FILTER-CAKE FILTRATION:

Putting the Principles to Work –

For Effective Operation, Know The Nature Of Your Solids

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Filter-cake filtration is probably the most popular solid-liquid separation method in the process industries. A good understanding of the principles behind the technique can foster its effective use.

Although the equipment takes several forms, its operation is basically the same. The solid-liquid feed stream passes through a porous screen that retains the solids but passes the liquid. As the flow continues, a cake builds up on the screen. This cake has a complex pore structure determined by the nature of the solid particles. The structure removes additional particles by a simple straining mechanism.

The effectiveness of the separation depends on cake permeability, pore size, particle size and compressibility. Complicating the picture, permeability itself is a function of the other three variables. Typically, filtration calculations assume permeability to be constant and determine its effect upon the fluid flow through the cake. In the discussion here, however, we also look into how compressibility, pore size and particle size affect permeability.

The equation that describes the flow of Newtonian fluids through a porous bed was formulated by a French geologist name d'Arcy. Disregarding gravitational effects on the fluid, a form of the d'Arcy equation adapted for filtration can e written as:

$$Q = KAP/ul \qquad (1)$$

where Q is liquid flowrate, K is permeability of the filter cake, P is pressure drop across the cake, A is filtration area, u is liquid viscosity and L is filter cake thickness.

This simple equation is adequate for geological use because the value of L is constant and Q can be calculated as a function of the other variables. During filter-cake filtration, however, the cake thickness increases as more liquid is filtered. To account for the changing thickness, the d'Arcy equation can be modified to give the differential equation:

$$dV/dT = KAP/uL \qquad (2)$$

The value of L increases as a function of the volume of liquid filtered as follows:

$$L = CV/ DA \qquad (3)$$

where C is mass of solids per unit volume of liquid, D is bulk density of solids deposited, V is volume of liquid filtered and A is filtration area.

Substituting the expression for L into the modified d'Arcy equation gives the following differential expression describing cake filtration:

$$VdV = (KA^2PD/uC)dT \qquad (4)$$

This equation can be integrated for the various flow conditions encountered by the process engineer.

The equation applies only to dilute slurries. When the solids volume is more than about 5% of the total volume of liquids filtered, other flow equations not covered in this article must be developed. However, the great majority of filter-cake filtrations in the process industries do treat slurries that are under that ceiling.

From the standpoint of the operating parameters, two special cases are industrially important. One is constant-rate filtration, wherein the rate feed delivery to the filter stays the same during the filtration cycle. The other is constant-pressure filtration, in which the feed is delivered under a pressure that does not vary over the cycle.

Constant-rate filtration

Constant rate or flow approximates numerous industrial filtrations because many slurry pumps have a fairly flat delivery-rate-vs.-head curve. In constant-rate filtration, the pressure drop across the screen and cake will be low during the early part of the filtration cycle. But as the cake thickens, the pressure drop will increase up to a final value dictated by either the pump characteristics or the pressure limits of the filter press. For constant-rate filtration, the d'Arcy equation becomes:

$$T = KDP/CuR^2 \qquad (5)$$

where P is the final pressure and R is equal to Q/A.

The equation implies a linear relationship between filtration time and pressure drop during constant-rate filtration. Practice shows, however, that most constant-rate filtrations exhibit some degree of curvature in the Plots of P vs T. The relationship is closest in to linear in those cases where the filter cake is composed of incompressible particles having a fairly narrow particle-size distribution.

Inspection of the equation also reveals that the most important variable to control is the specific flowrate R. By halving the flowrate, the engineer can increase the filtration time per cycle by a factor of four, thereby doubling the overall volume of liquid filtered per cycle. The specific flowrate is controlled either by changing the slurry delivery rate to an existing filter, or by adding more filter area.

Constant-pressure filtration

When the filtration cycle is conducted under constant pressure, the flowrate gradually decreases as the cake builds up. Such filtration is especially prevalent as a means for gathering test data — in support of, for instance, a process design or a plant retrofit because the cumulative volume of a filtration can be readily measured as a function of time.

In the laboratory, for example, such data can be obtained using a stirred pressurized bomb filter. A suitable inert gas imposes a constant pressure over the slurry in the bomb, which forces the liquid through the filter septum into a calibrated filtrate receiver.

The flow equation for constant-pressure filtration is:

$$V2/2 = KA2PDT/uC \qquad (6)$$

or, by rearrangement,

$$T = V2uC/2KA^2PD \qquad (7)$$

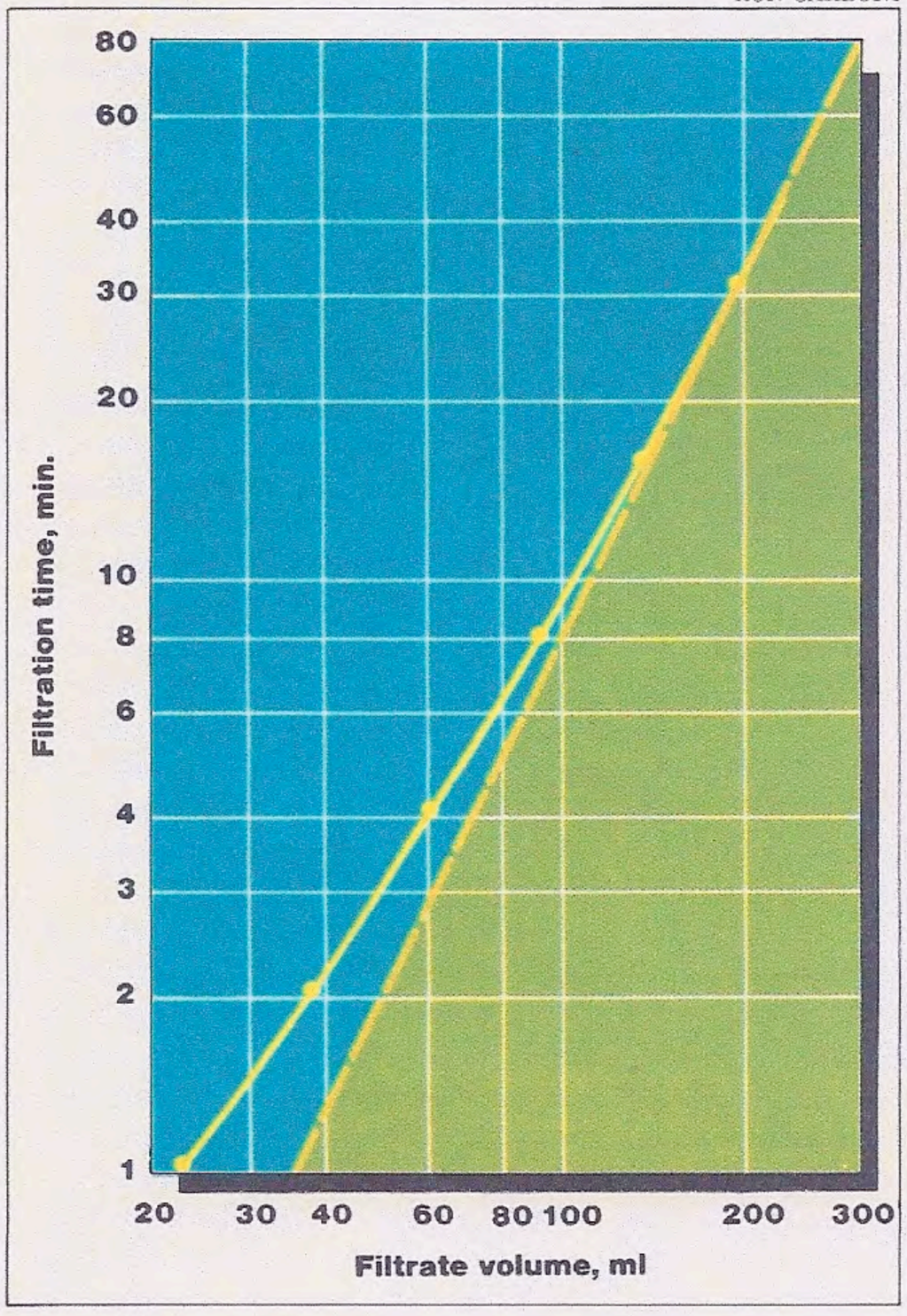
Thus, for a given test run, if the elapsed time is plotted against cumulative volume on log-log paper, the equation predicts a straight line having a slope of 2, with its intercept of the vertical axis at V=1 (log V =0) having a numerical value as follows:

$$Intercept = uC/2KA^2PD \quad (8)$$

(Conversely, cumulative volume can be plotted against elapsed time, giving a line with slope and intercept that are the reciprocals of the values indicated here.)

The intercept is of interest because it enables calculation of the filter-cake permeability. The viscosity u, solids concentration C, filtration test area A, filtration pressure P and apparent cake density D can all be determined, so the K can be calculated directly from Equation (8). When V is in cubic centimeters, u in centipoise, C and D in grams per cubic centimeter, A in square centimeters, P in atmospheres and T in seconds, the unit for K is known as the d'Arcy.

Figure 1 shows a typical test filtration. The plot is actually a slightly curved line, which asymptotically approaches a straight line having a slope of 2. The asymptote is extended downward to determine the intercept value, for determination of cake permeability.



For example, if Figure 1 (Left) were extended downward and leftward far enough that the asymptote could intersect the vertical axis where log V equals zero, the intercept would have a value of 0.00083 min (0.0498 sec). For the liquid being filtered, the viscosity is 1.2 centipoises, the apparent cake density 0.32 g/ cc, the test filter area 6.5 cm2, filtration pressure 10 psi (0.68 atm.), and solids concentration 0.005 g/cc. Substituting these values into Equation (8) gives

$0.0498 = 1.2(0.005)/2K(6.5)^2(0.68)(0.32)$ or K = 0.0066 d'Arcys.

Once we obtain the value of K, we can predict the behavior of the solids in the filter cake by adapting Equation (4) to the particular flow conditions of the process. For instance, if the process for this liquid requires a constant 100-gpm flow-rate and the available filtration area is 400 ft^2 and the terminal pressure is 40 psi (2.72 atm), the expected cycle length can be found from Equation (5).

The specific flowrate Q is 100/400, i.e., 0.25 gpm/ft2 (which is 0.017 cc/seccm2), and the other variables are as given earlier. Substituting these values into the equation gives

$T= 0.0066(0.32)(2.72)/(0.005)(1.2)(0.017)^2 =$ 3,313 sec, or 55 min.

Compressible filter cake

The flow equations discussed to this point assume that the permeability of the cake is constant. In some filtration the cake is compressible. During filtration involving such a cake, the outer surface of the cake is under lower compressive pressure than the portion near the filter septum. This results in a low permeability near the septum and a relatively high one at the cake surface. For a compressible filter cake, the previous flow equations become as follows.

For constant pressure:

$$T = V2uC(S+1)/2KA\ 2Dp(S+1)$$

For constant rate:

$$T = DKP(s+1)\ /(S+1)CuR^2$$

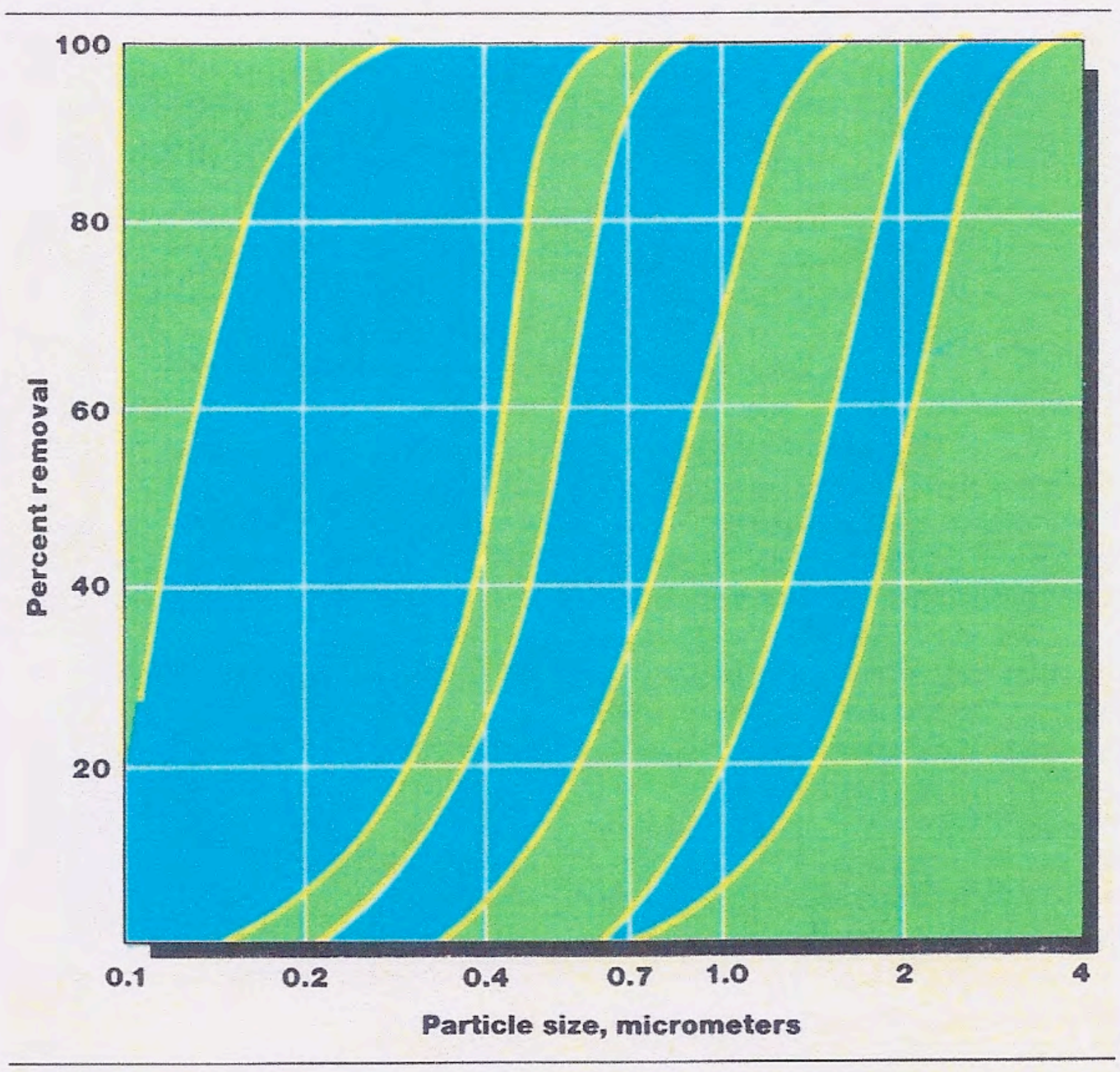
In these equations, S is the compressibility factor, which is a characteristic of the filter cake. For a compressible filter cake, the same test methods can be used, but constant-pressure testing will have to be performed at two pressure levelsto evaluate S.

A log-log plot constant-pressure filtration data will still approach a straight line having a slope of 2, the intercept in this case being $uC(S+1)/2KA^2DP(s+1)$. The intercept values obtained at two pressures will provide two simultaneous equations in two unknowns, K and S.

Filter aids control permeability

For most chemical-process operations, the permeability of the solids removed during filtration is very difficult to control. The relationship between process variables, particle size and compressibility of solids generated during most chemical processes is not well understood.

One way to increase permeability is to use filter aids, which impart a controlled porosity to the filter cake. The two most widely used filter aids are diatomaceous earth* and expanded perlite. These inert powders are added to the liquid being filtered. The filter aid has extremely fine pores that trap the solids and provide flow channels for the liquid, greatly extending the filtration cycle. Filter aids are normally used when the liquid is the valuable material to be recovered, and the solids are either extremely fine or gelatinous.



Besides increasing permeability, filter aids help control the pore size. Materials are available in a range of grades, each fostering the production of a particular median pore size. For a given grade, pores larger than the median provide drainage channels for fluid flow whereas those smaller enhance the clarifying ability of the cake. For example, a particular filter aid generating a median pore size of 2.5 pm can remove particles as small as 0.2 Bum, and one with a 17- pan median pore size can effectively take out particles down to 2 pm.

Apart from being mixed with the filter feed to increase cake porosity, filter aids are widely employed to precoat the filter medium. This not only protects the medium itself from fouling but also assures a more uniform and more effective surface for solids removal.

Figure 2 (Left) shows the removal efficiency of several filter aids using a

1/16-in. precoat. A thicker precoat would provide better filtration efficiency.

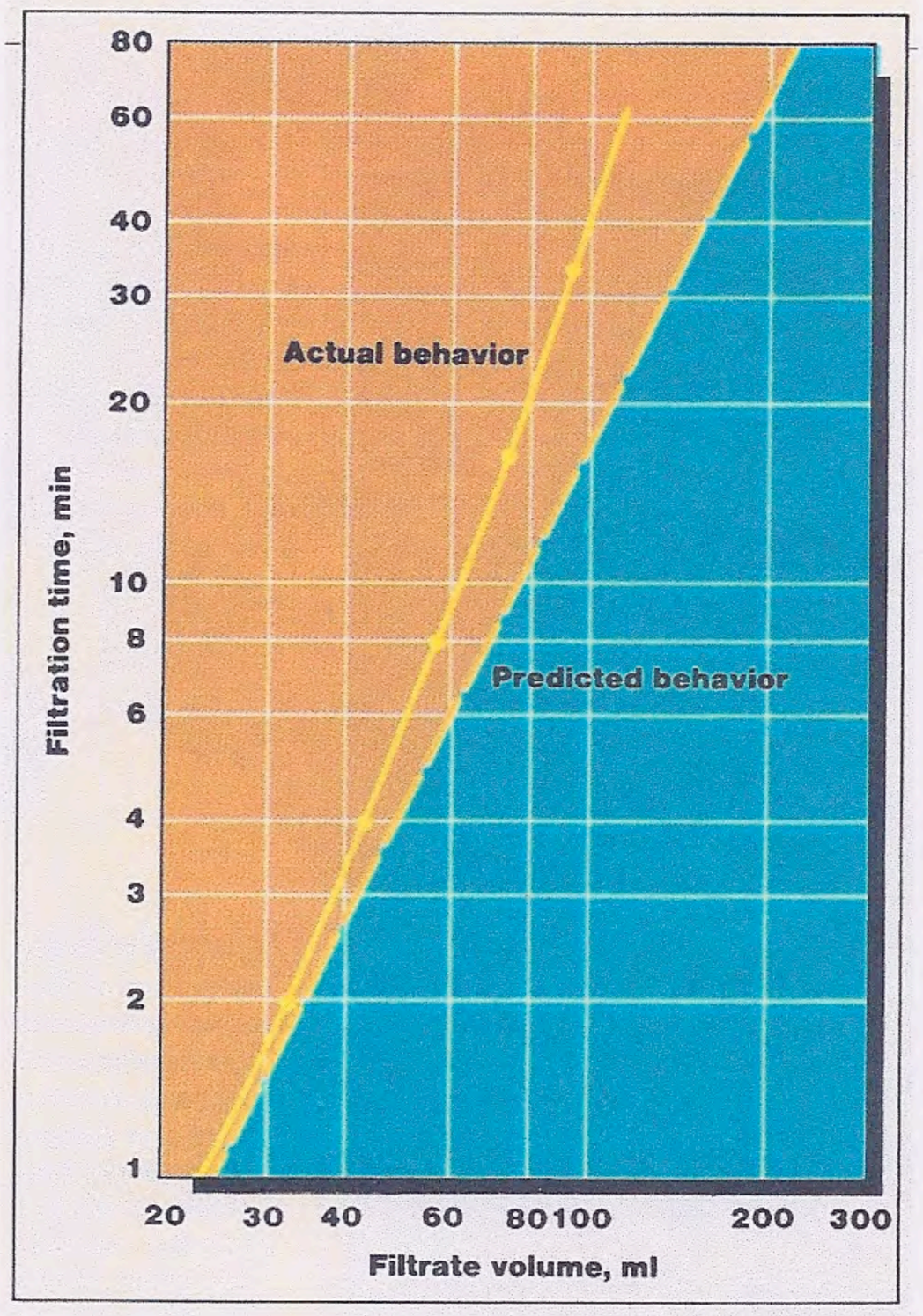
To use filter aids effectively, the engineer must determine both the optimum grade and dosage. For most filtrations, the optimum grade is one whose median pore size most closely matches the median particle size of the suspended solids. Occasionally, however, a slightly larger or slightly smaller size works better. The choice can be made by performing tests in a pressure bomb as previously described, using the grade having the best match and the grades having median pore sizes above and below the closest match.

To determine optimum dosage as well, two tests should be performed with each of the three grades. One test should use an amount of filter aid equal to the weight of the suspended solids; the other should use ten times as much. The permeability values obtained at the two doses are plotted vs. dose level on log-log paper, and a straight line is drawn between the two data points to give permeability values between the two data points. These values can be assessed to find the intermediate point that is optimal. Thus, six test filtrations will usually provide enough data for finding optimum filter aid grade and dosage.

Fine-particle caveat

Filtration performance can become very difficult to calculate or model if the filter cake contains a substantial amount of particles whose size is extremely small compared to the filter-cake pore sizes. This can occur when the solids to be filtered contain both very large and small particles. It can also occur when the filter aid pore size is larger than the turbidity solids' particle size.

Under these conditions, the small particles can migrate within the filter cake (depending upon flow conditions) and deposit in a region deeper within the cake. This will cause the permeability to vary unpredictably from point to point within the cake.



Such behavior is revealed during constant-pressure filtration testing. As noted earlier, the test data of cumulative volume vs. time should closely approach a straight line having a slope of 2 on log-log paper. When the extremely small particles are migrating within relatively large pores, the filtration curve will pull away from the slope of 2, as shown in Figure 3 (Left).

When this occurs, we lose our ability to predict filtration performance based on filtration theory. The moral is that the filtration equations will not give accurate results unless the engineer is sure that the pore size of the cake is smaller than the predominant ranges of particle size.

The author

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