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METHODS FOR CALCULATING AND SELECTING ROTARY DRUM VACUUM FILTERS FOR SEPARATING SUSPENSIONS

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Abstract: *The aim of present paper to estimate the capabilities of the methods for calculation of rotary drum vacuum filters used to separate suspensions. Their application is realized by preparing specific methodologies for the selection and calculation of continuous drum vacuum filter for separation of suspension with a mass concentration of the solid phase 10.6 mass %, a sediment (cake) thickness 9 mm and a given required flow rate of suspension. After applying calculation procedures, a drum vacuum filter with an exterior filtration surface was selected, as the filtration area, the number of filters, the drum rotation frequency, the time for the full suspension processing cycle, the productivity of filter by filtrate and the filtration rate for one filter operation cycle were determined.*

Keywords: *Continuous drum vacuum filters, methods for calculation and selection of filters, separation of suspensions*

INTRODUCTION

Filtration is one of the most often used processes in the chemical, food production, pharmaceutical and biochemical industries for the separation of suspensions, in some cases of colloidal solutions and for the purification of industrial technological waters (Towler, G., Sinnott, R. K., 2013; Genchev, Chr., Koleva, D., 2012). In most productions, the highest efficiency showed the continuous oparation filters, regardless of their complexity and cost. Universal and widely applicable are rotary drum vacuum filters, which allow for the simultaneous production of well-washed and dried sediment (cake) and concentrated filtrate. Drum filters operating under pressure are used mainly in inorganic production facilities for separation of hardly filtered suspensions and the separation of solid phase from volatile liquids (Towler, G., Sinnott, R. K., 2013; Genchev, Chr., Koleva, D., 2012; Sorsamaki, L., Nappa, M., 2015; Greencorn, N., 2009; Stickland, A. D., White, L. R., Peter J. Scales, P. J., 2011; Wang, J., Shi Li., Jin, H., Chen Bo., Huang Z., 2025).

Because of their wide use, the specifics of the process of separation and the versatility of device consrtuctions, the choice of a filter is based on specific methodologies relevent to particular type of filter. Some technological calculations are to be done related to the choice of a filter from a catalogue, determining its productivity and the amount of the obtained filtrate, which shoud ensure the desired productivity according to the overall production line where it would be implemented (Sorsamaki, L., Nappa, M., 2015; Greencorn, N., 2009; Zhuzhukov, V. A., 1961; Domansky, I.V., Isakov, V.P., et al., 1982). The selection of the type of filter is based on a preliminary analysis of the physicochemical properties of the separated suspension and the formed sediment, the technological requirements imposed on the filtration process and certainly economic factors. Comprehensive recommendations for the selection of filter type, taking into account all aspects, cannot be given (Sorsamaki, L., Nappa, M., 2015; Greencorn, N., 2009; Zhuzhukov, V. A., 1961; Domansky, I.V., Isakov, V.P., et al., 1982; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990). The methodologies for calculation of filters for separation of suspensions differ according to the constructive characteristics of the filter, the desired productivity by suspension, the filtering area, regime of maximum productivity, sediment thickness and its porosity, and the operating regime of filtration (Sorsamaki, L., Nappa, M., 2015; Greencorn, N., 2009; Zhuzhukov, V. A., 1961; Domansky, I.V., Isakov, V.P., et al., 1982; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990).

The aim of the present work is to consider and estimate the capabilities of methods for calculation of drum rotary vacuum filters for separation of suspensions, to make a choice of a drum vacuum filter and to calculate the surface area necessary for the filtration and separation of a suspension with a certain mass concentration of the solid phase, at given thickness of the sediment and the required flow rate of suspension.

EXPOSITION

The methodologies for calculation continuous filters include calculation of filter productivity, the velocity of movement of the filter surface, the time for the full cycle of processing the suspension and the distribution of the filter drum surface into technological zones. The determination of the necessary filtration area of the continuous filter is carried out in two stages.

In the first stage, the total aproximate filtration surface is determined, on this basis, the number and type of filter is selected (Domansky, I.V., Isakov, V.P., et al., 1982; Towler, G., Sinnott, R. K., 2013). The type of filter is selected after analysis of corrosive, explosive and other physicochemical properties of the suspension. Filters differ by the material they are made from, the size and the angle of the filtration zone. The filter surface is distributed into technological zones of the drum based on the selected filter type.

The second stage involves determination the exact productivity of the selected filter and the number of filters necessary to carry out the separation of the suspension. To carry out the calculations, it is necessary that the initial data should include the thickness of the sediment layer or it is chosen several times larger than the minimum thickness of the sediment layer, usually it should not be higher than (1,5 ÷ 2).h_{min} (Domansky, I.V., Isakov, V.P., et al., 1982; Towler, G., Sinnott, R. K., 2013). Approximate values of the minimum thickness of the sediment layer, taking into account the physicochemical properties of the sediment can be found in the literature.

To achieve the objectives of the present work, a drum rotary vacuum filter for separation of 5 701 kg/h suspension with mass concentration of the solid phase $x_1 = 10{,}6\, mass\%$ and a sediment layer thickness of $h_{sed} = 9\ mm$ was chosen as the object of study. The suspension is not toxic, flammable and explosive. The moisture content in the sediment is $w = 72\%$. The pressure drop during filtration and washing is $\Delta p = \Delta p_{washing} = 64\ kPa$. The average mass specific resistance of the sediment is $r_B = 27.10^{10}\ m/kg$. The resistance of the filter barrier is $R_{fb} = 42.10^{9}\ m^{-1}$. The density of the solid phase of the suspension is $\rho_{sol.ph} = 2540\ \text{kg}/m^3$, and the density of the liquid phase of the suspension is $\rho_{liq.ph} = 1080\ \text{kg}/m^3$. The dynamic viscosity of the filtrate is $\mu = 1{,}05\ cP$. The volume of the washing liquid per 1 kg of wet sediment is $V_{wash.liq} = 1.10^{-3}\ m^3/kg$. The dynamic viscosity of the washing water with a temperature of 50°C is $\mu_{wash.} = 0{,}5494\ cP$. The minimum time for final drying of the sediment is 30 s.

Initially, taking into account the main properties of the suspension and on the based of the mass concentration of the solid phase present in it and the high productivity of the suspension taken from the literature (Domansky, I.V., Isakov, V.P., et al., 1982; Towler, G., Sinnott, R. K., 2013), a preliminary choice of the filter type is made - continuous drum vacuum filters with an exterior filtration surface. In the first stage of the methods for calculation of continuous filters, it is necessary to determine the total approximate filter surface area, on the basis of which the number and type of filters are selected (Domansky, I.V., Isakov, V.P., et al., 1982; Towler, G., Sinnott, R. K., 2013). For the continuous operating filters, the filter productivity by filtrate is calculated using the average filtration rate for each cycle of processing the suspension in the filter. The time for the full cycle of processing the suspension in drum filters corresponds to the time of one revolution of the drum. The filtration time and the washing time in filters with continuous action are calculated for the filtration mode at a constant pressure drop $\Delta p = const$ (Domansky, I.V., Isakov, V.P., et al., 1982; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990; Shakhov, A., Koleva, D., 2023). The mathematical apparatus used for filter selection is described in (Domansky, I.V., Isakov, V.P., et al., 1982; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990; Shakhov, A., Koleva, D., 2023):

$$\rho_{sed} = \frac{\rho_{sol.ph} \cdot \rho_{liq.ph}}{\rho_{liq.ph} + (\rho_{sol.ph} - \rho_{liq.ph}).w} \ (1); \quad x_0 = \frac{x_1 . \rho_{liq.ph}}{\rho_{sed}[1-(w+x_1)]} \ (2); \quad x_B = \frac{x_1 . \rho_{liq.ph} .(1-w)}{1-(w+x_1)} \ (3)$$

$$b_1 = \frac{\mu . r_B . x_B}{2.\Delta p} \ (4); \ \vartheta_0 = \frac{R_{fb}}{r_B . x_B} \ (5); \ \tau_f = b_1 . \frac{h_{sed}}{x_0^2} . (h_{sed} + 2.x_0 . \vartheta_0) \ (6); \ N_{wash} = \frac{V_{wash.liq} . \rho_{sed} . r_{\mathbf{B}} . x_B . \mu_{wash}}{\Delta p_{washing}} \ (7);$$

$$\tau_{wash.} = \frac{N_{wash} . h_{sed}}{x_0} . (h_{sed} + x_0 . \vartheta_0) (8); \ h_{sed} = x_0 \sqrt{\left(\vartheta_0^2 + \left(\frac{\tau_f}{b_1}\right)\right)} - x_0 \vartheta_0 (9) \ \tau_{act.wash} (1{,}05 \div 1{,}2) . \tau_{wash} (10)$$

$$(\varphi_1' + \varphi_2') = \varphi_{dead2} + \varphi_0 + \varphi_{dead3} + \varphi_{reg} + \gamma_a; \qquad \gamma_a = \frac{360}{(2z_s)}, ^\circ \quad (11);$$

$$\omega = \left[\frac{360 - (\varphi_{pre-drying,1} + \varphi_1' + \varphi_2')}{\tau_f + \tau_{act.wash} + \tau_{drying}}\right] . \frac{\pi}{180} \ (12); \ \tau_{cycle} = \frac{2.\pi}{\omega} \ (13); \ V_{filter}^{total} = \frac{G_{suspension} \cdot \left[1 - \frac{x_1}{1-w}\right]}{\rho_{liq.ph}} (14);$$

$$V_{fb} = \frac{h_{sed}}{x_0} \quad (15); \qquad F_{necessary} = \frac{V_{filter}^{total} . \tau_{cycle}}{0{,}8 . V_{fb}} \ (16); \qquad n = \frac{60}{\tau_{cycle}} \quad (17);$$

Table 1 shows the results obtained from the calculations necessary for selection a continuous drum vacuum filter with an exterior filtration surface.

Table 1. Results obtained from calculations necessary for selection of continuous drum vacuum filter with an exterior filtration surface.

Parameters	**Results**
Filtration time - τ_f, s	$\tau_f = 138{,}7\ s$
Time for washing the sediment - $\tau_{wash.}$, s	$\tau_{wash.} = 91{,}29\ s$
Thickness of the sediment formed during filtration - h_{sed}, m	$h_{sed} = 9.10^{-3}$, m
Actual time for washing the sediment -$\tau_{act.wash.}$, s	$\tau_{act.wash} = 109{,}55$ s
Total angle of the zone sediment removal and the dead zone - $(\varphi_1' + \varphi_2')$, °	$(\varphi_1' + \varphi_2') = 66\ °$
Initial angular speed of rotation of the drum, ensuring the set thickness of the sediment and the subsequent washing and drying of the sediment - ω, rad/s	$\omega = 1{,}47.10^{-2} rad/s$
Total duration of the working cycle (for one rotation of the drum) - τ_{cycle}, s	$\tau_{cycle} = 427{,}21\ s$
Frequency of drum rotation - n, min^{-1}	$n = 0{,}14\ min^{-1}$
Total productivity of the filter - V_{filter}^{total}, m^3/s	$V_{filter}^{total} = 9{,}1.10^{-4}\ m^3/s$
Volume of the filtrate obtained from 1 m^2 of filter barrier for filtration time τ_f – V_{fb}, m^3/m^2	$V_{fb} = 1{,}76.10^{-2}\ m^3/m^2$
Necessary filtration surface – $F_{necessary}$, m^2	$F_{necessary} = 27{,}61 m^2$

Based on the calculations carried out and the necessary filtration surface area taken from the literature (Domansky, I.V., Isakov, V.P., et al., 1982; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990; Shakhov, A., Koleva, D., 2023) three continuous drum vacuum filters with an exterior filtration surface type BO10-2,6U (Fig. 1) were selected with technical characteristics described in Table 2.

Table 2. Technical characteristics of the selected continuous drum vacuum filter with an exterior filtration surface type BO10-2,6U.

Parameters	**Filter type BO10-2,6U**
Filtration area - F, m^2	$F = 10\ m^2$
Number of filters - z_f	3
Number of sections - z_s	$z_s = 24$
Angular speed of rotation of the drum - ω, rad/s	$\omega = 0{,}013 \div 0{,}20\ rad/s$
Frequency of drum rotation - n, min^{-1}	$n = 0{,}13 \div 2\ min^{-1}$
Distribution of technological zones on the drum surface	
Angle of the filtration zone - φ_f, °	$\varphi_f = 132°$
Angle of zone for pre-drying - $\varphi_{pre-drying1}$,°	$\varphi_{pre-drying1} = 59{,}5°$
Sum of the angles of the zones for washing and final drying of the sediment - $(\varphi_1' + \varphi_2')$, °	$(\varphi_{wash} + \varphi_{fin.dry.2}) = 103°$
Angle of zone for removal the sediment - φ_0°	$\varphi_0 = 20°$
Angle of zone for regeneration the filter fabric - φ_{reg},°	$\varphi_{reg} = 20°$
Angle of dead zone 1 - φ_{dead1}, °	$\varphi_{dead1} = 2°$
Angle of dead zone 2 - φ_{dead2}, °	$\varphi_{dead2} = 5°$
Angle of dead zone 3 - φ_{dead3},°	$\varphi_{dead3} = 13{,}5°$
Angle of dead zone - φ_{dead4}, °	$\varphi_{dead4} = 5°$
Angle taking into account the fluctuations between the filtration zone and the filter fabric regeneration zone - γ_a °	$\gamma_a = 12{,}5°$
Power of drum drive - N, kW	$N = 1{,}7\ kW$

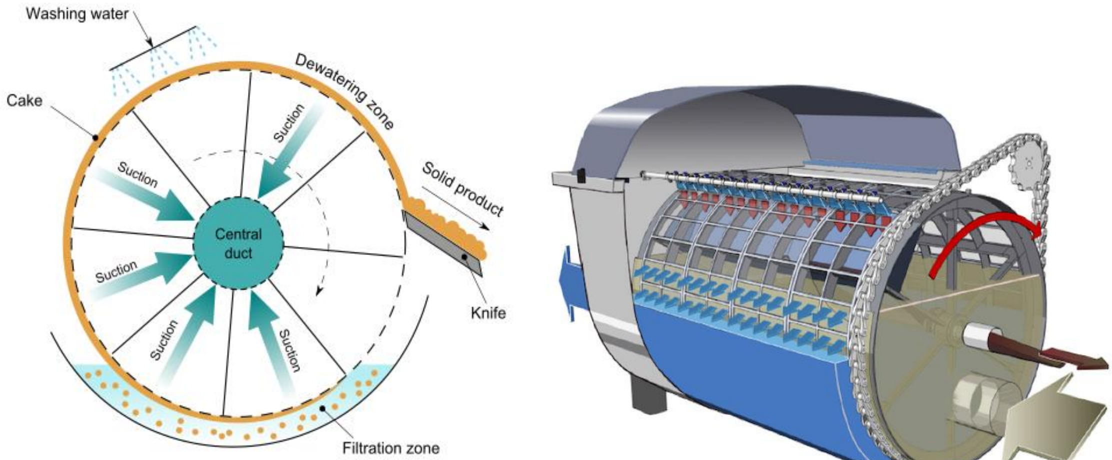

Fig. 1. The schematic of a continuous drum vacuum filter with an exterior filtration surface.

In the second stage of the calculation methods for continuous-action filters, the filter surface is first distributed into technological zones of the drum for the selected filter type. Then, the exact productivity of the selected filter and the number of filters required to carry out the separation of the suspension, the speed of movement of the filtration surface, the time for the full cycle of processing the suspension, the filtration rate for one cycle of operation and corrections to the angles of the technological zones are determined. The mathematical apparatus used for the calculations is described in (Domansky, I.V., Isakov, V.P., et al., 1982; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990; Shakhov, A., Koleva, D., 2023):

$$\varphi_f = \omega.\tau_f.\frac{180}{\pi} \quad (18); \qquad \omega_1 = \left(\frac{\varphi_f.\pi}{\tau_f.180}\right) \quad (19); \qquad \omega_2 = \left[\frac{\varphi_{wash}+\varphi_{fin.dry.2}}{\tau_{act.wash}+\tau_{drying}}\right].\frac{\pi}{180} \quad (20);$$

if $\omega_2 < \omega_1$ accepted $\omega = \omega_2$; $\varphi_{f,min1} = \omega.\tau_f.\frac{180}{\pi}$(21); $\varphi_{dead4} = \varphi_{dead4} + (\varphi_f - \varphi_{f,min1})$(22);

$$\tau_{full\ cycle} = \frac{360(\tau_{act.wash}+\tau_{drying})}{\varphi_{wash}+\varphi_{fin.dry.2}}(23) \qquad V_{filter} = \frac{V_{fb}}{\tau_{full\ cycle}}.0{,}8.F(24); \qquad n = \frac{60}{\tau_{full\,cycle}} \quad (25);$$

$$V_{total} = z_f.V_{filter} \quad (26); \qquad w_{f.cycle} = \frac{V_{fb}}{\tau_{full\ cycle}} \quad (27)$$

Table 3 shows the results obtained from the additional calculations for a drum vacuum filter type BO10-2,6U.

Table 3. Results obtained from the additional calculations for the selected continuous drum vacuum filter with an exterior filtration surface type BO10-2,6U.

Parameters	Results
Check of the possibility to carry out the process by comparing the calculated (φ_f) and the standard angle ($\varphi_{f.stand}$) of the filtration zone	$\varphi_f = 116{,}81° < \varphi_{f.stand} = 132°$
Minimal necessary angle of the filtration zone - $\varphi_{f.min1}$, °	$\varphi_{f,min1} = 101°$
Increased angle of the dead zone 4 - $\varphi_{incr.dead4}$, °	$\varphi_{incr.dead4} = 21°$
Angular velocity of drum rotation - ω, rad/s corresponding to the assumed angle of the filtration zone φ_f and the calculated filtration time τ_f, , s	$\omega = \omega_2 = 1{,}28.10^{-2} rad/s$
Time for the full cycle of suspension processing - $\tau_{full\ cycle}$, s	$\tau_{full\ cycle} = 487{,}75\ s$
Filter productivity, V_{filter}, m^3/s	$V_{filter} = 2{,}89.10^{-4}\ m^3/s$
Frequency of drum rotation - n, min^{-1}	$n = 0{,}13\ min^{-1}$
Total productivity of the selected number of filters - V_{total}, m^3/s	$V_{total} = 8{,}67.10^{-4}\ m^3/s$
Filtration rate for one cycle - $w_{f.cycle}$, $m^3/m^2.s$	$w_{f.cycle} = 3{,}61.10^{-5}\ m^3/m^2.s$

CONCLUSION

The capabilities of the methods for calculation and choice of rotary drum vacuum filters for separation of suspensions are considered. Their application is realized by elaborating specific methodologies for calculation of continuous drum vacuum filter. For the realization of separation of suspension with mass concentration of the solid phase 10,6 mass %, sediment layer thickness 9 mm и and required flow rate of suspension 5 701 kg/h, after carrying out calculation procedures, three continuous drum vacuum filters type BO10-2,6U with an exterior filtration surface were selected. As a result of the calculation procedures carried out for vacuum drum filters type BO10-2,6U, the following parameters were obtained: filtration area $F = 10\ m^2$, number of filters $n = 3$, angular velocity $\omega = 1{,}28.10^{-2} rad/s$ and frequency of drum rotation $n = 0{,}13\ min^{-1}$; time for the full cycle of suspension processing $\tau_{full\ cycle} = 487{,}75\ s$, productivity of the filter by filtrate $V_{filter} = 2{,}89.10^{-4}\ m^3/s$, total productivity of the three filters $V_{total} = 8{,}67.10^{-4}\ m^3/s$ and the filtrating rate for one cycle of filter operation $w_{f.cycle} = 3{,}61.10^{-5}\ m^3/m^2.s$. The selected type of vacuum filter satisfies to the given separation conditions and required productivity by suspension. The methods applied can successfully be used for calculation and choice of continuous rotary drum vacuum filters, as well as in the education of students in fields Chemical engineering and Chemical technology.

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