IMPROVED DESIGN OF DRUM AND DISK FILTERS

V. L. Radushkevich

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The Institute of Scientific-Research and Design Engineering for Concentration of Solid Mineral Fuels has made a study of the mechanism of separation of suspensions in drum and disk filters and of the operational characteristics of these machines.

In continuous filters each element of the filtering surface can be considered to operate as a periodic filter. Consequently each cell of the drum (Fig. 1a) or each sector of the disk (Fig. 1b) vacuum filter can be treated as a mechanical periodic filter.

The operation of individual filter elements will now be analyzed in detail. After filling each cell or sector with a suspension and connecting it through a regulator to a vacuum line, the filtering process occurs simultaneously over the whole of the filter surface. Discharge of suspension from different elements of the filter occurs at different times. For the drum filter this time varies from a minimum for the loading edge (line I–I) of the filter cell to a maximum for the trailing edge (line II–II). For the disk filter this time varies for each point on the surface of a sector with both its circumferential and axial positions. It has a minimum value for point n and a maximum for point m on the surface of the sector (Fig. 1b). The drying times for sediment placed at different points on the filter element will also vary, the longest time corresponding to points of the element surface for which the filtering time is shortest and vice versa.

The areas of the surface of the drum or disk, positioned respectively between cells or sectors are not operational. The sediment in these areas either does not settle (when separating average or difficult to separate suspensions) or is not removed from the surface of the filter. An exception to this statement occurs for drum filters with convergent blades from which all the sediment is always removed.

With an increase in the number of filtering sections, the average filtering time approaches the maximum for the leading edge of the cell. Consequently, the individual efficiency of each sector also increases. In this case however, the total nonoperational surface between the sections also increases and reduces the total filtering surface of the machine. The filter efficiency is therefore related to the number of sections in a way which must be determined experimentally.

In present calculation procedures [1, 2] the filtering time is assumed to be constant over the whole area of the filter elements and to be equal to the time within the suspension of points along a radial or axial line on the elements. The effect of the nonoperational areas is neglected which results in some error.

To allow more accurate calculations to be made the basic differential equation of the filtering process sediment formation is employed [3]

$$\frac{dV'}{d\tau}=\frac{p}{\mu(\alpha q_T V'+\beta)}=\frac{p}{2b_1\left(V'+V_0'\right)}, \tag{1}$$

where V' is the filtrate volume per unit filter surface area, m^3/m^2; τ is the filtering time; p is the pressure drop during filtering, kN/m^2; μ is the liquid viscosity, $kN\cdot sec/m^2$ at operational temperature; α is the average specific resistance of the sediment, m/kg; q_t is the solid phase mass deposited in the filter per unit volume of filtrate, kg/m^3; β is the resistance of the filter element per meter for unit viscosity; $b_1 = \mu q_t \alpha/2p$ is the constant in the equation of the filtering process per unit surface area, sec/m^2; $V_0' = \beta/q_t\alpha$ is the filtrate volume which produces a layer of sediment per unit surface area given a pressure drop equal to that across the filter element, m^3/m^2.

It is assumed that the concentration of the suspension and the dispersion of the solid phase in it are constant throughout the filter trough. Then, since the filter considered here operates at constant pressure,

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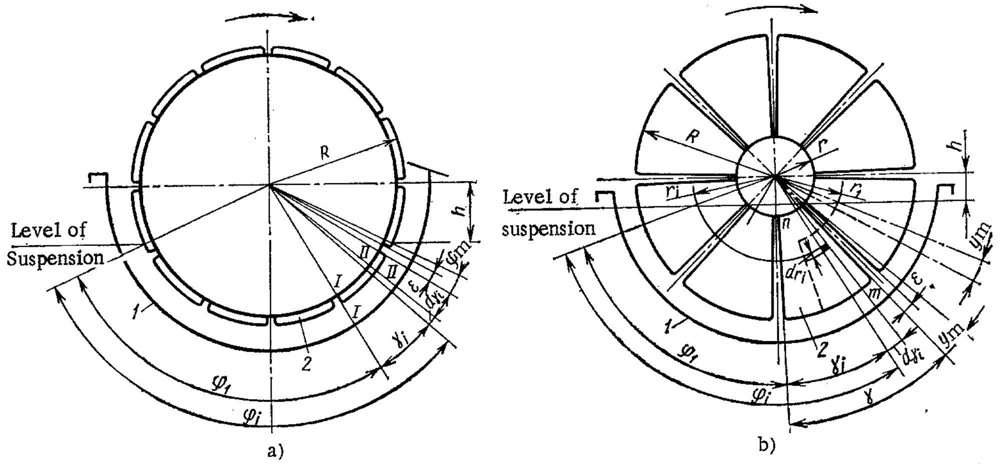

Fig. 1. Data for basic equation of filtering process: a) drum; b) disk; 1) filter trough; 2) cell or sector of the filter.

after integration of Eq. (1) with p = const and rearrangement of the equation obtained for V' we get

$$V' = \left[(V_0')^2 + \frac{\tau}{b_1} \right]^{0,5} - V_0'. \tag{2}$$

Consider a strip of infinitesimally small width $d\gamma_i$ (Fig. 1a) of a cell of a drum filter and of length L equal to the length of the drum. The amount of filtrate obtained per unit time from the strip is given by

$$dQ_{1f} = \left(\frac{\pi}{180} RLd\gamma_i \right) nV_i', \tag{3}$$

where Q_{1f} is the filtrate produced for the surface of one cell of the drum filter, m^3/sec; R is the external radius of the drum (or sector), m; n is the rotational speed of the drum (or disk) filter, rev/sec; and i is a flow parameter.

The filtration time of the strip considered can be expressed as

$$\tau_i = \frac{\varphi_i}{360\,n},$$

where φ_i is the flow angle of the filter zone (in deg) which is given by

$$\varphi_i = \varphi_1 + \gamma_i,$$

or

$$\varphi_i = 2 \arccos \frac{h}{R} - \varphi_m - \gamma + \gamma_i. \tag{4}$$

where φ_1 is part of the filter zone angle, deg (Fig. 1); γ_i is the angle between the leading edge of the cell (or sector) and the strip considered, deg; h is the distance from the axis of the drum (or disk) to the liquid level in the filter trough, m; φ_m is the angle between the nonoperational area to the nearer edge of the cell (or sector), deg; γ is the angle of the cell (or sector), deg.

Using Eqs. (2) and (4) the amount of filtrate produced by one cell of a drum filter can be obtained by integrating equation (3) from 0 to γ:

$$Q_f = \frac{\pi RLn}{180} \int_0^{\gamma} \left\{ \left[(V_0')^2 + \frac{2 \arccos \frac{h}{R} - \varphi_m - \gamma + \gamma_i}{360\,nb_1} \right]^{0.5} - V_0' \right\} d\gamma_i. \tag{5}$$

Substituting the value of γ from

$$\gamma = \frac{360}{z} - \varepsilon, \tag{6}$$

into the integral of equation (5) gives

$$Q_{1f} = \frac{\pi RLn}{180} \left\{ 240\,nb_1 \left(\left[(V_0')^2 + \frac{2 \arccos \frac{h}{R} - \varphi_m}{360\,nb_1} \right]^{1.5} - \left[(V_0')^2 + \frac{2 \arccos \frac{h}{R} - \varphi_m - \frac{360}{z} + \varepsilon}{360\,nb_1} \right]^{1.5} \right) - V_0' \left(\frac{360}{z} - \varepsilon \right) \right\}, \tag{7}$$

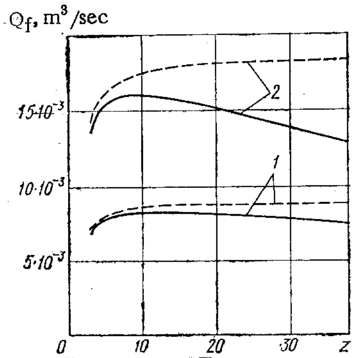

Fig. 2

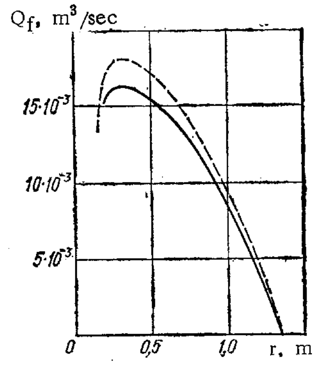

Fig. 3

Fig. 2. Variation of filtrate production Q_f with number z of elements in filters for the separation of carbon in suspension at $\alpha = 15 \cdot 10^9$ m/kg; p = 66.65 kN/m²; c = 30%; n = 8.33 $\cdot 10^{-3}$ rev/sec: ——) calculated from Eqs. (8), (9), (13), and (14); – – –) calculated from Eqs. (15) and (16); 1) type BOU-40 drum vacuum filter; 2) Ukraina-80 disk vacuum filter.

Fig. 3. Variation of the filtrate productivity Q_f with the internal radius of the sector when separating carbon in suspension using a Ukraina-80 filter disk vacuum filter (for filtering conditions see Fig. 2): ——) calculated from Eqs. (13) and (14); – – –) calculated from Eq. (16).

where z is the number of cells round the circumference of the drum (the whole number taken from the series $(360/(2\arccos(h/R) - \varphi_m + \varepsilon)) \le z \le (360/\varepsilon)$); ε is the angle between two adjacent cells (or sectors), deg.

If the resistance of the filter element is small, Eq. (7) can be simplified without appreciable error to

$$Q_{1f} = \frac{\pi RL}{5120}\left(\frac{n}{b_1}\right)^{0.5}\left[\left(2\arccos\frac{h}{R} - \varphi_m\right)^{1.5} - \left(2\arccos\frac{h}{R} - \varphi_m - \frac{360}{z} + \varepsilon\right)^{1.5}\right]. \qquad (8)$$

The filtrate produced by the cylindrical filter is given by

$$Q_f = Q_{1f}\, z. \qquad (9)$$

To determine the performance of the disk filter consider an infinitesimally small part of its surface of radial thickness dr_i and of angle $d\gamma_i$ (Fig. 1b). The amount of filtrate obtained from this small part of the surface per unit time is given by

$$dQ'_{1f} = \left(\frac{\pi}{180} r_i dr_i d\gamma_i\right) nV'_i, \qquad (10)$$

where r_i is its radius, m.

After making the necessary substitutions in Eq. (10) an equation for the amount of filtrate produced by this small part is obtained as follows:

$$Q'_{1f} = \frac{\pi n}{180}\int_{0(\gamma_i)}^{\gamma(\gamma_i)}\int_{r(r_i)}^{R(r_i)}\left\{\left[(V'_0)^2 + \frac{\arccos\frac{h}{r} + \arccos\frac{h}{r_i} - \varphi_m - \gamma + \gamma_i}{360 n b_1}\right]^{0.5} - V'_0\right\} r_i dr_i d\gamma_i, \qquad (11)$$

where r is the internal radius of the sector, m.

Integration of Eq. (11) with limits for γ_i from 0 to γ and substituting the value from Eq. (6) for γ gives

$$Q'_{1f} = \frac{\pi n}{180}\int_r^R\left\{240 n b_1\left(\left[(V'_0)^2 + \frac{\arccos\frac{h}{r} + \arccos\frac{h}{r_i} - \varphi_m}{360\, n b_1}\right]^{1.5}\right.\right.$$

$$\left.\left. - \left[(V'_0)^2 + \frac{\arccos\frac{h}{r} + \arccos\frac{h}{r_i} - \varphi_m - \frac{360}{z} + \varepsilon}{360\, n b_1}\right]^{1.5}\right) - V'_0\left(\frac{360}{z} - \varepsilon\right)\right\} r_i dr_i, \qquad (12)$$

where z is the number of sectors in the disk (the whole number taken from the series $(360/(2\ \mathrm{arc\,cos}(h/r) - \varphi_m + \varepsilon)) \le z \le (360/\varepsilon))$.

The integral of Eq. (12) can be obtained approximately by determining the area bounded by the curve $(dQ'_{1f}/dr_i) = f(r_i)$ between the limits of r to R. The value of Q'_{1f} can be taken with sufficient accuracy for practical purposes [4] as a trapezium

$$Q'_{1f} = 0.5(R-r)(y_R + y_r),$$

where $y_R = (dQ'_{1f}/dr_i)_{r_i=R}$ and $y_r = (dQ'_{1f}/dr_i)_{r_i=r}$.

Neglecting the resistance of the filter element ($V'_0 = 0$) the Eq. (12) can be simplified to

$$Q'_{1f} = \frac{\pi}{5120}\left(\frac{n}{b_1}\right)^{0.5} \int\limits_r^R \left[\left(\arccos\frac{h}{r} + \arccos\frac{h}{r_i} - \varphi_m\right)^{1.5} - \left(\arccos\frac{h}{r} + \arccos\frac{h}{r_i} - \varphi_m - \frac{360}{z} + \varepsilon\right)^{1.5}\right] r_i dr_i. \qquad (13)$$

The maximum production of filtrate for all the surfaces of disk filters is given by

$$Q_f = 2Q'_{1f}\, z z_d, \qquad (14)$$

where z_d is the number of disks.

Examination of equations obtained shows that determination of the optimum number of filter elements for maximum production of filtrate is analytically difficult. It can however be seen from Eqs. (8), (9), (13), and (14) that the optimum value of z depends only on the geometrical dimensions of the filter. The present study to determine the optimum filter dimensions uses modified equations. These are:

for drum filters

$$Q_f = \frac{\pi RL}{9.5}\left(\frac{n}{b_1}\right)^{0.5} \cdot \left(2\arccos\frac{h}{R} - \varphi_m - \frac{180}{z}\right)^{0.5}, \qquad (15)$$

for disk filters

$$Q_f = \frac{\pi}{4.75}\left(\frac{n}{b_1}\right)^{0.5} \cdot z_d \int\limits_r^R \left(\arccos\frac{h}{r} + \arccos\frac{h}{r_i} - \varphi_m - \frac{180}{z}\right)^{0.5} r_i dr_i. \qquad (16)$$

Figure 2 shows that the optimum number of cells is 12 for the BOU-40 drum vacuum filter with a trough level h = 0.33 m. Furthermore, this number can be varied from 9 to 24 without appreciably reducing (<3.5%) the production of the filters.

For the Ukraina-80 disk vacuum filter with h = 0.15 m the optimum number of sectors in one disk is 10, but this number can vary from eight to sixteen without appreciable loss in performance.

After determining the approximate optimum number of filter elements, the final exact choice can be made as follows. The resources required for manufacture of the filter and maintenance during operation decrease with the number of elements. On the other hand the conditions for the removal of filtrate deteriorate as the number of elements decreases, and in the case of disk filters, as the weight increases. The rates of production of filtrate in drum and disk filters shown in Fig. 2 and calculated from Eqs. (15) and (16) are somewhat high and result in undersizing the filter or installing an insufficient number of filters for the required production. Hence in the present examples the errors are about 10% in determining the amount of filtrate produced by the Ukraina-80 filter with 12 sectors in each disk and the 24 cell BOU-40 drum filter. Therefore, for example, filters calculated to require 10 disks should have this number increased by one.

From Eqs. (13) and (14) it is evident that the optimum value of r depends on the dimensions of the filter. This optimum can only be determined graphically. As can be seen from Fig. 3 when the suspension level h = 0.15 mm the optimum radius is r = 0.3 m.

To reduce the weight of the sectors and the rate at which the elements are consumed it is recommended that internal radii and angles of sectors larger than optimum are selected. Figure 3 shows that an increase in r to 0.5-0.6 m results in reducing the theoretical productivity by 5-10%.

However, as shown above and as confirmed by use in the coal industry the parts of sectors of disk vacuum filters nearest to the axis of the disk operate under the most unfavorable conditions and it is on these parts particularly that some sediment is left after removal. Hence the reduction in the production of filtrate will be much less than theoretically estimated. Furthermore, by increasing the filter element angle with a consequent thickening of the sediment layer, the rotational speed of the disks can be raised. The rotational speed with sectors reduced to give minimum sediment thickness similar to that obtained with sectors of optimum size can be determined (neglecting the resistance of the filter elements) from

$$n_1 = n \frac{2 \arccos \frac{h}{r_1} - \varphi_m - \frac{360}{z} + \varepsilon}{2 \arccos \frac{h}{r_{op}} - \varphi_m - \frac{360}{z} + \varepsilon}, \quad (17)$$

where r_1 is the accepted value of the internal radius of sector, m; r_{op} is the optimum internal radius, m. In filters with smaller sectors because of the formation of the more uniform sediment layer on each sector surface and because of reduction in the surface the drying effectiveness and removal of sediment are improved.

Taking a value of $r_1 = 0.6$ m for the Ukraina-80 filter equation (17) gives $n_1 = 11.2 \cdot 10^{-3}$ rev/sec. At this speed the filter with smaller sectors produces $16.75 \cdot 10^{-3}$ m^3/sec of filtrate, i.e., it exceeds the optimum value by $0.54 \cdot 10^{-3}$ m^3/sec.

Increasing r by 0.2 m (Ukraina-80 filters now have sectors of r = 0.395 m) allows the sector weight to be reduced approximately by about 11% and reduces the cost of filtering by 13%. These effects together with the increased productivity of the filter result in substantial economic advantages.

The theory and recommendations presented here can be used for operational calculations and in the design of continuous drum and disk filters.

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