FILTRATION

Separation of suspended solid particles from fluid by forcing the fluid through a porous bed.

Driving force – pressure difference:
- hydrostatic pressure of suspension (gravity filters)
- pump or gas pressure (pressure filters)
- centrifugal force (filter centrifuges)

Surface filtration

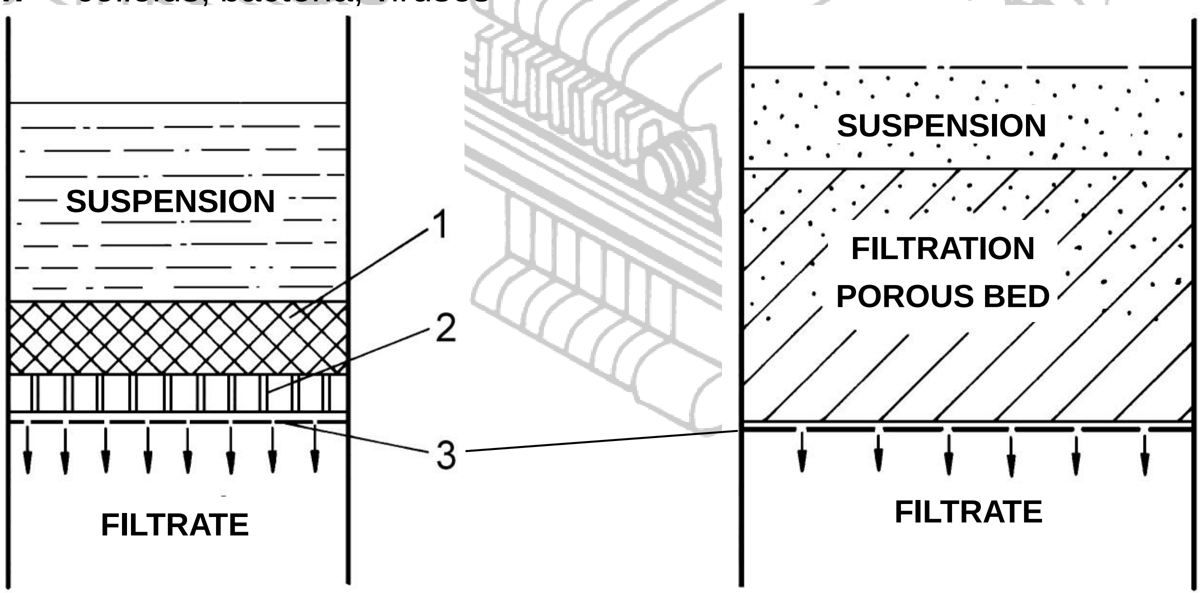
solids deposition on filter medium surface

- ***cake filtration*** – concentrated suspensions, increasing cake forming
- ***ultra-filtration*** – colloids, bacteria, viruses

Deep-bed filtration

particle deposition in porous bed (sand, ceramics) by inertial and gravity forces, diffusion and hydrodynamic effects

- low-concentrated suspensions



1 – filter cake, ***2*** – filter cloth, ***3*** – perforated or slotted frame (screens or grids)

Basic parameters of filtration

Efficiency of filtration

Ratio of the mass of particles separated m_z to the mass of particles in suspension m (lower at beginning of filtration):

$$\eta = \frac{m_z}{m}$$

Rate of filtration

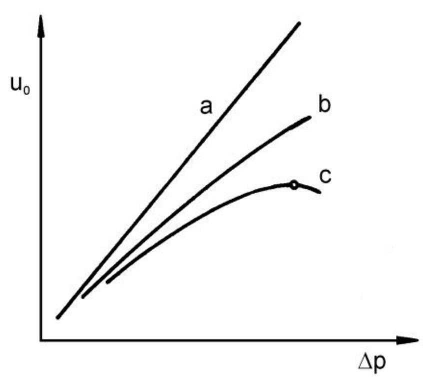
Volume of filtrate V per unit filtrate area S and time t (usually lower than 1 m/h):

$$u_0 = \frac{1}{S}\frac{dV}{dt}$$

Rate of filtration depends on:

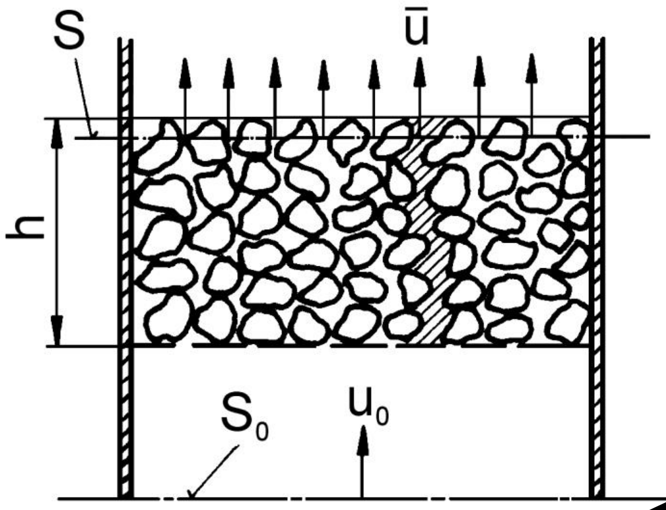
- properties of filtrate (viscosity)
- particle characteristics (size, distribution …)

  Improvement – agglomeration by coagulation (change of electrical separation forces), flocculation (aggregation of particles), filter aids (improve permeability of cakes)
- pressure drop (can make worse filterability of suspensions with compressible cakes)
- physico-chemical phenomena (electrical double-layer at filtration of fine suspensions decrease diameter of pores)



Basic theory of filtration

Pressure drop of fluid through filter cake



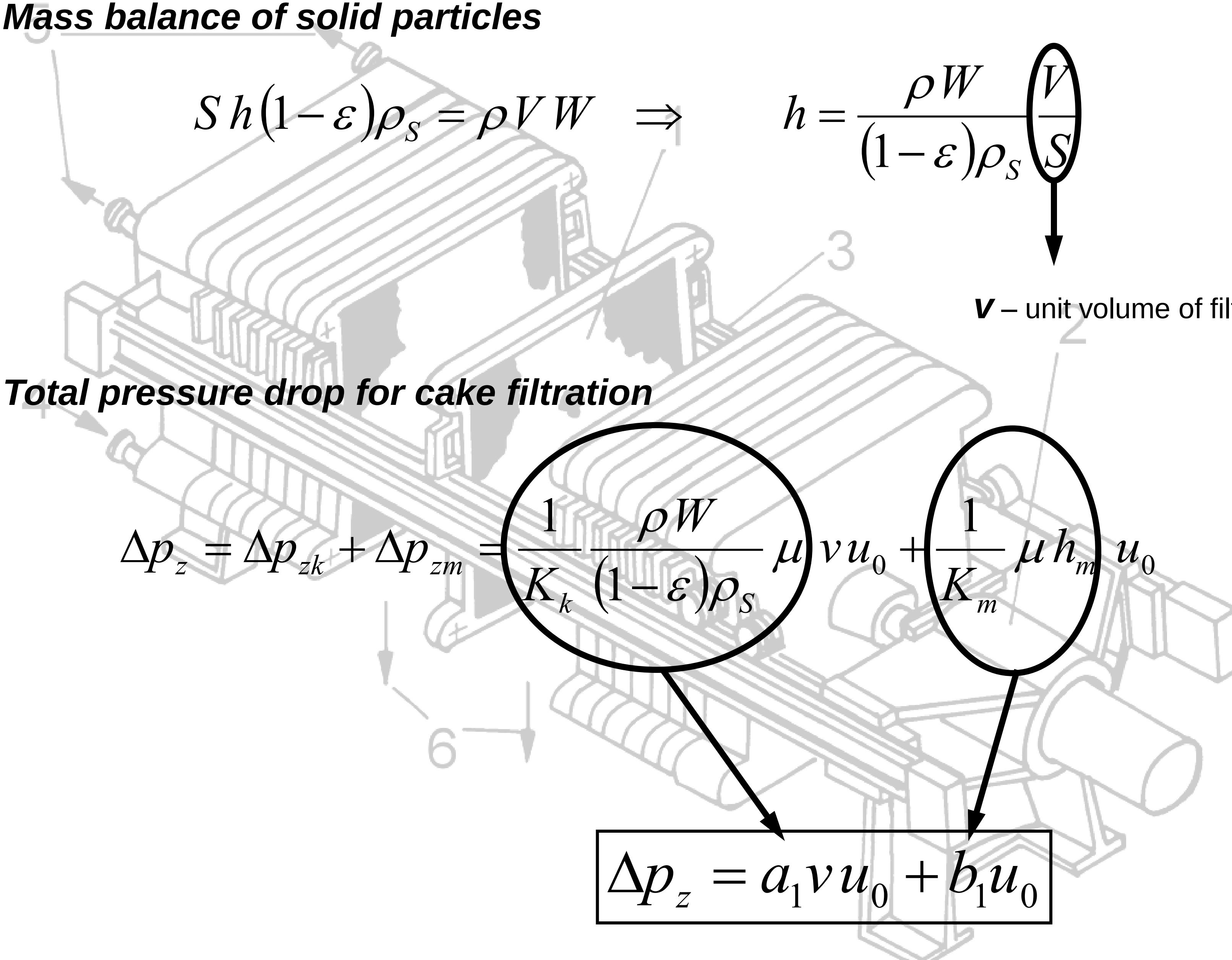
$$\Delta p_z = \lambda' \frac{1-\varepsilon}{\varepsilon^3} \frac{h}{D_p} u_0^2 \rho$$

Filter cake and medium is ordinarily forming from fine-grained materials ⇒ creep flow regime:

$$\lambda_c' = \frac{A'}{Re'} \qquad Re' = \frac{u_0 D_p \rho}{(1-\varepsilon)\mu}$$

$$\Delta p_z = \lambda' \frac{1-\varepsilon}{\varepsilon^3} \frac{h}{D_p} u_0^2 \rho = \frac{A'(1-\varepsilon)\mu}{u_0 D_p \rho} \frac{1-\varepsilon}{\varepsilon^3} \frac{h}{D_p} u_0^2 \rho = \frac{1}{K} \mu h u_0$$

K* – *permeability of filter medium (express only physical properties of porous bed)



Mass balance of solid particles

$$S\,h\left(1-\varepsilon\right)\rho_S = \rho V W \quad \Rightarrow \quad h = \frac{\rho W}{\left(1-\varepsilon\right)\rho_S}\frac{V}{S}$$

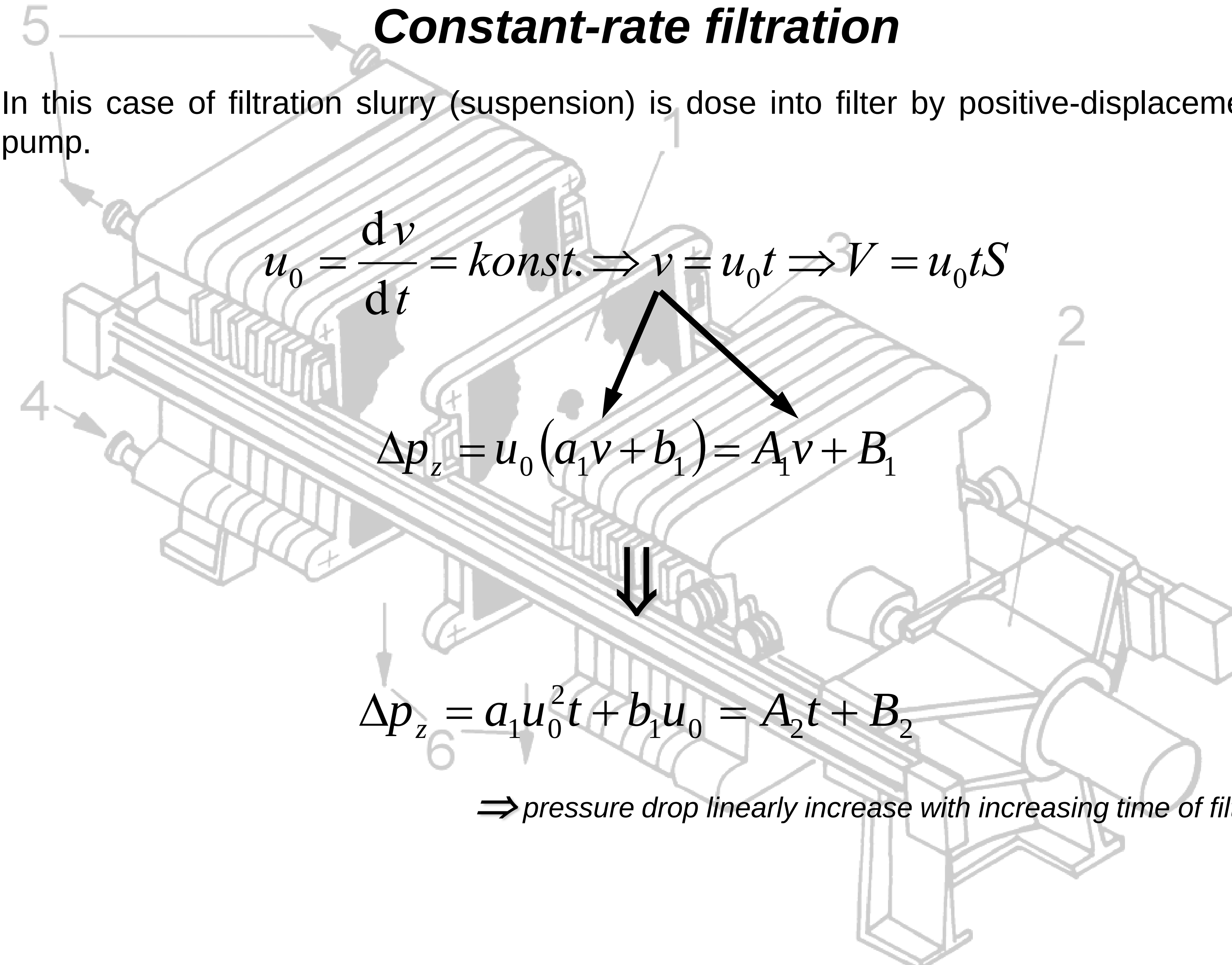
v – unit volume of filtrate

Total pressure drop for cake filtration

$$\Delta p_z = \Delta p_{zk} + \Delta p_{zm} = \frac{1}{K_k}\frac{\rho W}{\left(1-\varepsilon\right)\rho_S}\mu\, v\, u_0 + \frac{1}{K_m}\mu\, h_m\, u_0$$

$$\Delta p_z = a_1 v\, u_0 + b_1 u_0$$

Constant-rate filtration



In this case of filtration slurry (suspension) is dose into filter by positive-displacement pump.

$$u_0 = \frac{\mathrm{d}v}{\mathrm{d}t} = konst. \Rightarrow v = u_0 t \Rightarrow V = u_0 t S$$

$$\Delta p_z = u_0\left(a_1 v + b_1\right) = A_1 v + B_1$$

$$\Downarrow$$

$$\Delta p_z = a_1 u_0^2 t + b_1 u_0 = A_2 t + B_2$$

$\Rightarrow$ *pressure drop linearly increase with increasing time of filtration*

Constant-pressure filtration

Constant pressure drop is keep by constant pressure of gas over slurry (suspension) surface or constant pressure under filtration medium (vacuum filter).

$$\Delta p_z = a_1 v u_0 + b_1 u_0 = konst.$$

$$\boxed{\frac{1}{u_0} = \frac{\mathrm{d}t}{\mathrm{d}v} = \frac{a_1}{\Delta p_z} v + \frac{b_1}{\Delta p_z} = av + b}$$ ***Equation of filtration line***

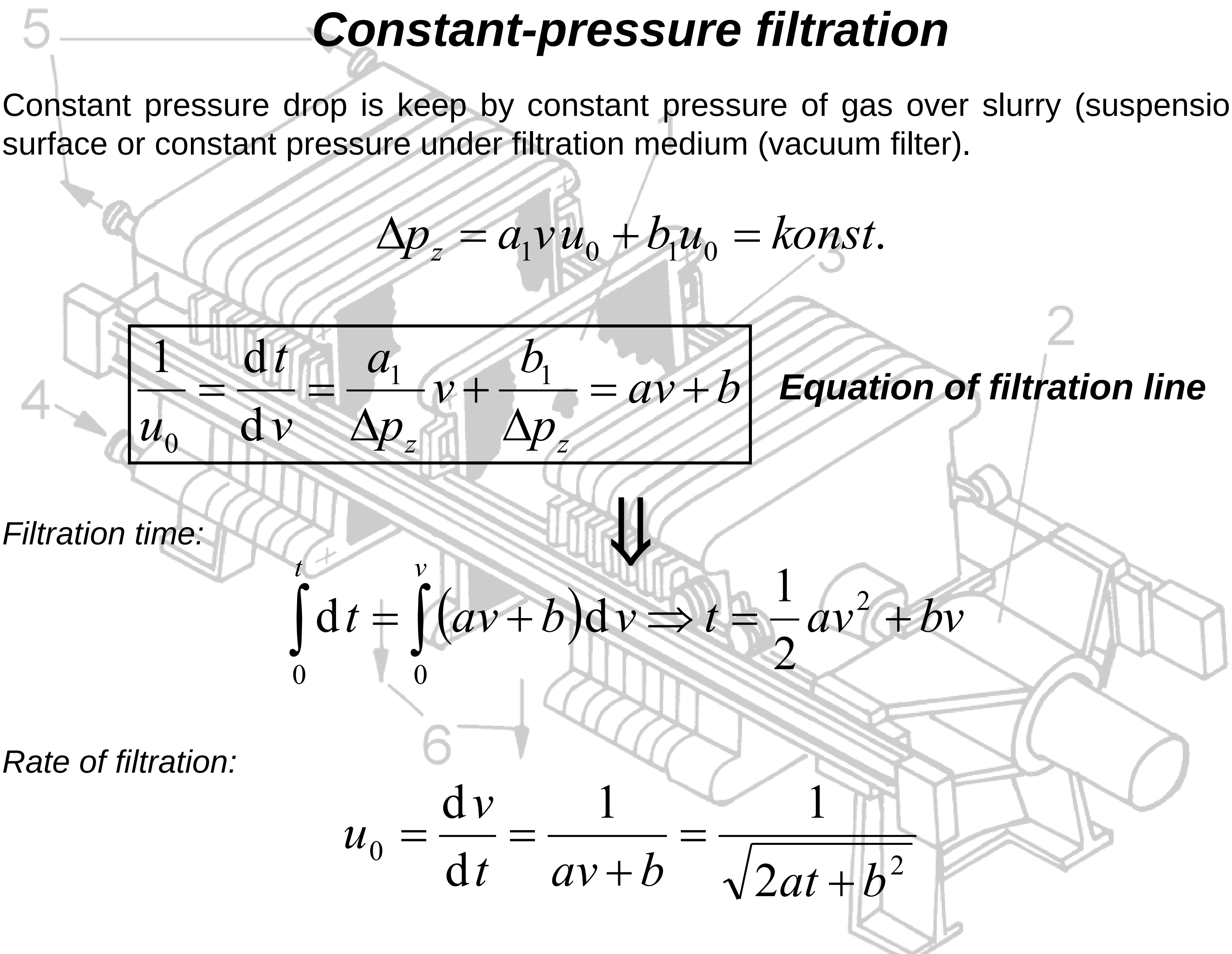
$$\Downarrow$$

Filtration time:

$$\int_0^t \mathrm{d}t = \int_0^v (av + b)\,\mathrm{d}v \Rightarrow t = \frac{1}{2} a v^2 + bv$$

Rate of filtration:

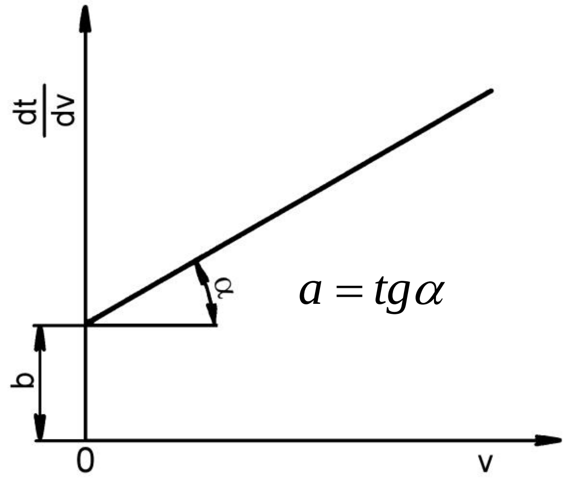
$$u_0 = \frac{\mathrm{d}v}{\mathrm{d}t} = \frac{1}{av + b} = \frac{1}{\sqrt{2at + b^2}}$$



Filter test – *evaluation of filtration constant* ***a*** *and* ***b***

Equation of filtration line

$$\frac{\mathrm{d}t}{\mathrm{d}v} = \frac{a_1}{\Delta p_z} v + \frac{b_1}{\Delta p_z} = av + b$$



EXAMPLE: Evaluation of filtration constant

Filtration test was carried out on experimental filter with filtration surface *S* = 0.05 m^2 for constant value negative pressure 50 kPa. Experimental given values of filtrate volume *V* and filtration time *t* are listed in table:

V [l]	1	2	3	4	5	7	10	15
t [s]	22	53	100	160	233	420	800	1700

Variable pressure and rate filtration

Filtration pressure was generated by centrifugal pump transporting of slurry (suspension) into filter.

$$\Delta p_z = \left(a_1 v + b_1\right) u_0 = \left(\frac{a_1}{S} V + b_1\right)\frac{\dot V}{S} = \frac{a_1}{S^2} V \dot V + \frac{b_1}{S}\dot V$$

$$v = V/S$$

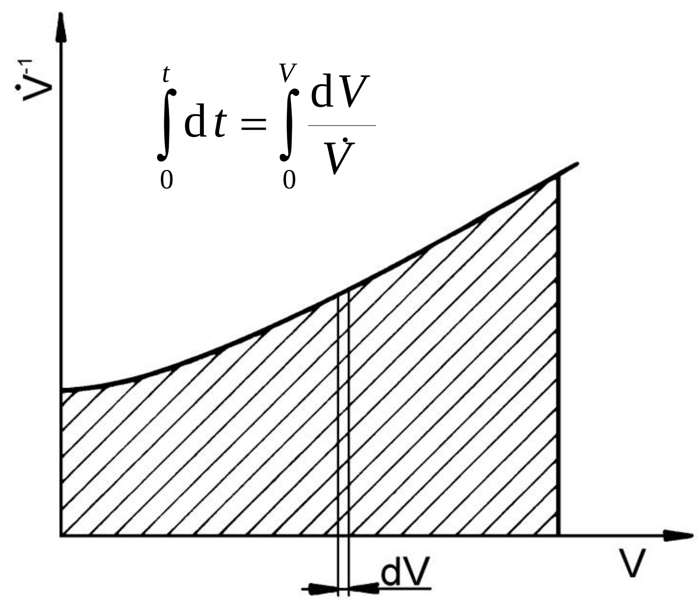
$$u_0 = \dot V / S$$

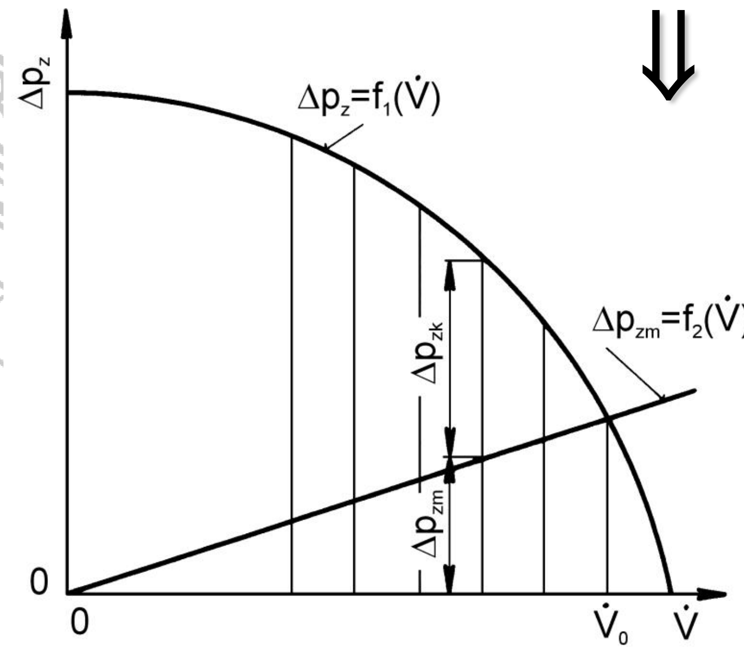
$$\Delta p_z = K_1 V \dot V + K_2 \dot V = \Delta p_{zk} + \Delta p_{zm}$$

$\Downarrow$

Filtration time:

$$\int_0^t \mathrm{d}t = \int_0^V \frac{\mathrm{d}V}{\dot V}$$





Time cycle of cake filtration

➢***Filtration***

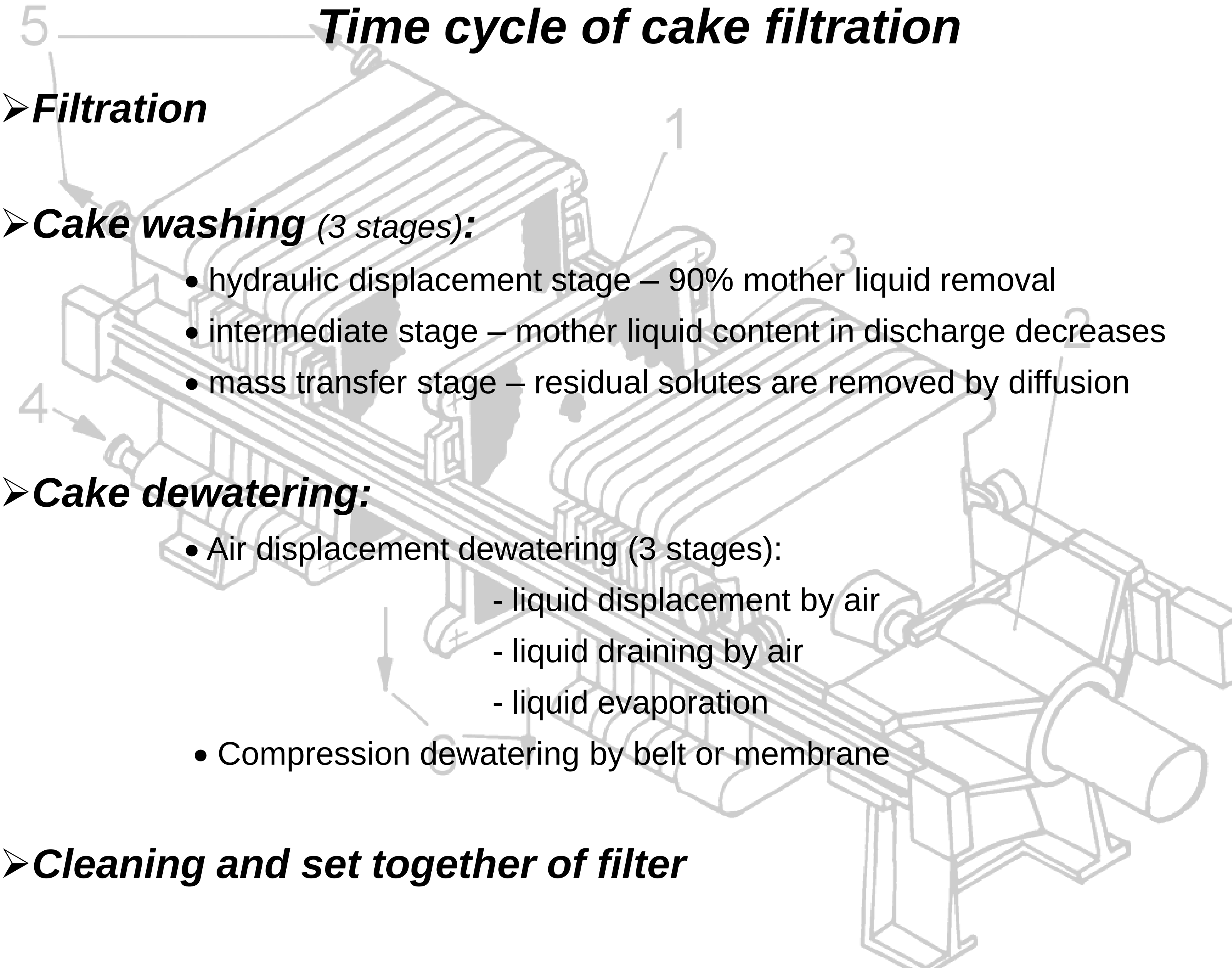
➢***Cake washing*** *(3 stages)****:***

- hydraulic displacement stage – 90% mother liquid removal
- intermediate stage – mother liquid content in discharge decreases
- mass transfer stage – residual solutes are removed by diffusion

➢***Cake dewatering:***

- Air displacement dewatering (3 stages):
  - liquid displacement by air
  - liquid draining by air
  - liquid evaporation
- Compression dewatering by belt or membrane

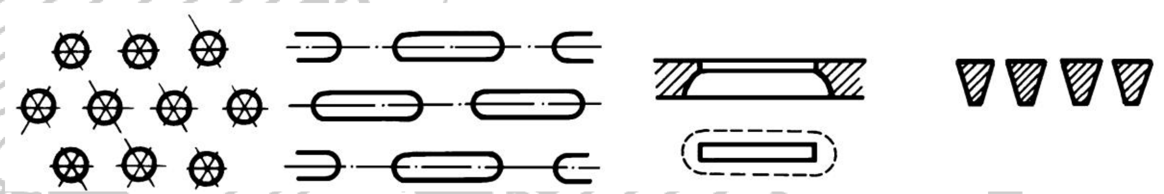
➢***Cleaning and set together of filter***



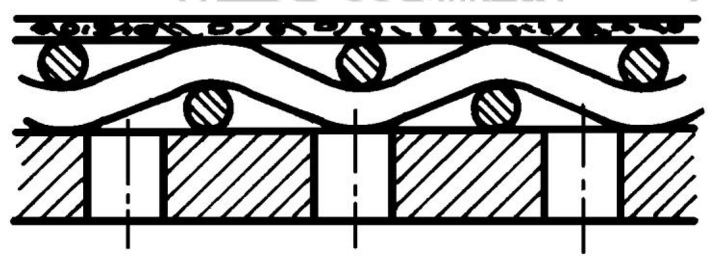
Types and design of filters

Filter media:

- screens and grids (coarse-granied suspense, supporting frame)



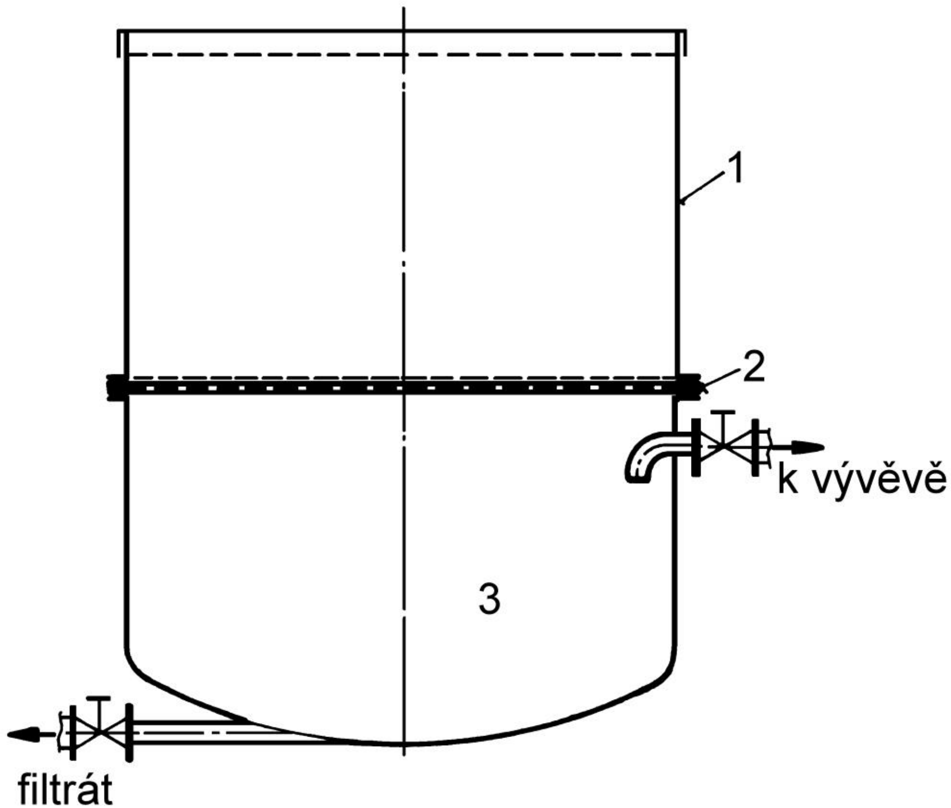
- metal clothes – steel, brass and copper (often as a support of cloth)
- natural clothes – cotton, wool, silk, paper
- polymeric clothes – PA, acryl, Teflon



- porous bed – deep-bet filters (particles, sand)
- membranes – ultra-filtration

Cake filters – batch operated

Nutsche *(pressure, vacuum)*



Vakuum nutche
1 *– tank for suspension,* ***2*** *– filter cloth,* ***3*** *– filtrate*

Advantages:

- simple
- cheap

Disadvantages:

- laborious cake removal
- great ground plan dimensions

Cake thickness: 5 – 40 cm

Leaf filters *(vacuum, pressure)*

- Leaf with cloth in shape of sack, suspension outside, filtrate removed from hollow wire framework
- Limited cake thickness- small concentrations

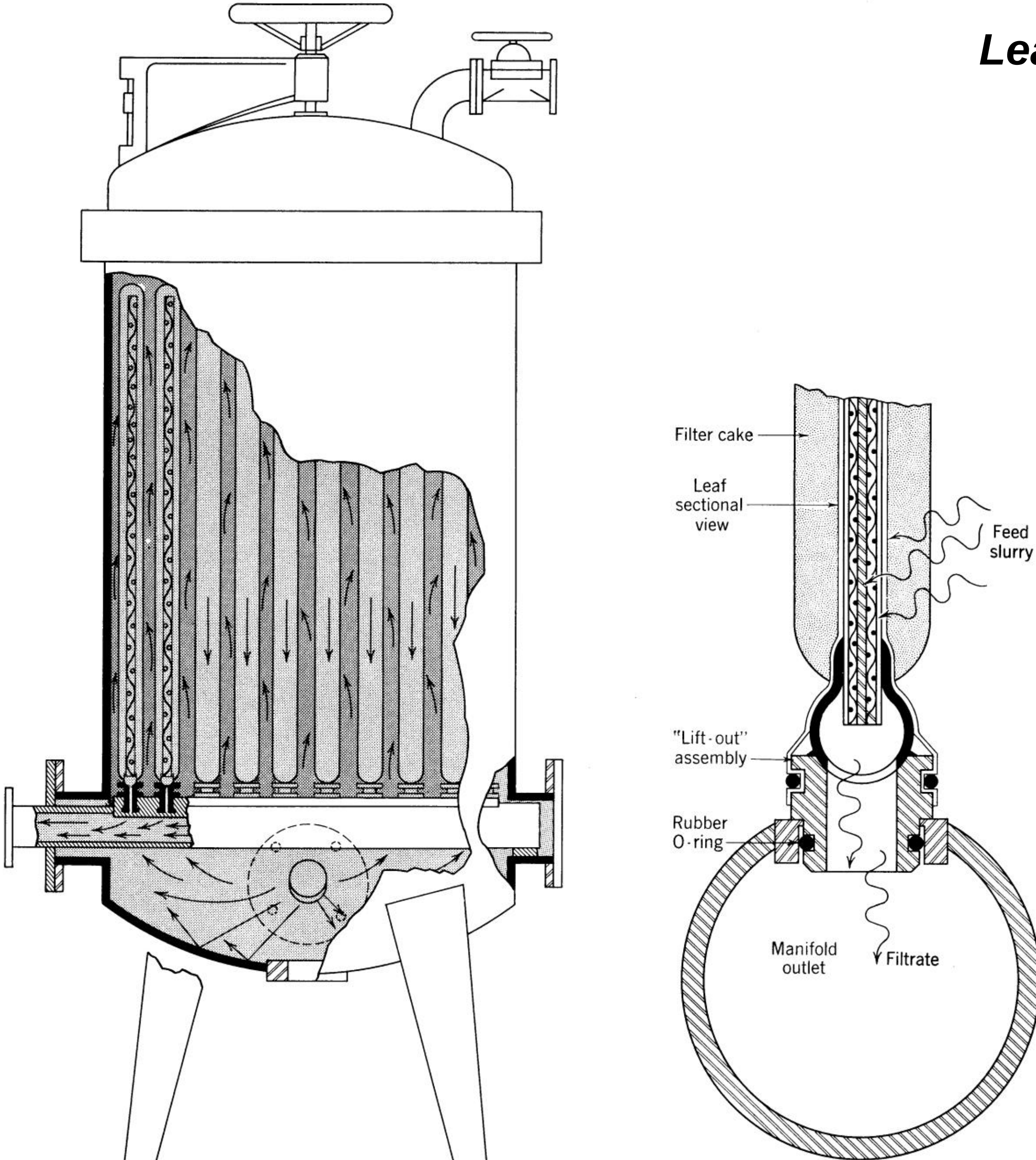
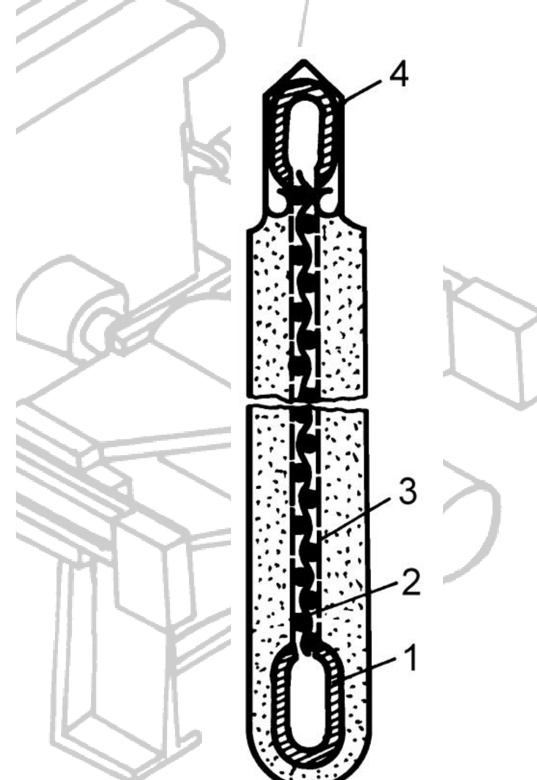
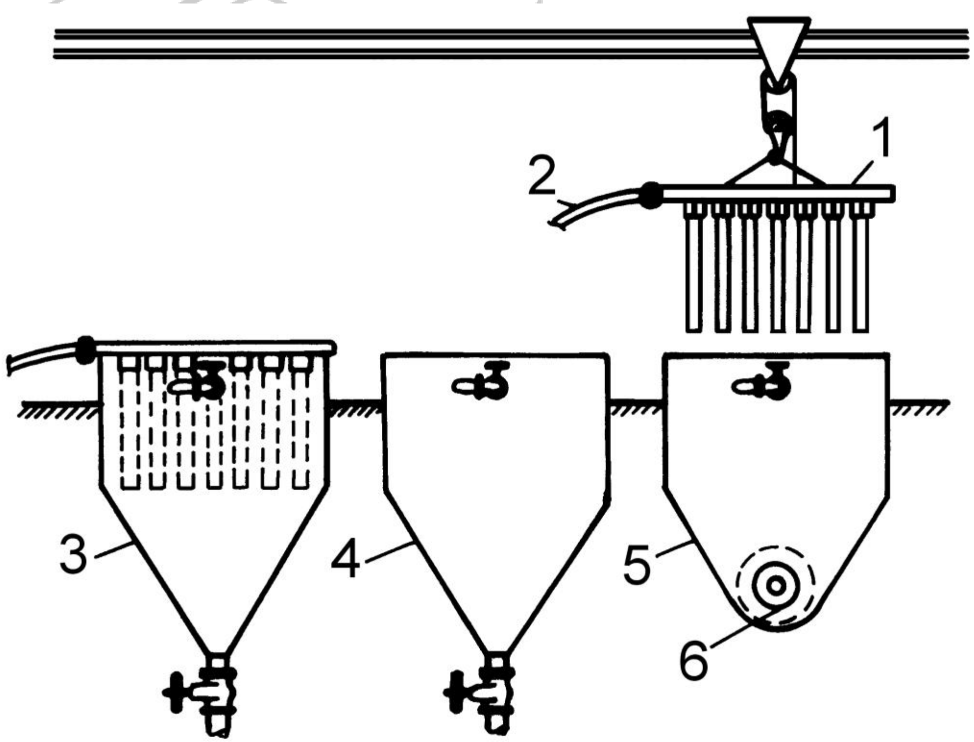


Figure 22.45. Cutaway view of a vertical-leaf filter and sectional diagram showing filter-leaf construction. (Courtesy Industrial Filter & Pump Mfg. Co.)



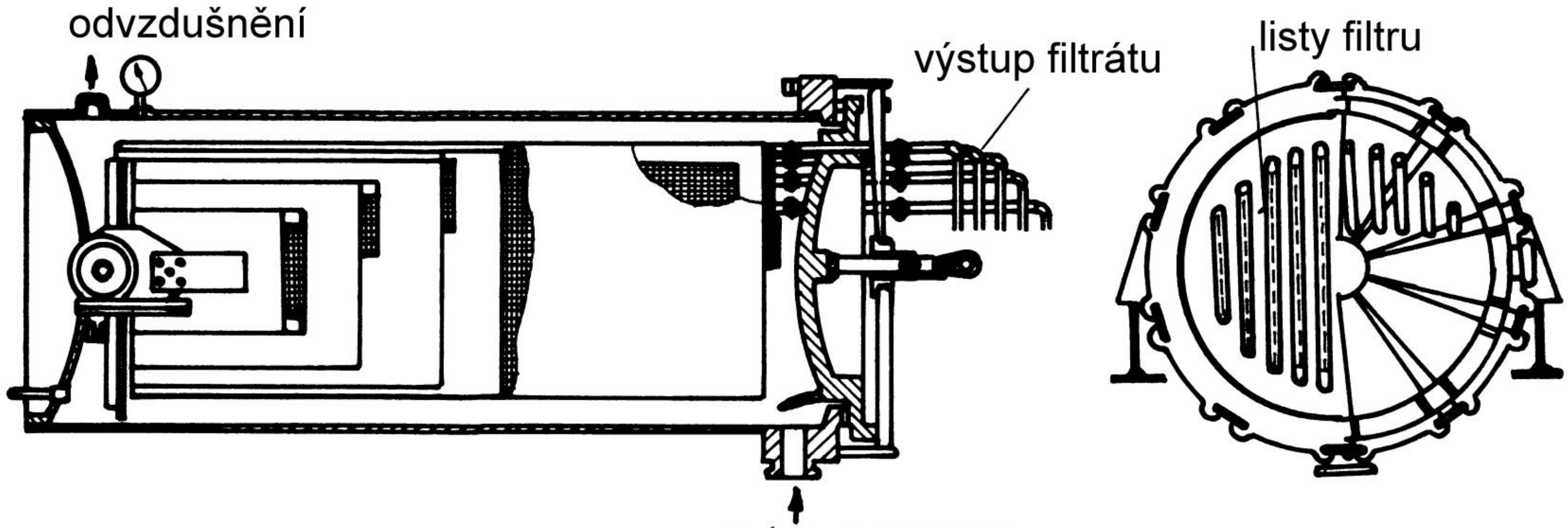
Vacuum leaf filter



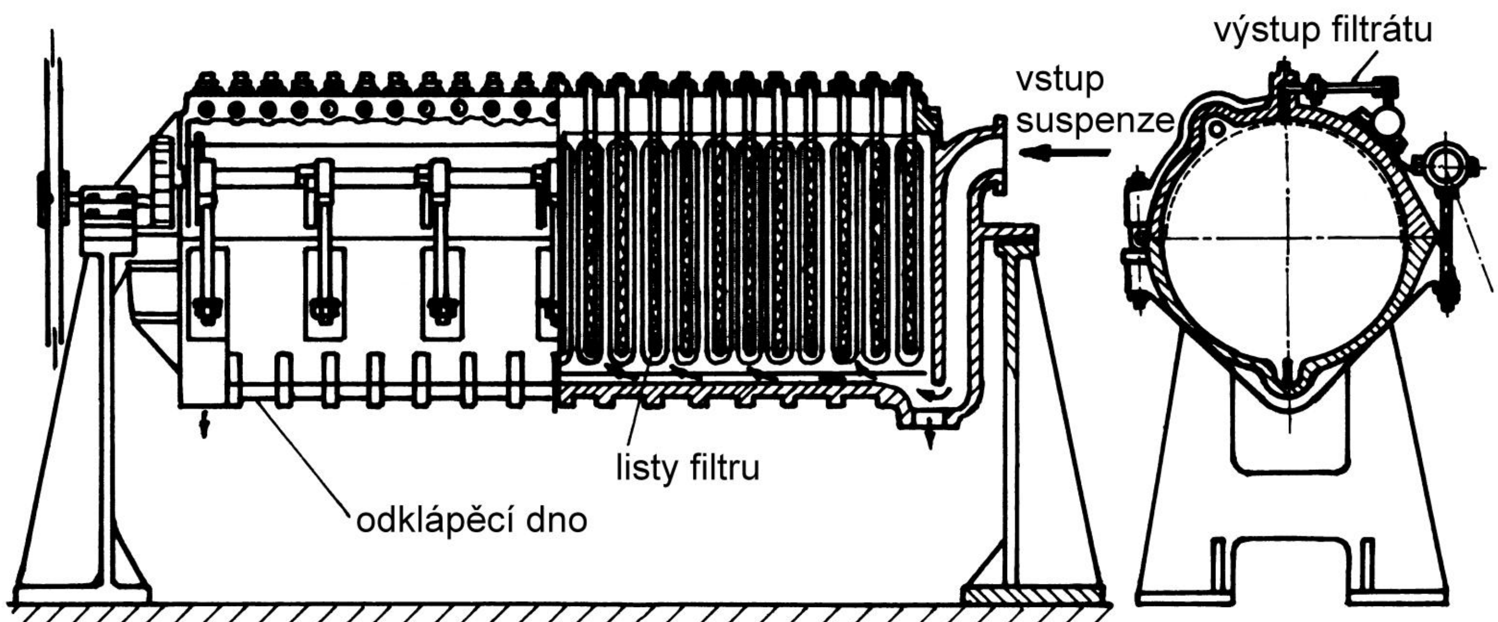
Time cycle of vacuum leaf filter
1 *– collecting tube,* ***2*** *– connection of vacuum,* ***3*** *– tank for slurry (suspension),* ***4*** *– Tank for washing liquid,* ***5*** *– tank for removed filter cake,* ***6*** *– feed screw*

Pressure leaf filters

Design by ***Kelly***

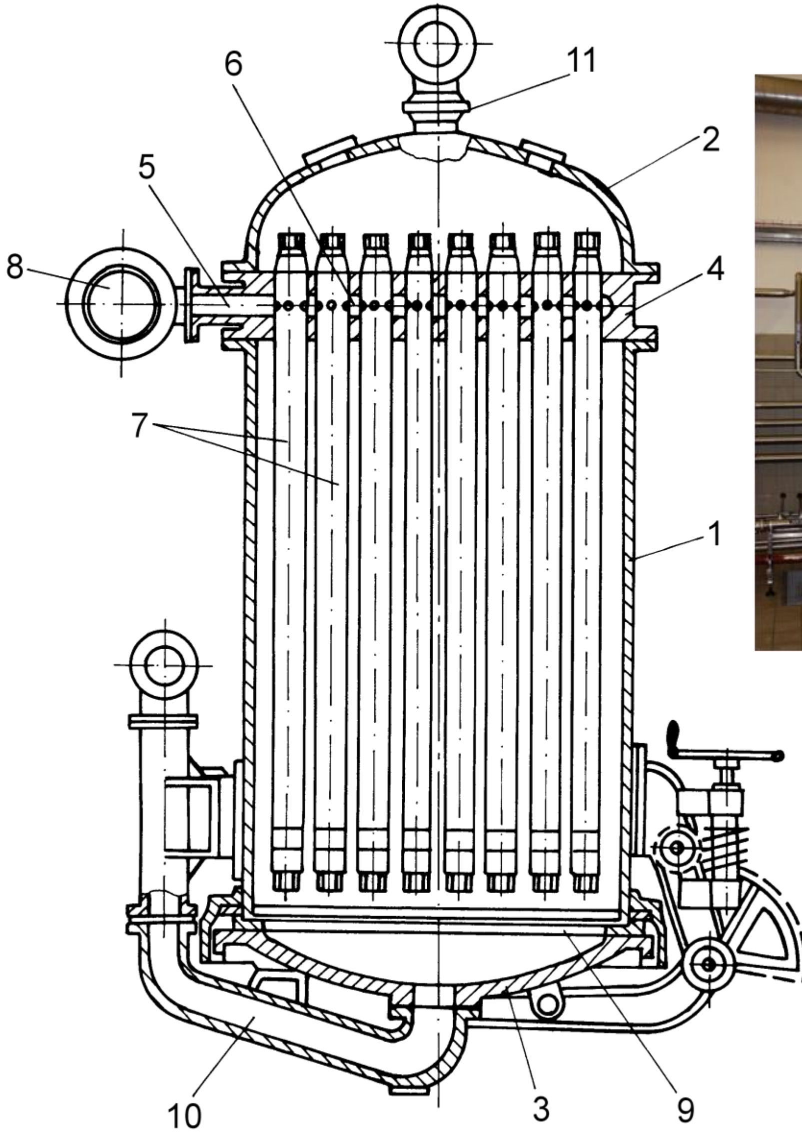


Design by ***Sweetland***

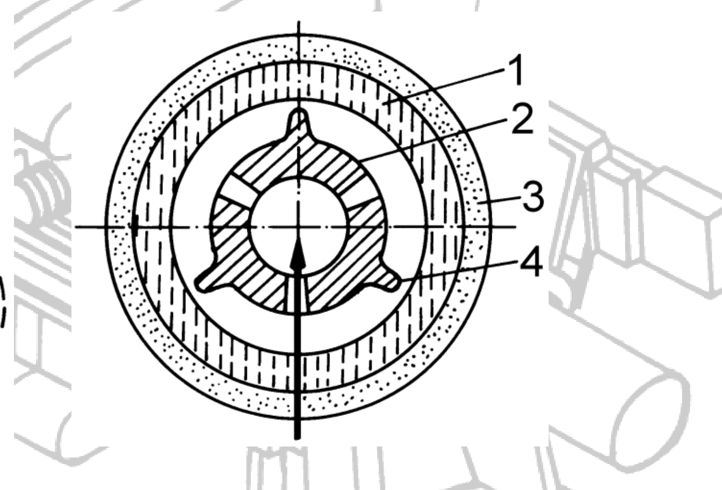


Cartridge filter

- Filtration element – porous tube (cartridge)
- For dilute suspensions



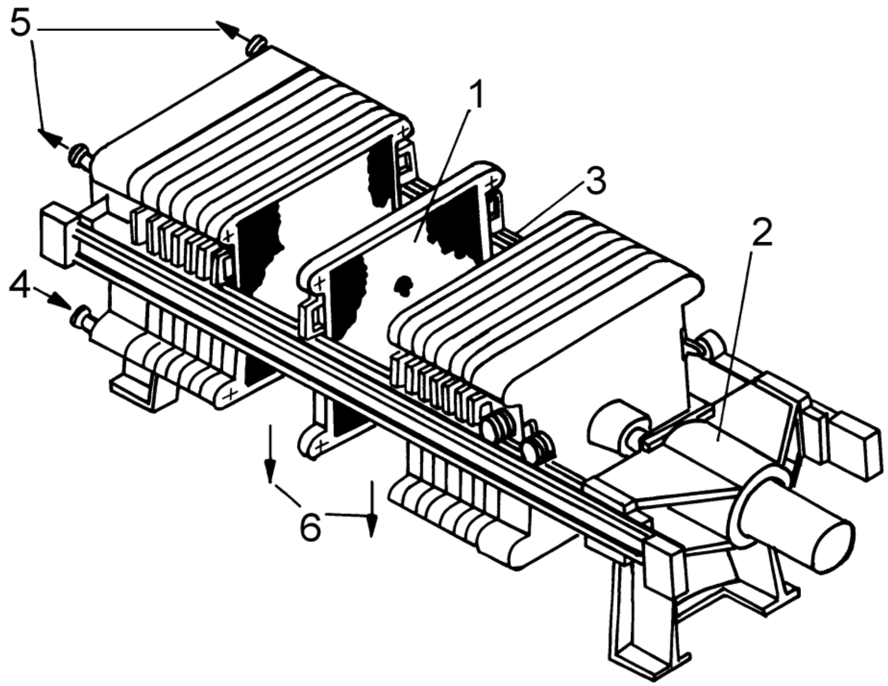
Svíčkový filtr
1 *– plášť filtru,* ***2*** *– víko,* ***3*** *– odklápěcí dno,* ***4*** *– deska,* ***5****,* ***6*** *– kanálky pro filtrát,* ***7*** *– filtrační svíčky,* ***8*** *– sběrač filtrátu,* ***9*** *– perforovaná přepážka,* ***10*** *– přívod suspenze,* ***11*** *– hrdlo pro cirkulující suspenzi*



Řez filtračním elementem svíčkového filtru
1 *– porézní válec (svíčka),* ***2*** *– centrální trubka,* ***3*** *– filtrační koláč,* ***4*** *– podélná žebra*

Filter presses *(plate-and-frame, chamber)*

- For higher concentrations
- Suitable for badly filtrated cakes
- For grater capacities or for unhealthy (dangerous) materials
- Elements are clasped by press (smaller – central screw, greater – hydraulics)
- Disadvantage – laborious cleaning
- Modern – automated discharging x expensive



Uspořádání kalolisu
1 *– filtrační přepážka,* ***2*** *– mechanické nebo hydraulické uzavírací zařízení,*
3 *– nosníky pro uložení filtračních elementů,* ***4*** *– vstup suspenze,* ***5*** *– výstup filtrátu,*
6 *– výstup filtračního koláče*

Plate-and-frame press

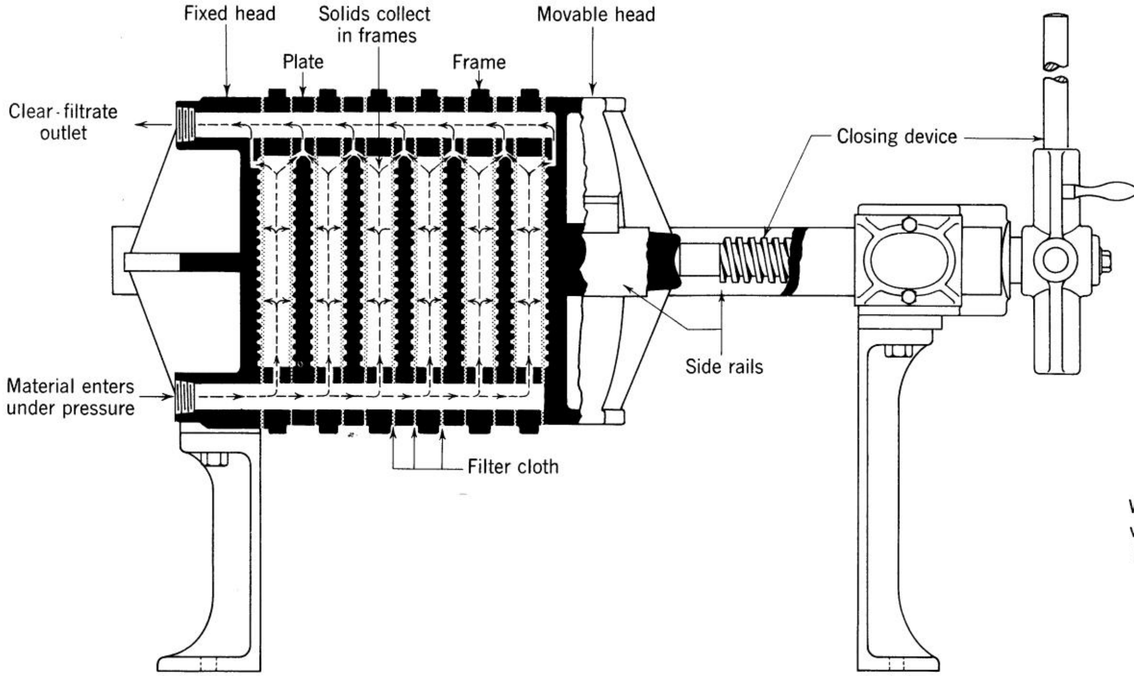


Figure 22.40. Schematic diagram of filter press in operation. (Courtesy T. Shriver and Company.)

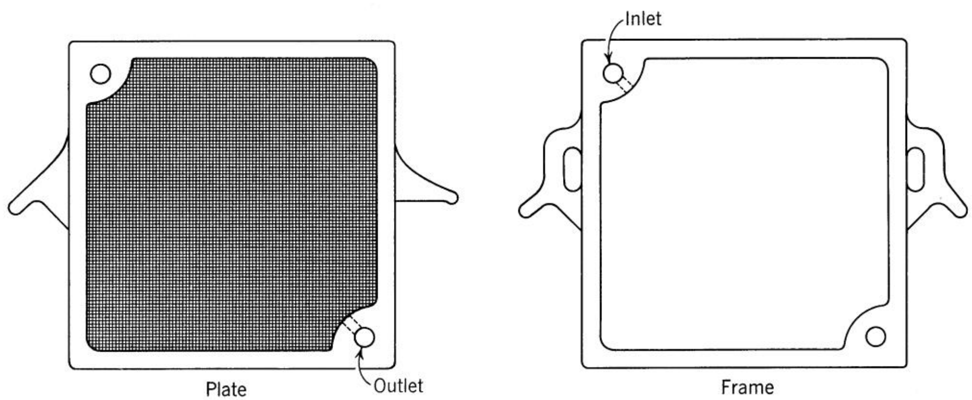


Figure 22.39. Plate-and-frame pair of simple corner-hole nonwashing design with closed discharge and waffle-grid surface. (Courtesy T. Shriver and Company.)

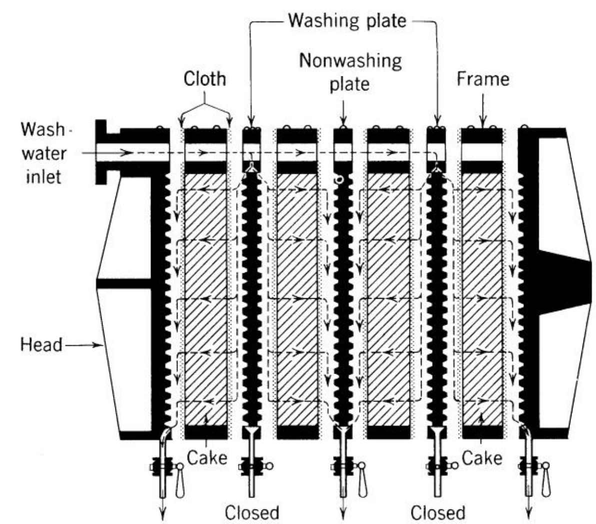
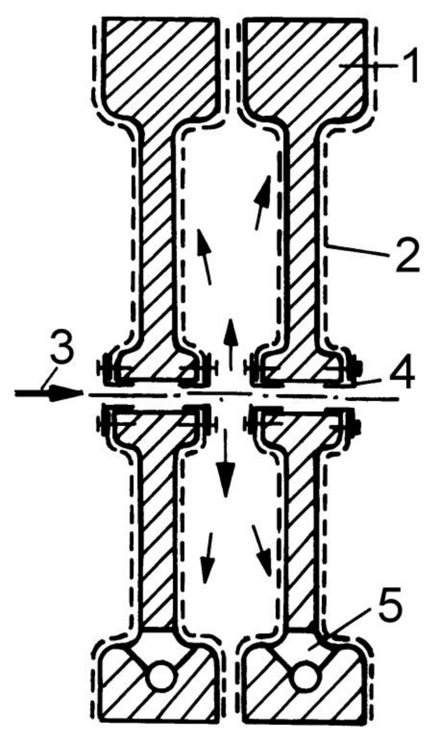


Figure 22.42. Schematic diagram of through-washing in a plate-and-frame filter press with open delivery. Note one-button, two-button, three-button coding on the top edge of the plates and frames. (Courtesy T. Shriver & Co.)

Chamber filter press

- Only plates, chambers between plates for cake
- Disadvantage – laborious cloth set-up

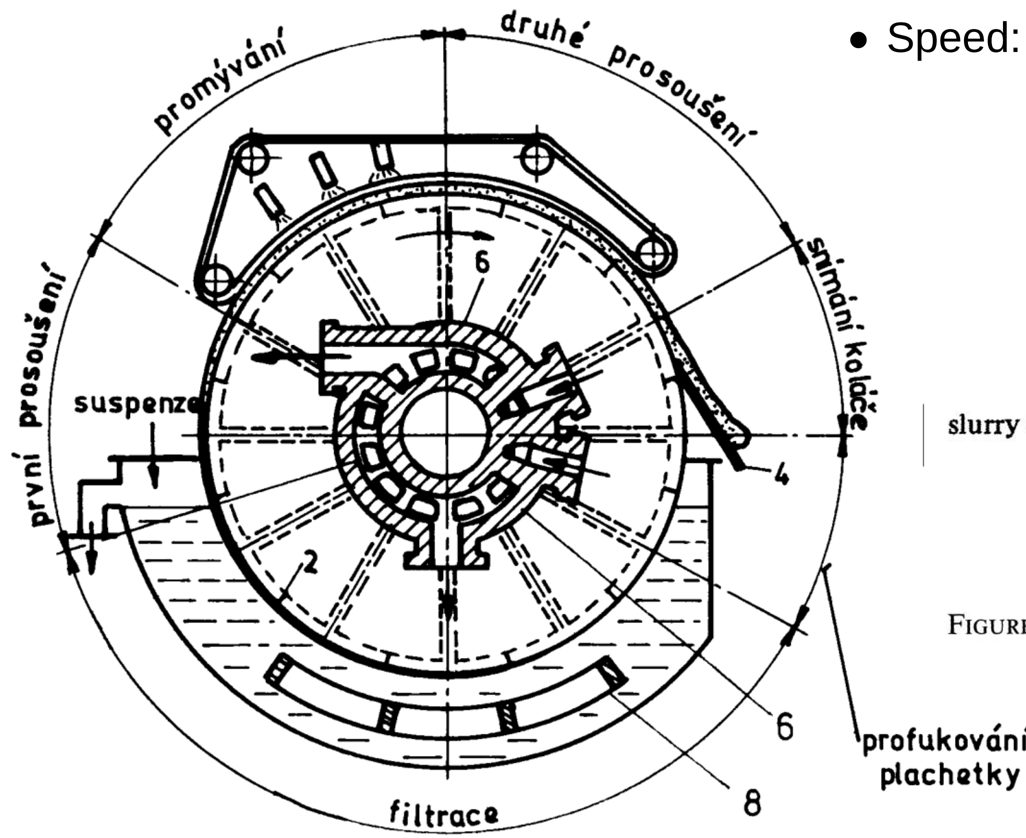


1 *– plate,* ***2*** *– cloth,* ***3*** *– suspension inlet,* ***4*** *– seal,* ***5*** *– field drain*

Cake filters – continuously operated

Continuous rotary-drum filter

- Space of drum: 12–24 chambers connected with automated valve – outlet for filtrate, washing water, inlet for air
- Speed: 0.1–3 rpm, Drum diameter: 1.8–3.6 m



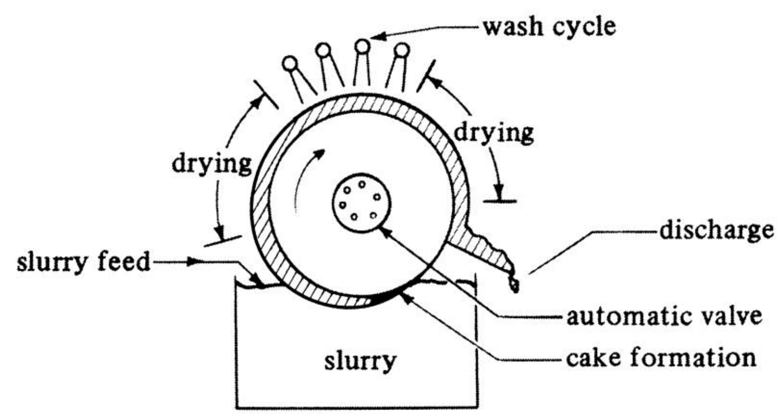
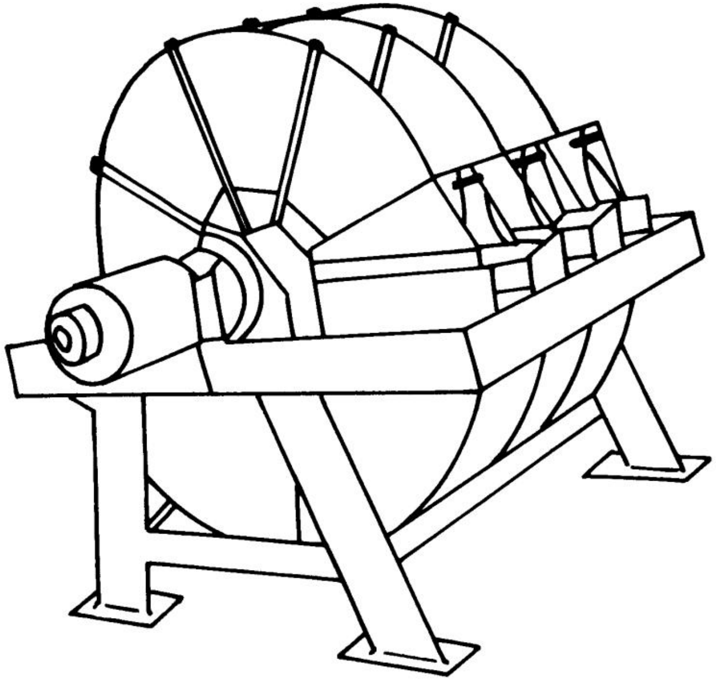


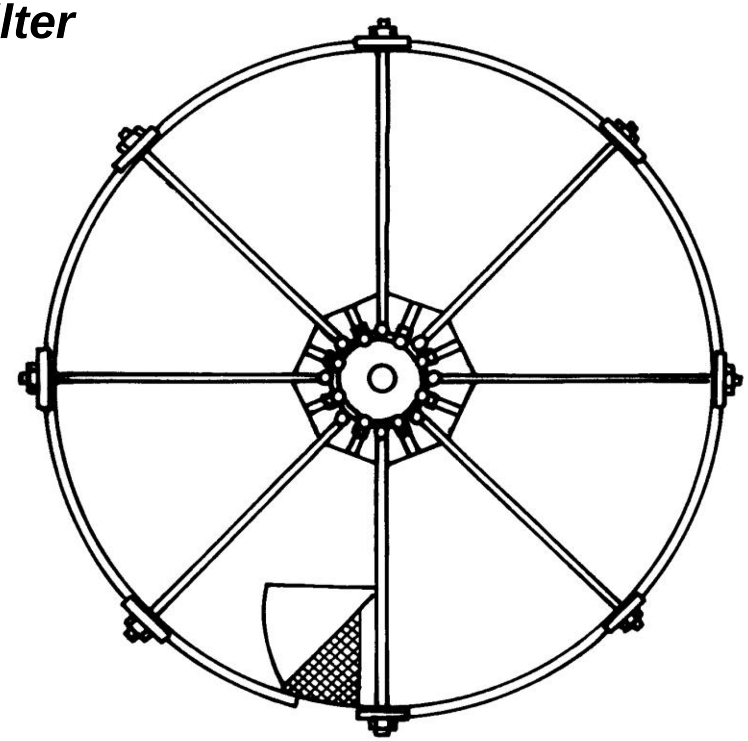
FIGURE 14.2-5. *Schematic of continuous rotary-drum filter.*

Bubnový filtr celový (komůrkový)

***1** – plášť bubnu s filtrační plachetkou, **2** – podélné přepážky, **3** – vnitřní plášť, **4** – snímací nůž, **5** – trubky, **6** – rozváděcí hlava, **7** – kruhový disk s otvory, **8** – míchadlo*

Disc filter





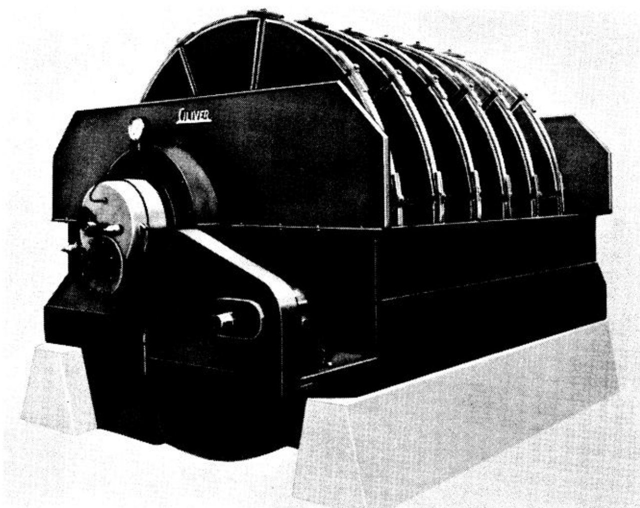
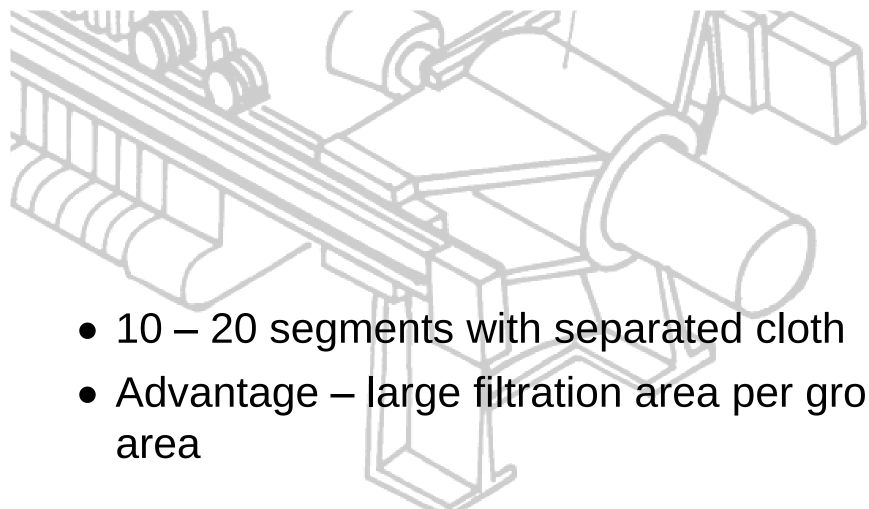
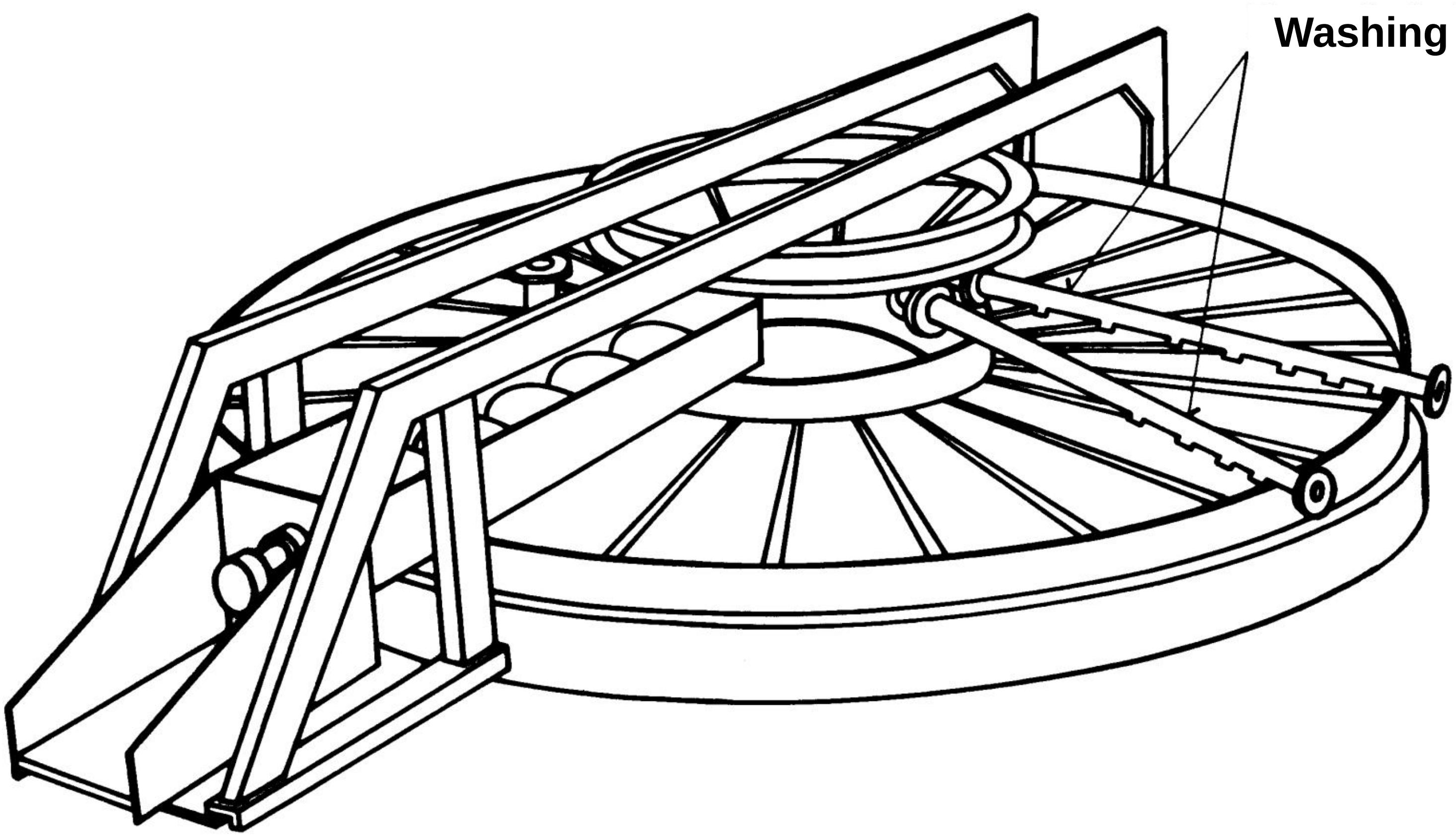


Figure 22.50. Rotary-disk vacuum filter, 8-ft face by 6 disk, shown from valve and drive end. (Courtesy Dorr-Oliver, Inc.)



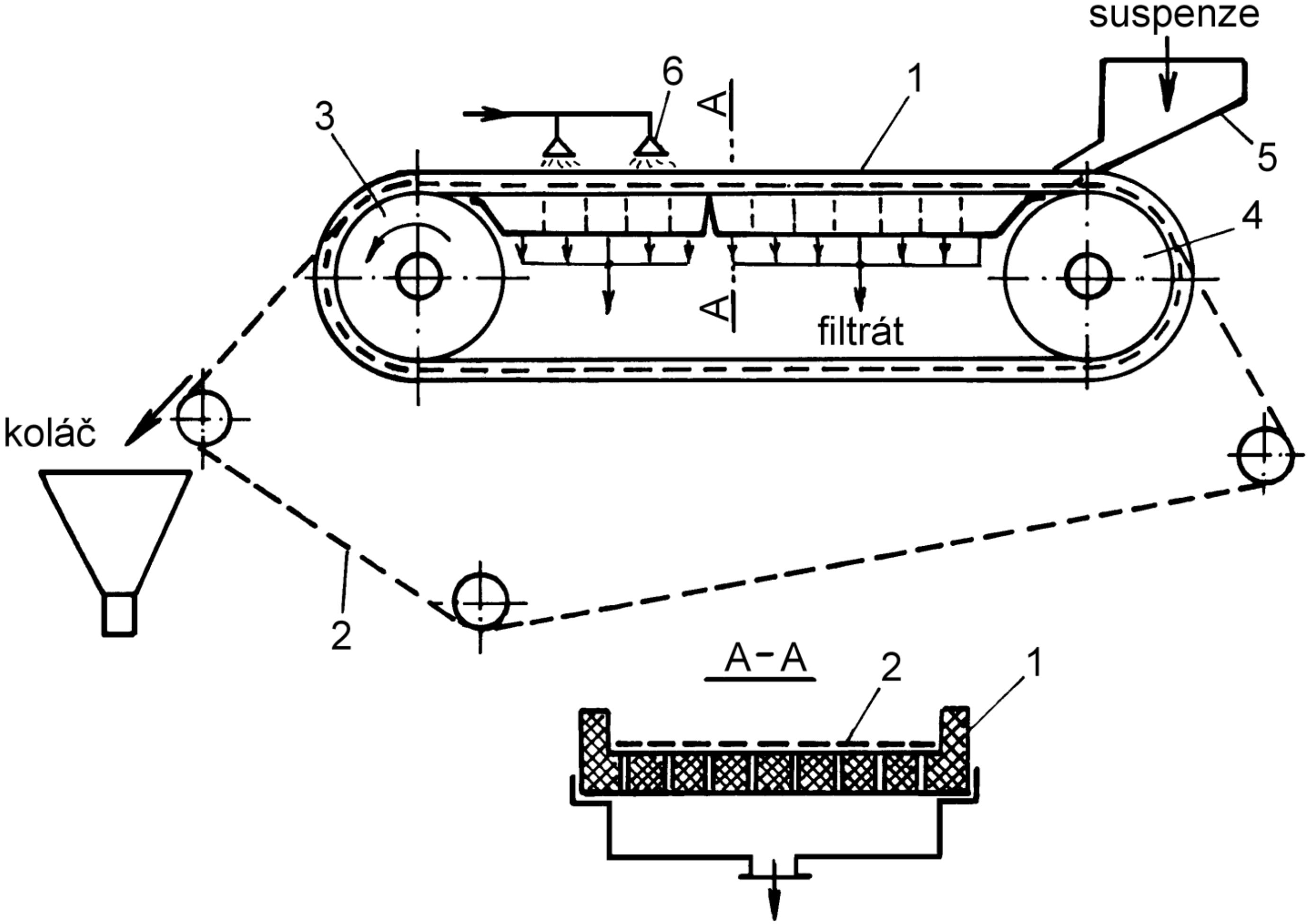
- 10 – 20 segments with separated cloth
- Advantage – large filtration area per ground area

Horizontal rotary filter



- Coarse suspensions
- Good washing
- Greater cake thickness x large ground area

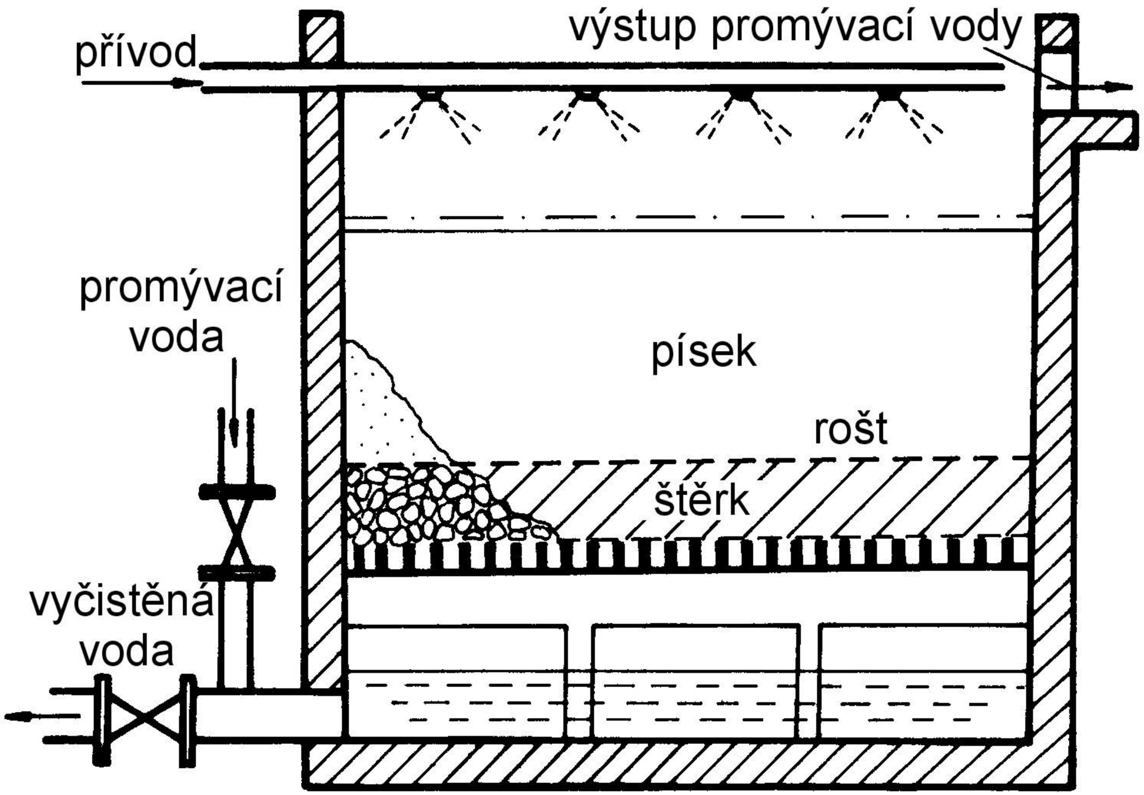
Belt filter



1 *– pryžový pás,* ***2*** *– filtrační plachetka,* ***3*** *– hnací buben,* ***4*** *– napínací buben,*
5 *– přívod suspenze,* ***6*** *– přívod promývací vody*

Deep bed filters

Open sand filter



- Small velocity
- Great ground area
- Gravity filter – driving force is hydrostatic pressure of suspension

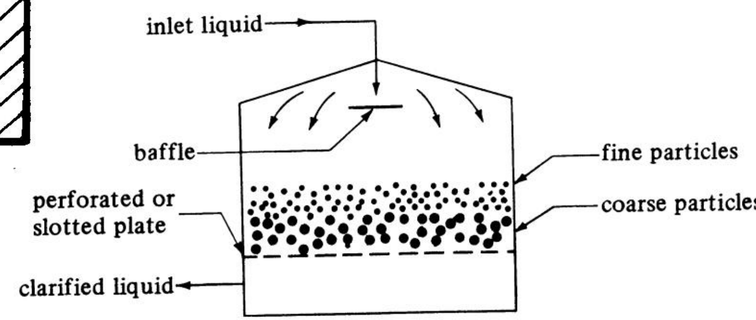
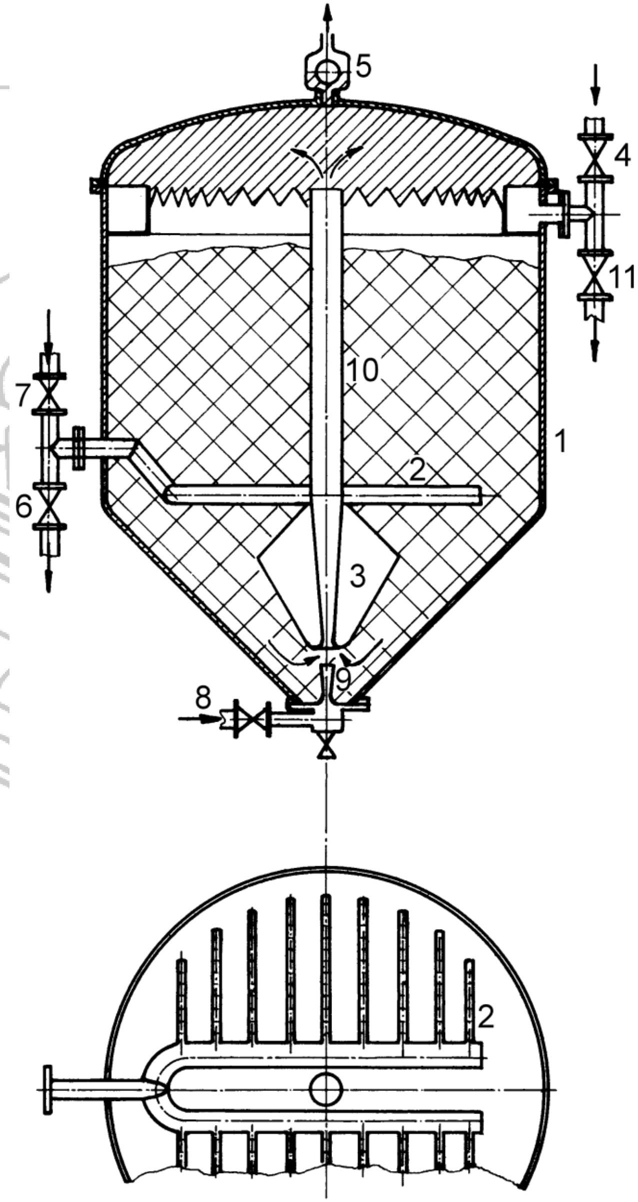


FIGURE 14.2-2. *Bed filter of solid particles.*

Closed sand filter

- Quick water filtration
- Pressure filter



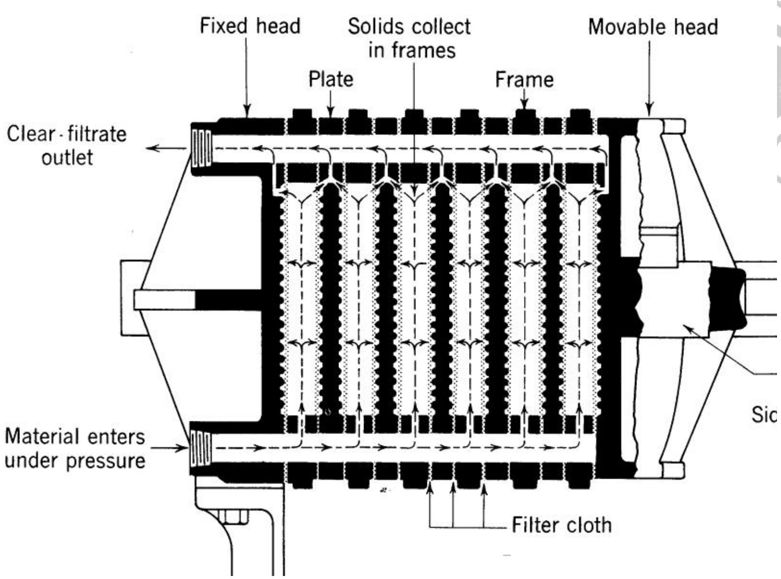
1 *– tlaková nádoba,* ***2*** *– trubkový scezovací systém,*
3 *– injektorové promývací zařízení,* ***4*** *– ventil,* ***5*** *– odvzdušňovací ventil,*
6*,* ***7****,* ***8*** *– ventily,* ***9*** *– tryska,* ***10*** *– centrální trubka,* ***11*** *– ventil*

EXAMPLE: Plate-and-frame press

Plate-and-frame press has 25 frame with inside dimensions 600 × 600 × 40 mm. Volumetric concentration of particles in slurry is 6 % and volumetric content of filtrate in cake is 20 %. Determinate volumetric capacity of this filter. Volume of washing water is 10 % from total volume of filtrate and total operating time is 30 min. Filtration and washing is realized for same and constant value of pressure. Viscosity of filtrate is 1.5 mPa•s and washing water is 1 mPa•s.

Following values of filtration constants were obtained on experimental filter for identical condition: a = 66.7 h•m^{-2}, b = 0.67 h•m^{-1}

Filtration



Cake washing