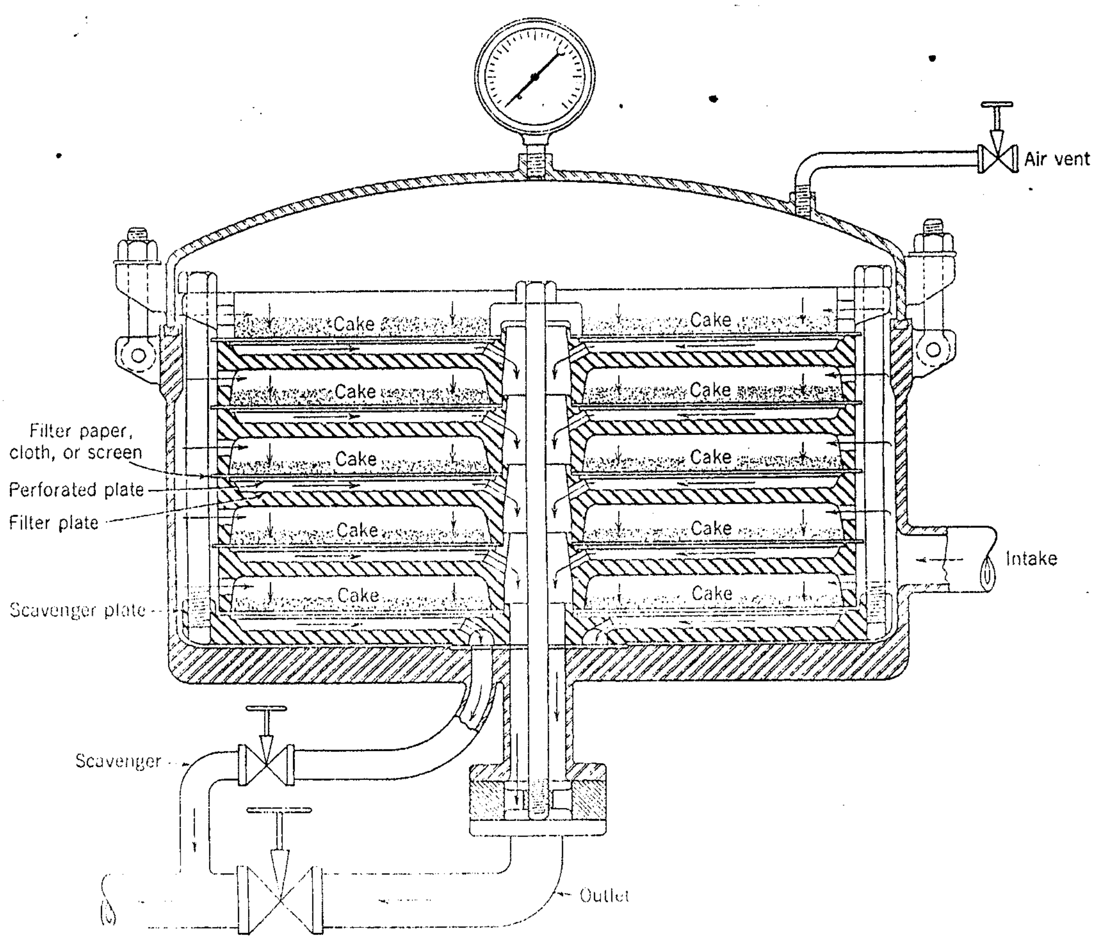


Figure 4.7 Cross-sectional schematic diagram of a horizontal plate filter. Patented scavenger-plate filters last of each batch. The scavenger valve is opened during precoating and closed until the end of the cycle. Then the outlet valve is closed, scavenger valve opened, and remaining liquid is filtered through the scavenger plate by introducing air or gas pressure through the intake. (Courtesy Sparkler Mfg. Company.)

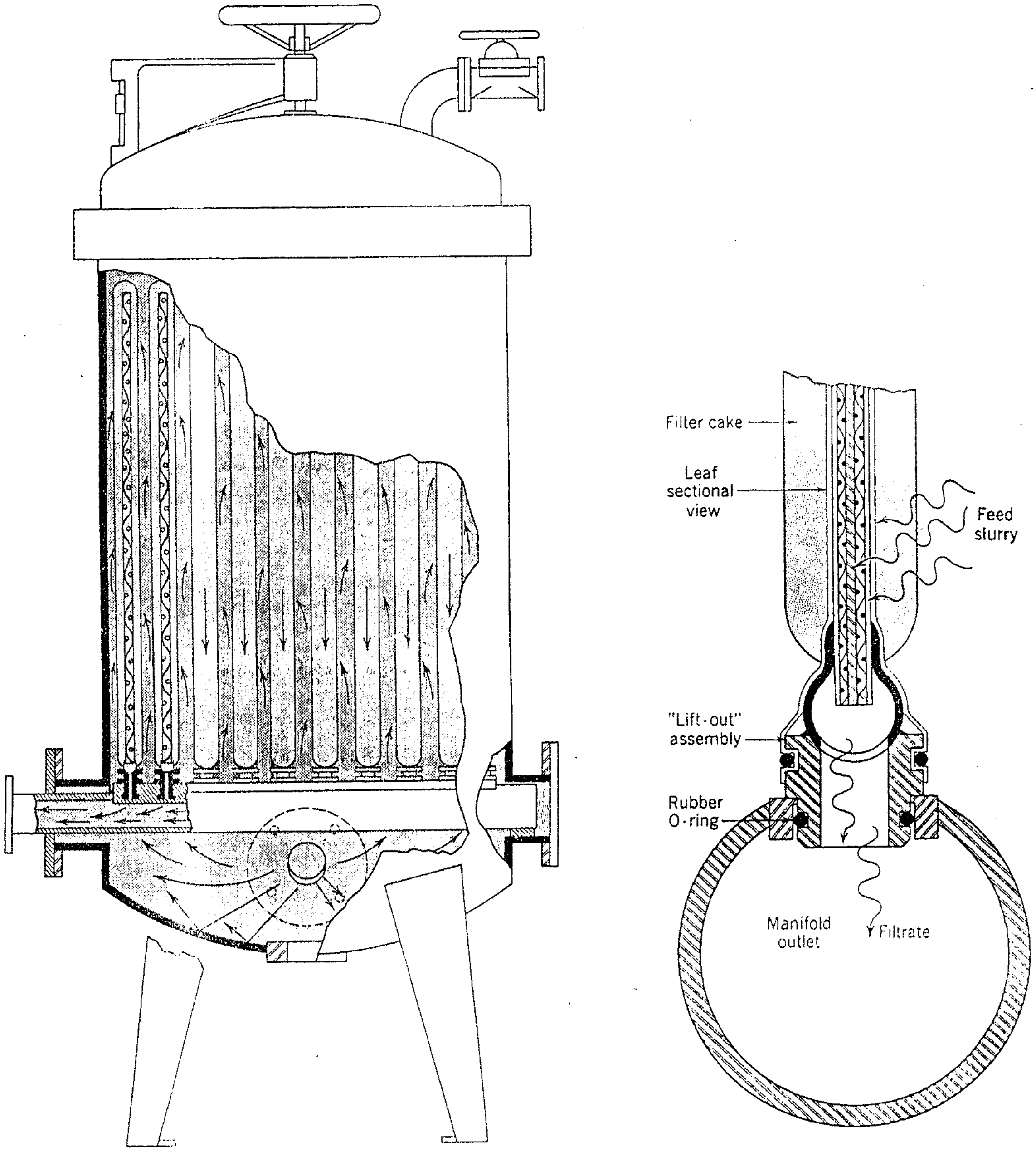


Figure 4.8 Cutaway view of a vertical-leaf filter and sectional diagram showing filter-leaf construction. (Courtesy Industrial Filter & Pump Mfg. Co.)

4.4 Continuous Filters

Modern, high-capacity processing has made the development of continuous filters mandatory, and several varieties are in common use. In such filters, the slurry is fed continuously, and cake and filtrate are produced continuously.

The horizontal rotary filter of Figures 4.11 and 4.12 is particularly well adapted to the filtering of quick draining crystalline solids. Its horizontal surface prevents the solids from falling off or from being washed off by the wash water, and an unusually heavy layer of solids can be tolerated. This filter consists of a circular horizontal table that rotates around a center axis. The table is made up of a number of hollow pie-piece-shaped segments with perforated or woven metal tops. Each of the sections is covered with a suitable filter medium and is connected to a central valve mechanism that appropriately times the removal of filtrate and wash liquids and the dewatering of the cake during each revolution. Each segment successively receives slurry, is then sprayed with wash liquid in two applications, has its cake dewatered by pulling air through the cake, and has its cake scooped off the surface by the discharge scroll.

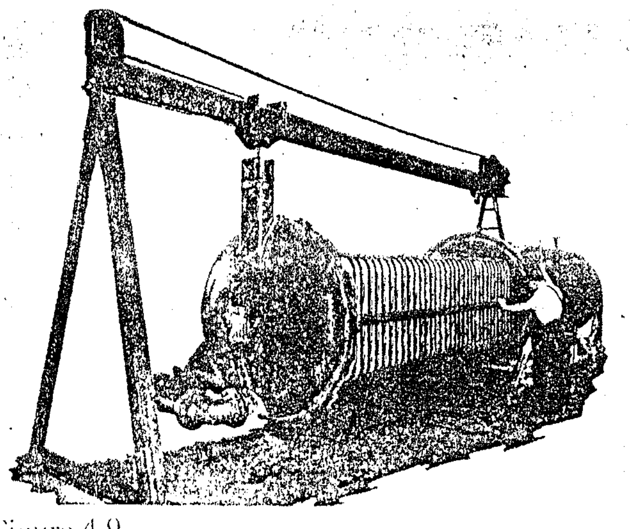


Figure 4.9 A large horizontal-leaf filter open for cleaning. This filter has 800 sq ft of filtering area and a capacity of up to 800 gal/min of water. (Courtesy Niagara Filters Division, American Machine and Metals, Inc.)

The rotary-disk vacuum filter is shown in Figure 4.13. This filter gives an especially high filtration rate for a given floor space. The filtering medium is again a wedge-shaped leaf covered with a filter medium. Here, the leaves rotate in a vertical plane around a horizontal axis. The slurry to be filtered fills the filter basin almost up to the filter axis. As the leaf dips through the slurry, it collects a cake on its surfaces while the filtrate passes through to a central discharge system. The leaf then carries the filter cake through the upper half of its rotation while air pulled through the cake dries it. The cake is scraped off the leaves by doctor knives or is blown off with compressed air fed inside the leaves before they dip again into the slurry. No provision is made for washing the cake. If a filter cloth becomes worn or torn the single segment may be removed and replaced with a new one relatively quickly.

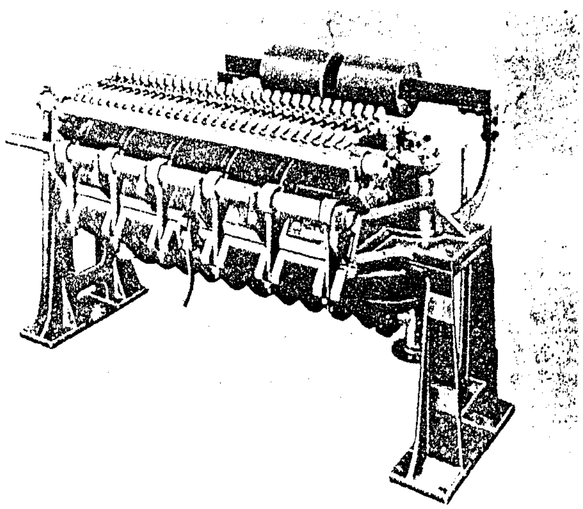


Figure 4.10 A Sweetland Pressure Filter Closed for Filtration

The rotary-drum vacuum filter with string discharge is shown schematically in Figure 4.14, and a somewhat different rotary vacuum filter is pictured in Figure 4.15. With either unit, the cycle is very much like that of the horizontal vacuum filter. Filter cake is picked up from a slurry pool by dipping the drum surface and applying vacuum. The cake is then carried around the drum where it is successively washed and dewatered by the continuous application of vacuum to the inside of the drum. The string-discharge system leads the cake away from the drum and over a roll with sharp curvature which causes the cake to drop off. Figure 4.14 shows

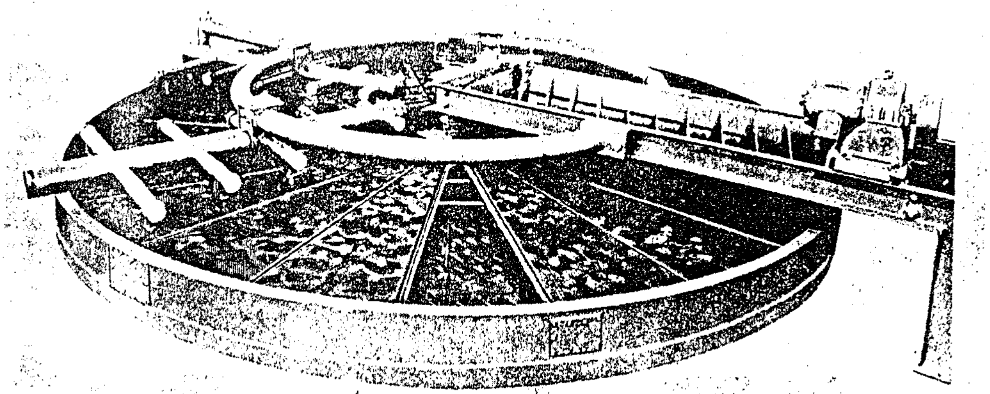


Figure 4.11 Horizontal-rotary vacuum filter showing arrangement of piping for two stages of wash and scroll cake-removal mechanism. One section of filter medium is removed to illustrate deck support and drainage slope. (Courtesy Dorr-Oliver, Inc.)

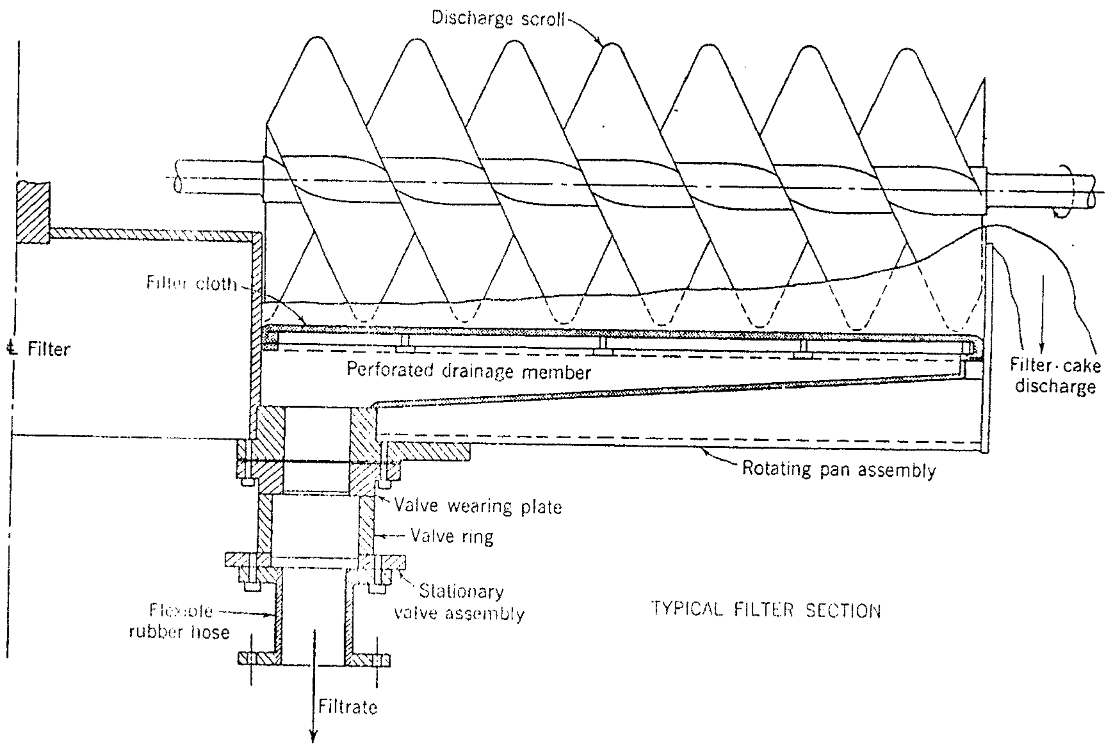


Figure 4.12 Cross-sectional view of a rotary horizontal vacuum filter showing filtrate-removal system, filter cloth, and discharge scroll. (Courtesy Filtration Engineers Division, American Machine and Metals, Inc.)

the agitator in the slurry pool that prevents settling of the slurry, the discharge valve that controls withdrawal of filtrate and wash liquids and the dewatering of the cake, the drain lines that apply vacuum to the drum surface, and the drum surface construction. For coarse particles which settle rapidly and form a porous cake, a feed hopper on top of the drum is more satisfactory than the dipping hopper shown.

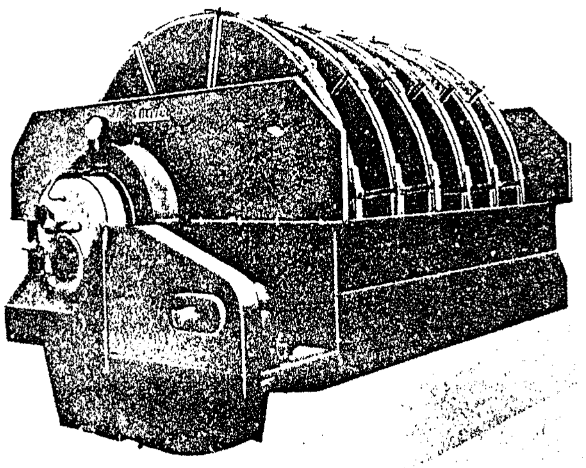


Figure 4.13 Rotary- Disk Vacuum Filter, 8 – ft Face by 6 Disk, Shown from Valve and Drive End

The unit shown in Figure 4.15 duffers from that in Figure 4.14 mainly in the cake-discharge mechanism. This unit uses a motor-driven doctor knife that moves toward the filter drum at an extremely slow rate. This permits the application of an initial, or precoat, layer of filter aid perhaps 1 to 2 in. thick. After this layer is in place the slurry is fed to the dip tank, and filter cake builds up on the precoat layer of filter aid. The doctor knife removes the filter cake and a very thin layer of filter aid. As filtration progresses the filter-aid layer gets progressively thinner until a new layer must be applied. However, the doctor knife moves so slowly that a precoat layer will last as long as a week.

4.5 Filter Media and Filter Aids

As mentioned above filter media consisting of cloth, paper, or woven or porous metal may be used. The criteria upon which a filter medium is selected must include ability to remove the solid phase, high liquid throughput for a given pressure drop, mechanical strength, and chemical inertness to the slurry to be filtered and to any wash fluids.

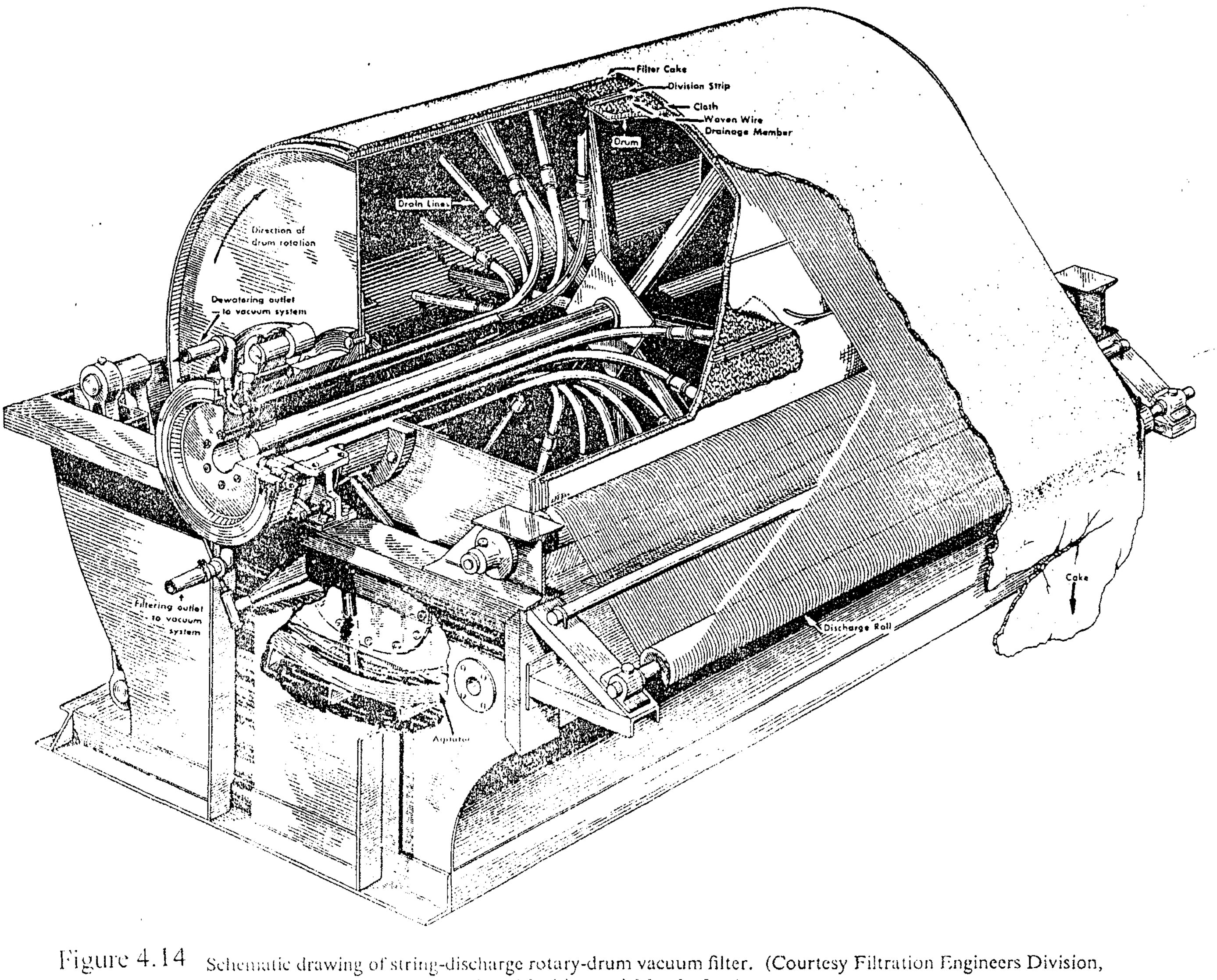


Figure 4.14 Schematic drawing of string-discharge rotary-drum vacuum filter. (Courtesy Filtration Engineers Division, American Machine and Metals, Inc.)

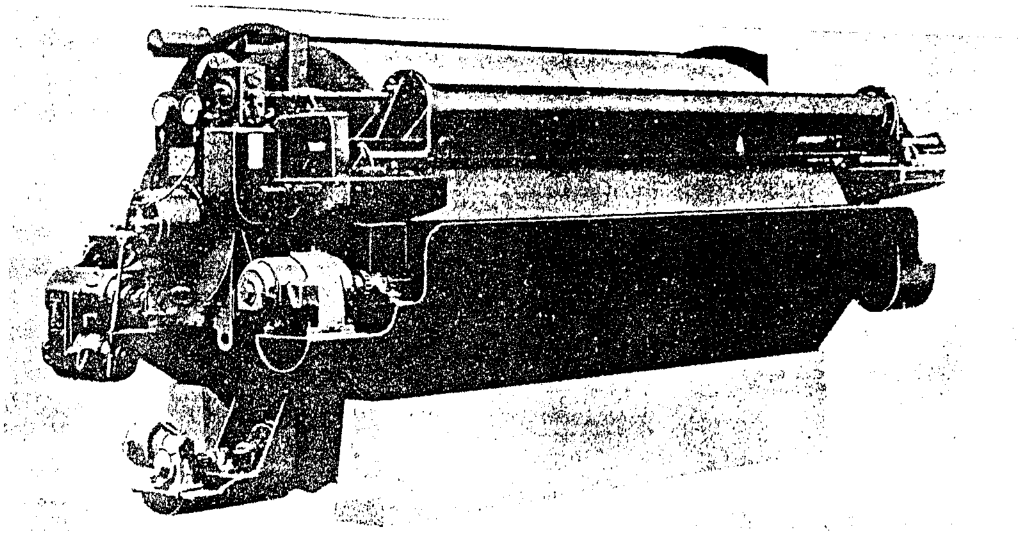


Figure 4.15 Continuous vacuum precoat filter, 5 ft 3 in. diameter × 8 ft face. (Courtesy Dorr-Oliver, Inc.)

Of course, each of these considerations is tempered by the economics involved, so that the filter operator tries to choose a medium that meets the required filtration standards while contributing to the lowest possible over-all filtration cost.

A variety of filter media have been tested for poresize distribution. The tests showed that with a woven-cloth medium both interfiber and interyarn pores exist with 30 to 50 per cent of the total pore volume being made up of interfiber pores. The interfiber pores are the spaces between the fibers making up a single thread of the cloth, whereas interyarn pores are the spaces between the threads woven to form the cloth. These inbterfiber pores were less than 10 microns in radius. The interyarn pores were found to range between 70 and 200 microns in radius. With a felt medium, all the pores are interfiber, but, because of the random fiber orientation, they were found to vary between about 2 and about 180 microns nearly following a logarithmic normal-distribution function with a mean between 10 and 20 microns. The sintered-metal media tested had a much more uniform pore-size distribution with 90 per cent of the pore volume falling between 20 and 50 microns in radius.

In operation, some filter-cake solids usually penetrate the filter medium and fill some of the pores. As filtration continues, these particles are thought to bridge across the pores and cake begins to form on the face of the medium. In normal cases, between 5 and 25 per cent of the pore volume of the filter medium is filled with solids. As a result, the resistance to flow through the medium increases sharply. In some cases, the solids fill the filter medium to such an extent that the filtration rate is seriously reduced.

Filter aids are often used to speed filtration or to make it possible to collect more completely the finest particles held in the slurry. The filter aids are finely divided, hard-structured solids that themselves form an open, noncompressible cake. The most common example is diatomaceous earth, which consists of the skeletons of very small prehistoric marine animals. This material is mined from large surface deposits mainly in California, Oregon, and Nevada. It is practically pure silica and has a very complicated structure. Applied as a precoat on the filter cloth, the filter aid acts as the primary filter medium and permits complete removal of very fine solid particles from the slurry. Another method of application is to mix the filter aid into the slurry. Here, it distributes throughout the cake, keeping the cake relatively open for flow and continuously supplying a large surface for adhesion of very finely divided solids. This action is particularly valuable when filtering colloidal solids that form a very dense and compressible cake, which is not to be recovered. During 1950, some 180,000 tons of diatomaceous earth were used as filter aid in the United States.

4.6 Filtration Calculations – General Relations

The flow of filtrate through the filter cake should be describable by any of the general equations for flow through packed beds. Actually, in almost all practical cases, flow is laminar, and the Carman-Kozeny equation

$$\frac{(-\Delta P)_f g_c}{L} = 180 \frac{(1-\epsilon)^2}{\epsilon^3} \frac{\mu v_s}{D_p^2}$$

applies. This equation relates the pressure drop through the cake to the flow rate, the cake porosity and thickness, and the solid-particle diameter. Some modification of the equation is necessary so that the measureable variables of filtration can be introduced into it.

In its more usual form, it is written in terms of the specific surface area of the particles by incorporating Equation.

$$D_p = \frac{6}{\dfrac{A_p}{V_p}} = \frac{6}{S_0}$$

Where S_0 = specific surface area of particle, sq ft/cu ft of solid volume

Thus

$$\frac{(-\Delta P)_f g_c}{L} = \frac{5(1-\epsilon)^2 \mu v_s S_0^2}{\epsilon^3} \tag{4.1}$$

Solving this equation for the velocity of flow gives

$$v_s = \frac{(-\Delta P)_f g_c \epsilon^3}{5L\mu S_0^2(1-\epsilon)^2} = \frac{1}{A}\left(\frac{dV}{d\theta}\right) \qquad (4.2)$$

Where $dV/d\theta$ = the filtration rate, that is, the volume of filtrate passing through the bed per unit time

A = filtration area

In order to integrate Equation 4.2 to obtain a relation usable over the entire process, only two variables may appear in the equation. As written, the quantities V, θ, L, $(-\Delta P)_f$, S_0, and ε may all vary. The cake thickness (L) may be related to the volume of filtrate by a material balance, since the thickness will be proportional to the volume of feed delivered to the filter.

$$LA(1-\varepsilon)\rho_s = w(V + \varepsilon LA) \qquad (4.3)$$

Where ρ_s = density of the solids in the cake

W = weight of solids in the feed slurry per volume of liquid in this slurry

V = volume of filtrate which has passed through the filter cake

The final term of Equation 4.3, (εLA) represents the volume of filtrate held in the filter cake. It is normally infinitesimal compared to V, the filtrate which has passed through the bed. Assuming this term negligible and combining Equation 4.2 with Equation 4.3 to eliminate L gives

$$\frac{1}{A}\frac{dV}{d\theta} = \frac{(-\Delta P)_f g_c \epsilon^3}{5\dfrac{wV}{A\rho_s}\mu(1-\epsilon)S_0^2} = \frac{(-\Delta P)_f g_c}{\dfrac{\alpha\mu w V}{A}} \qquad (4.4)$$

where α is the specific cake resistance, defined as

$$\alpha = \frac{5(1-\epsilon)S_0^2}{\rho_s \epsilon^3} \qquad (4.5)$$

A similar equation in terms of L could also be obtained by eliminating V between Equations 4.2 and 4.3.

Equation 4.4 is the basic filtration equation in terms of the pressure drop across the filter cake alone. The collection of all terms involving the filter-cake properties into the specific cake resistance does not infer that the resistance (α) will be constant for a given feed slurry, regardless of filtering pressure drop or of filter type or size. The specific cake resistance may not even remain constant throughout a given filter operation at constant $(-\Delta P)_f$ because of variations in ε and S_o. The void fraction (ε) usually varies with variation of the compacting stress applied to the bed. This stress will be directly proportional to $(-\Delta P) / L$, and, since L varies throughout the process, ε may also vary. Both ε and S_o are sensitive to the degree of flocculation of the precipitate in the feed. The flocculation may vary with the turbulence of flow of slurry fed to the press and hence may be a function of the filter rate. However, in most constant-pressure filtrations, α is constant except in the initial moments of filtration when the flow rate is very high and the form of the filter cake has not been fixed. In fact, for many filter cakes, α is relatively insensitive to changes in $(-\Delta P)_f$ Such cakes are said to be incompressible, though probably no cakes is completely incompressible.

4.7 Filtration Calculations-Inclusion of Filter-Medium Resistance

Equation 4.4 is expressed in the familiar form of a rate proportional to a driving force divided by a resistance. Here, both driving force and resistance apply to the filter cake alone. However, practically any ($-\Delta P$) measured will at least include the pressure drop across the filter medium and will probably include the pressure drop of various flow channels before and after the actural filtering area. If such an over-all pressure drop is to be used in an equation like ~~Equation~~ 4.4 the resistance term must also include the flow resistances of the additional parts of the apparatus. Since these resistances are arranged in series, Equation 4.4 becomes

$$\frac{dV}{A\,d\theta} = \frac{(-\Delta P_t)g_c}{\mu\left(\frac{\alpha w V}{A} + R_M\right)} \tag{4.6}$$

where R_M has the units $(ft)^{-1}$ and represents the resistance of filter medium and piping to filtrate flow. For convenience in analyzing filtration-performance data, the resistance of filter cloth and flow channels is usually expressed in terms of an equivalent volume of filtrate

$$\frac{dV}{A\,d\theta} = \frac{(-\Delta P_t)g_c}{\frac{\mu\alpha w}{A}(V + V_e)} \tag{4.7}$$

Here V_e is the volume of filtrate necessary to build up a fictitious filter cake, the resistance of which is equal to the resistance of the filter medium and the piping between the pressure taps used to measure $(-\Delta P_t)$. The filter medium resistance of significance here is the resistance of the medium with the pores partially blanked with filter cake and with the initial layer of filter cake, on which the bulk of the filter cake will be built, in place. It is considerably greater than the resistance to water flow of he clean filter cloths.