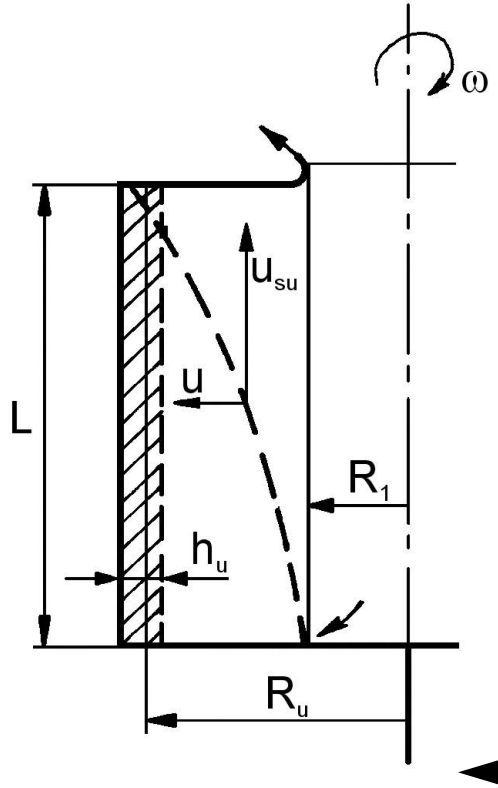
CENTRIFUGES

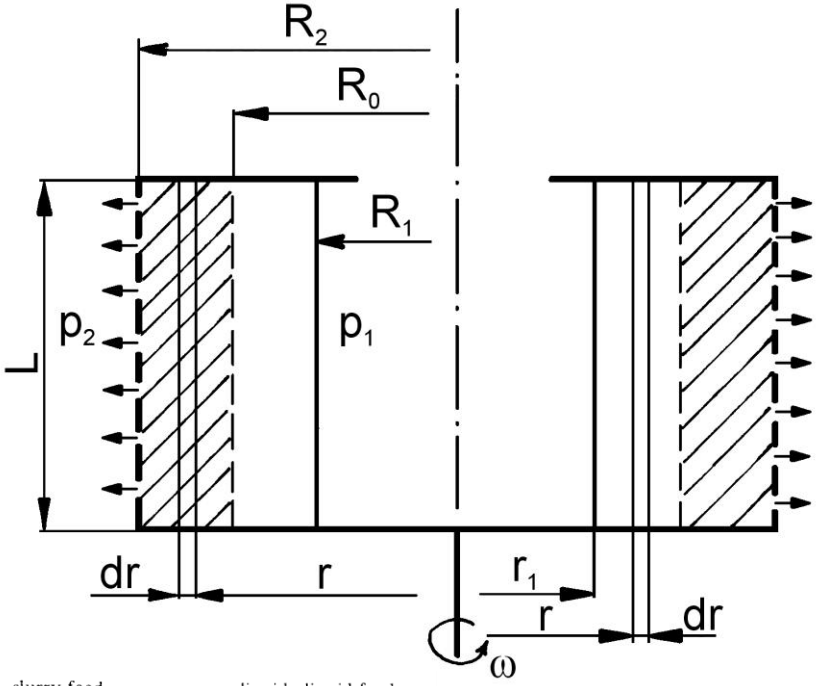
Sedimentation

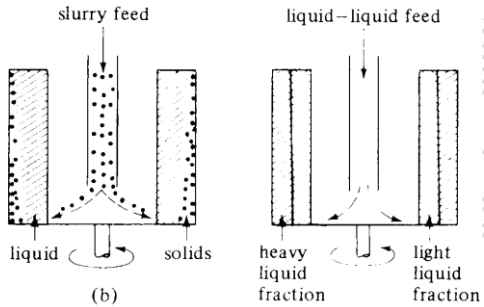
- imperforated basket
- phase with greater density creates layer at bowl wall, phase with smaller density is at liquid level near axis.
- centrifuges to separation of emulsions – ***purification***, centrifuges for separation of small amounts of solids – ***clarification***.



Filtration

- perforated basket with sieve or cloth as at cake filters



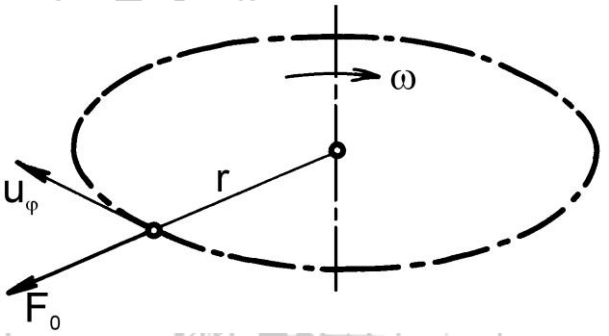


Settling in centrifuges

Settling velocity in centrifuges

Forces acting on particle settling in rotating liquid

- Centrifugal force $\vec{F}_o$
- Buoyant force in centrifugal force field $\vec{F}_{ov}$
- Coriolis force $\vec{F}_c$
- Gravitation force $\vec{G}$
- Buoyant force in gravitational field $\vec{F}_v$
- Drag force $\vec{F}$
- Inertial force – due to centrifugal acceleration $\vec{F}_s$



Force balance in radial direction

$$F_o - F_{ov} - F_r - \cancel{F_{sr}} = 0 \Rightarrow u = \sqrt{\frac{4}{3}\frac{D(\rho_s - \rho) r\omega^2}{C_D \rho}}$$

$$F_o = \frac{\pi D^3}{6}\rho_s r\omega^2 \qquad F_{ov} = \frac{\pi D^3}{6}\rho r\omega^2 \qquad F_r = C_D \frac{\pi D^2}{4}\frac{u^2}{2}\rho$$

$$u = \sqrt{\frac{4}{3}\frac{D(\rho_s - \rho)r\omega^2}{C_D\rho}}$$

Settling velocity in centrifugal force field can be determined from equation for settling velocity in gravitational field replacing acceleration due to gravity of centrifugal acceleration.

$$g \rightarrow r\omega^2$$

Stokes region:

$$u = \frac{D^2(\rho_s - \rho)\omega^2}{18\mu}r$$

Transition region:

$$u = 0{,}153\frac{D^{1{,}14}(\rho_s - \rho)^{0{,}71}\omega^{1{,}42}}{\rho^{0{,}29}\mu^{0{,}43}}r^{0{,}71}$$

Newton region:

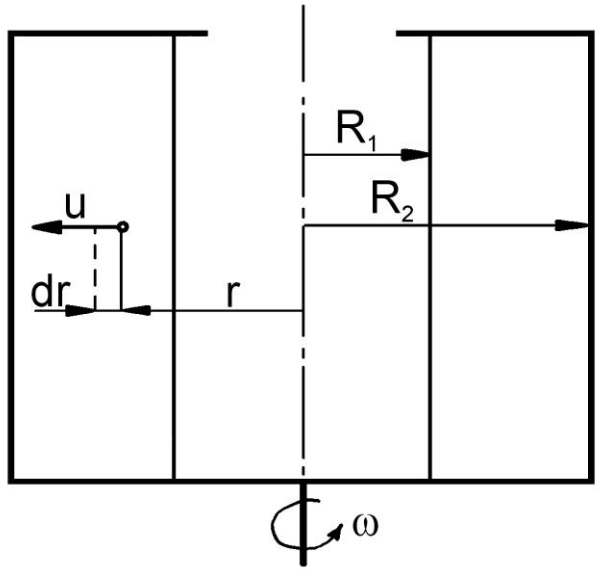
$$u = 1{,}74\frac{D(\rho_s - \rho)\omega^2}{\rho}r$$

Most of industrial centrifuges (95 %) working in the Stokes region!

Time of sedimentation in bowl centrifuges

$$\mathrm{d}r = u\,\mathrm{d}t$$

$$\int_0^t \mathrm{d}t = \int_{R_1}^{R_2} \frac{\mathrm{d}r}{u}$$



Stokes region:

$$t = \frac{18\mu}{D^2(\rho_s - \rho)\omega^2} \int_{R_1}^{R_2} \frac{\mathrm{d}r}{r} = \frac{18\mu}{D^2(\rho_s - \rho)\omega^2} \ln \frac{R_2}{R_1}$$

Transition region:

$$t = \frac{\rho^{0,29}\mu^{0,43}}{0{,}153 D^{1,14}(\rho_s - \rho)^{0,71}\omega^{1,42}} \int_{R_1}^{R_2} \frac{\mathrm{d}r}{r^{0,71}} = 22{,}5 \frac{\rho^{0,29}\mu^{0,43}}{D^{1,14}(\rho_s - \rho)^{0,71}\omega^{1,42}} \left(R_2^{0,29} - R_1^{0,29}\right)$$

Newton region:

$$t = \frac{1}{1{,}74\sqrt{D(\rho_s - \rho)\omega^2}} \int_{R_1}^{R_2} \frac{\mathrm{d}r}{r^{1/2}} = 1{,}15 \sqrt{\frac{\rho}{D(\rho_s - \rho)\omega^2}} \left(\sqrt{R_2} - \sqrt{R_1}\right)$$

Volumetric flow rate in bowl centrifuges

Batch centrifuges

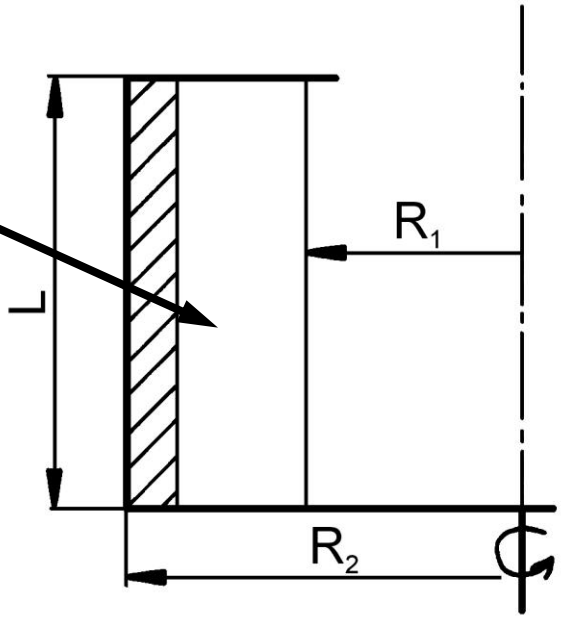
coarse suspensions with solid sediment

Time of one working period t_p :

- time of sedimentation in centrifuge ***t***
- handling time t_m (filling, starting, discharging, braking and stopping)

$$V = \pi L\left(R_2^2 - R_1^2\right)$$

$$\dot{V}_{stř} = \frac{\pi L\left(R_2^2 - R_1^2\right)}{t + t_m}$$



Semi-batch centrifuges

coarse suspensions with solid sediment

Mass balance of solid phase: $m_u w_u = m_{su} w_{su}$

weight of sediment layer at bowl wall

$$m_u = 2\pi R_u L h_u \rho_u$$

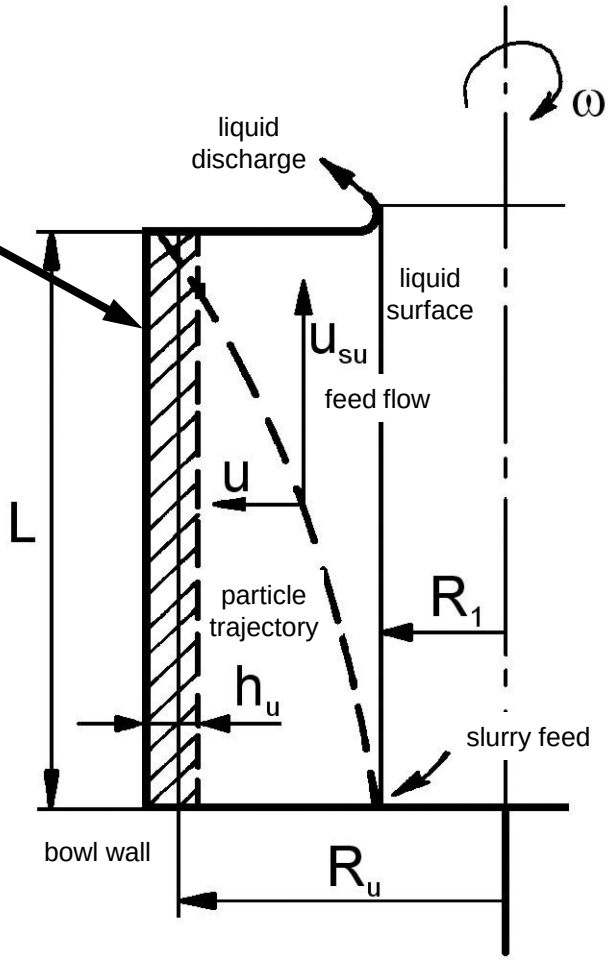
⇓

Weight of suspension from one working period:

$$m_{su} = m_u \frac{w_u}{w_{su}} = 2\pi R_u L h_u \rho_u \frac{w_u}{w_{su}}$$

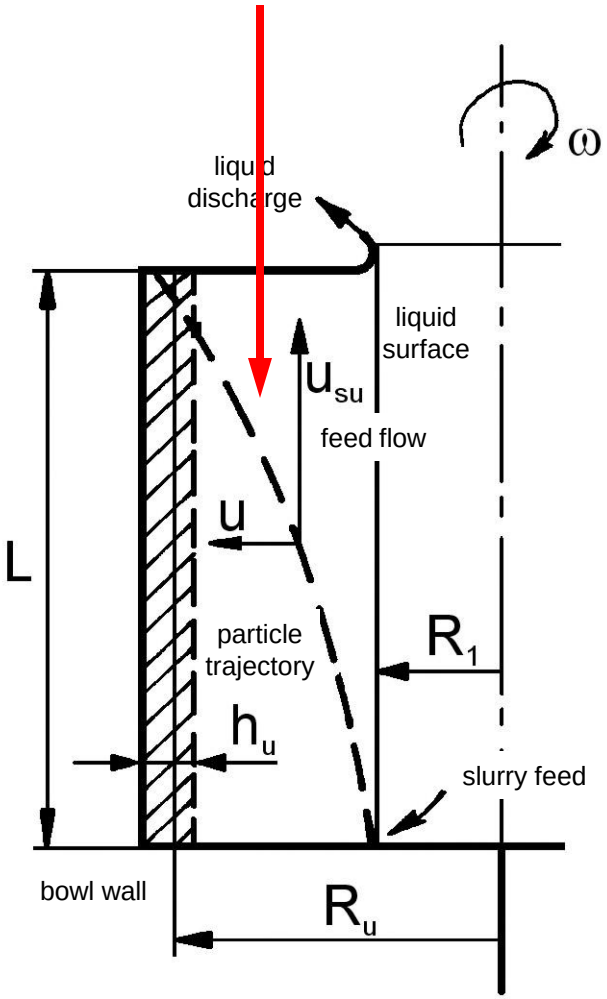
Volume of suspension from one working period:

$$V_{su} = 2\pi R_u h_u L \frac{\rho_u}{\rho_{su}} \frac{w_u}{w_{su}}$$



Basic working condition for semi-batch centrifuges *– residence time of suspension must be equal to sedimentation time of particle in centrifuge*

$$t_z = \frac{V}{\dot{V}_{su}} = t$$



Flow rate of suspension:

$$\dot{V}_{su} = \frac{V}{t} = \frac{\pi\left(R_u^2 - R_1^2\right)L}{t}$$

Time of centrifugation:

$$t_o = \frac{V_{su}}{\dot{V}_{su}} = 2R_u h_u \frac{\rho_u}{\rho_{su}} \frac{w_u}{w_{su}} \frac{t}{R_u^2 - R_1^2}$$

Average volumetric capacity:

$$\dot{V}_{stř} = \frac{V_{su}}{t_o + t_m}$$

Continuous centrifuges

fine suspensions with fluid sediment

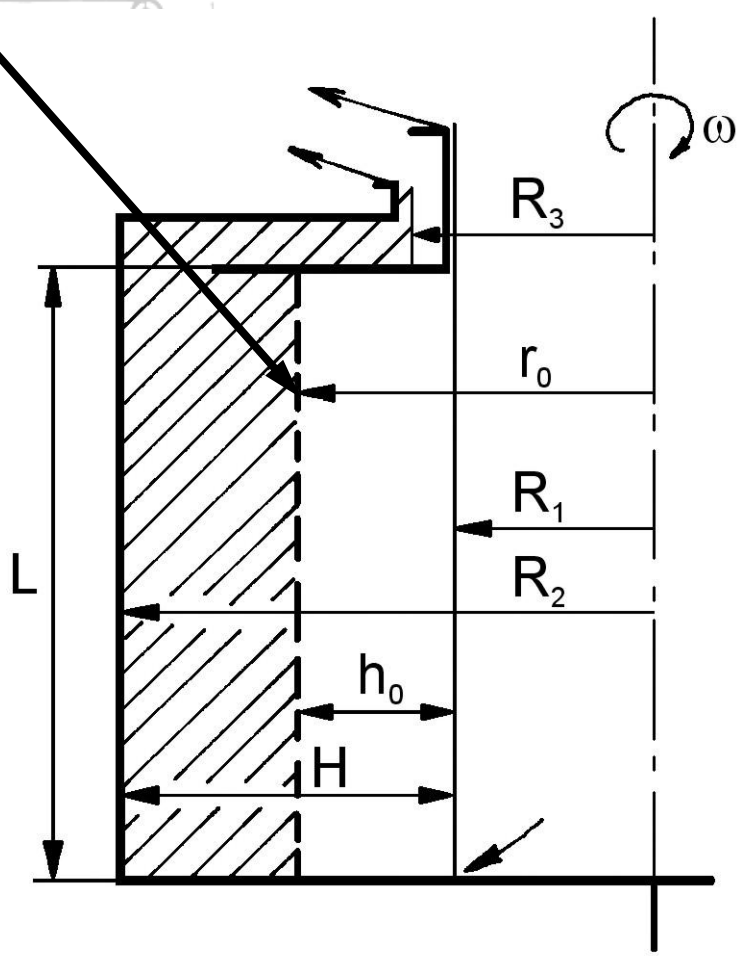
Radius od interface between fluid sediment and liquid:

pressure balance of interface

$$p_a + \frac{1}{2}\omega^2 \rho\left(r_o^2 - R_1^2\right) = p_a + \frac{1}{2}\omega^2 \rho_u \left(r_o^2 - R_3^2\right)$$

$$\Downarrow$$

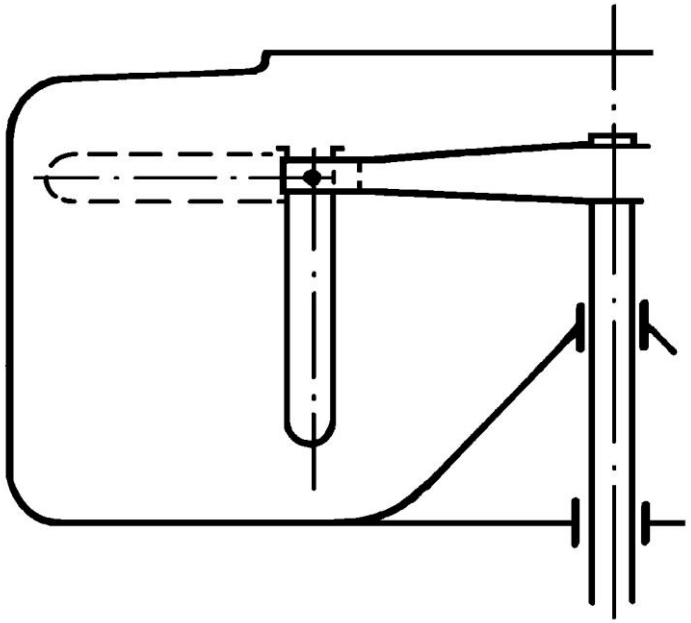
$$r_o = \sqrt{\frac{\rho_u R_3^2 - \rho R_1^2}{\rho_u - \rho}}$$



Design of centrifuges

Sedimentation centrifuges

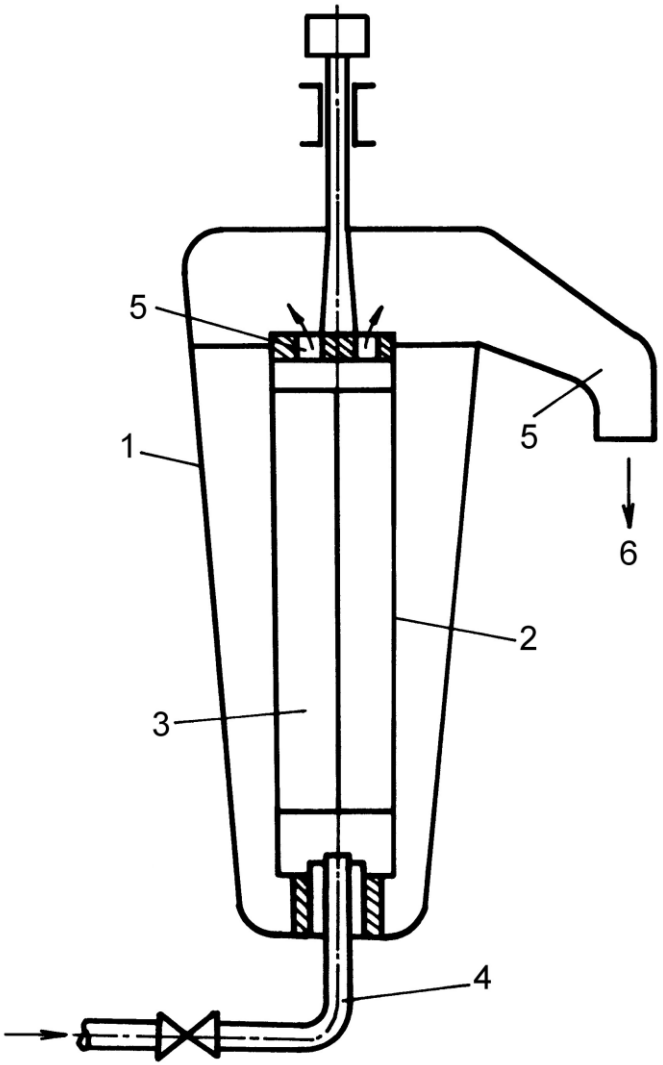
Test tube (cell) centrifuges



- boxes for glass cells with volume up to 1litre
- laboratory use for determination of clarification velocity or content of suspended particles

Tubular-bowl centrifuges

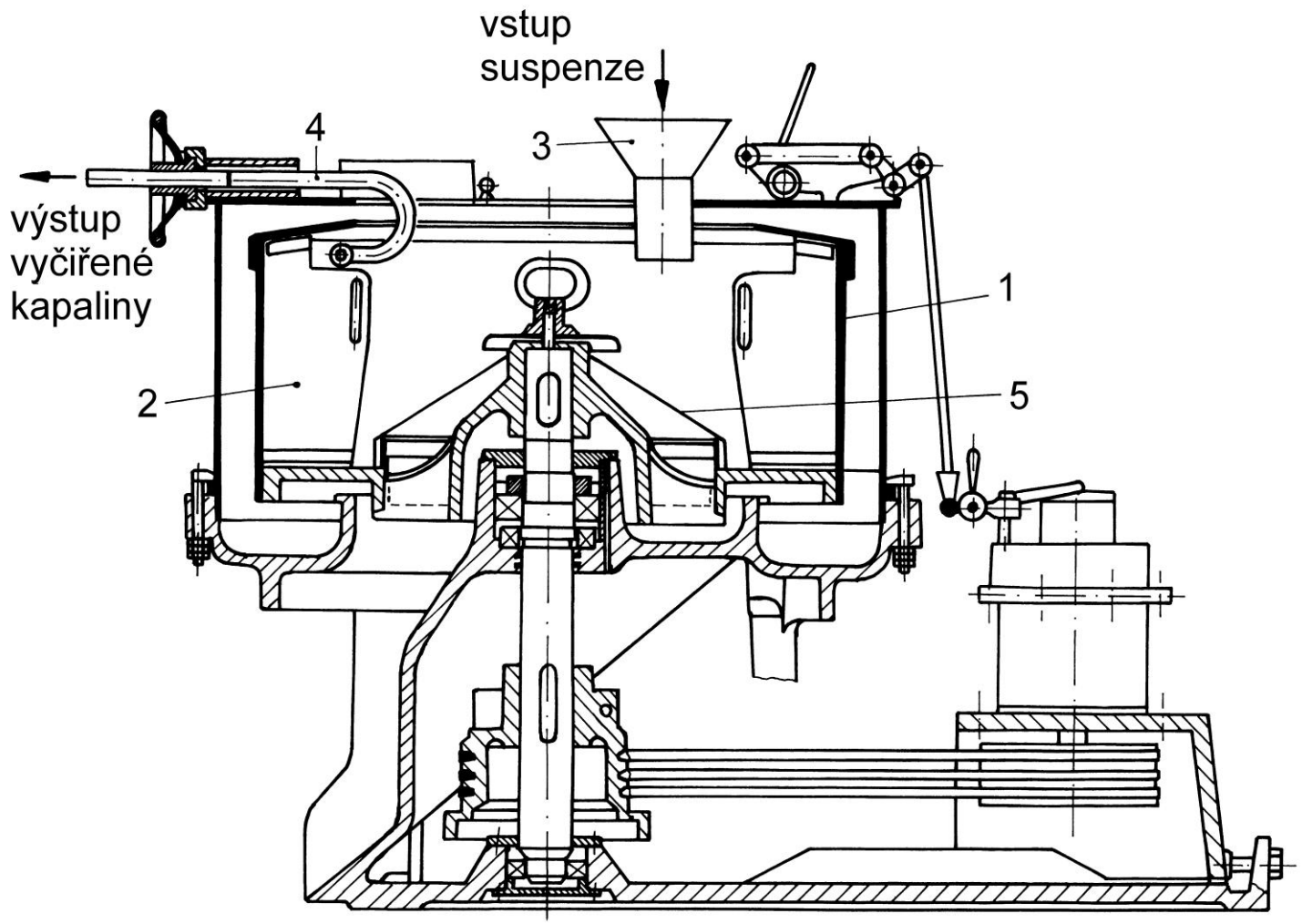
- small diameter of slender bowl
- high speed
- high values of Froude number
- sufficient residence time
- small capacities
- pharmaceutical industry



***1** – plášť, **2** – buben, **3** – radiální lopatky,*
***4** – přívod suspenze, **5** – otvory,*
***6** – výstup*

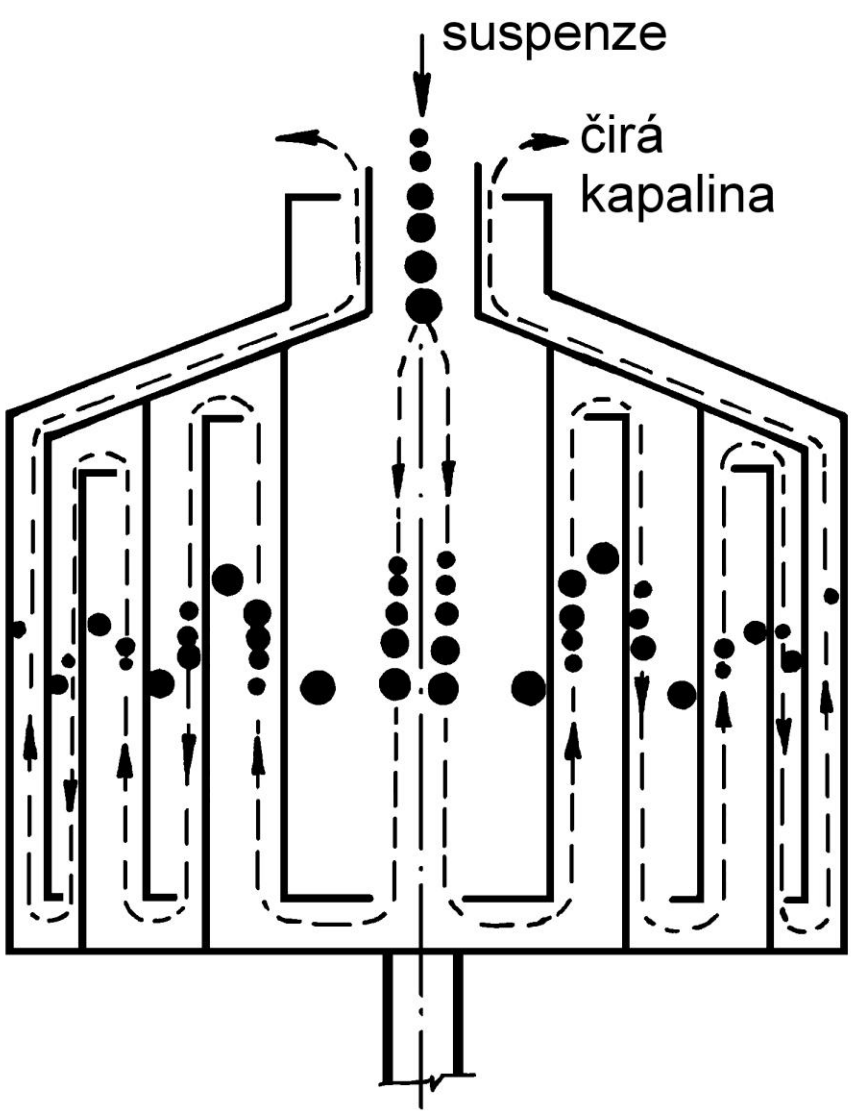
Bowl centrifuges

common industrial use

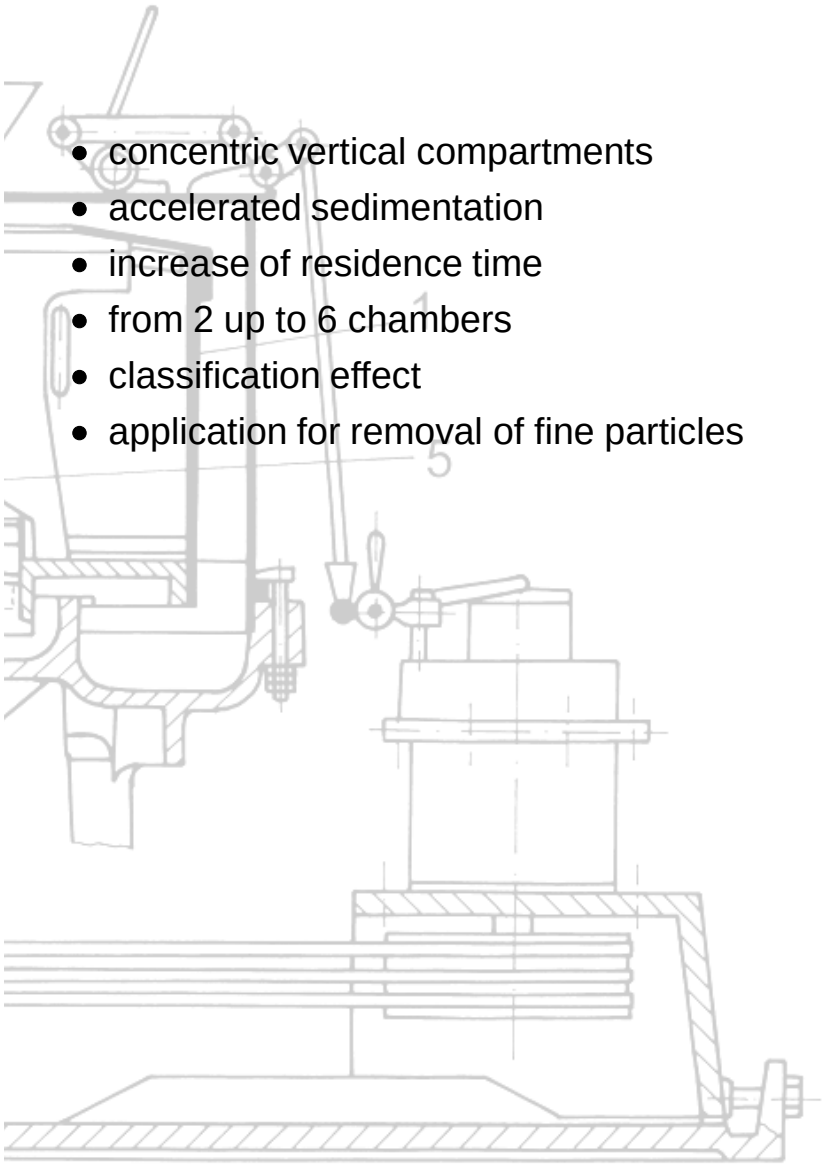


***1** – buben, **2** – radiální přepážky, **3** – přívod suspenze, **4** – odsávací trubka, **5** – uzavírací kužel*

Multi-chamber centrifuges

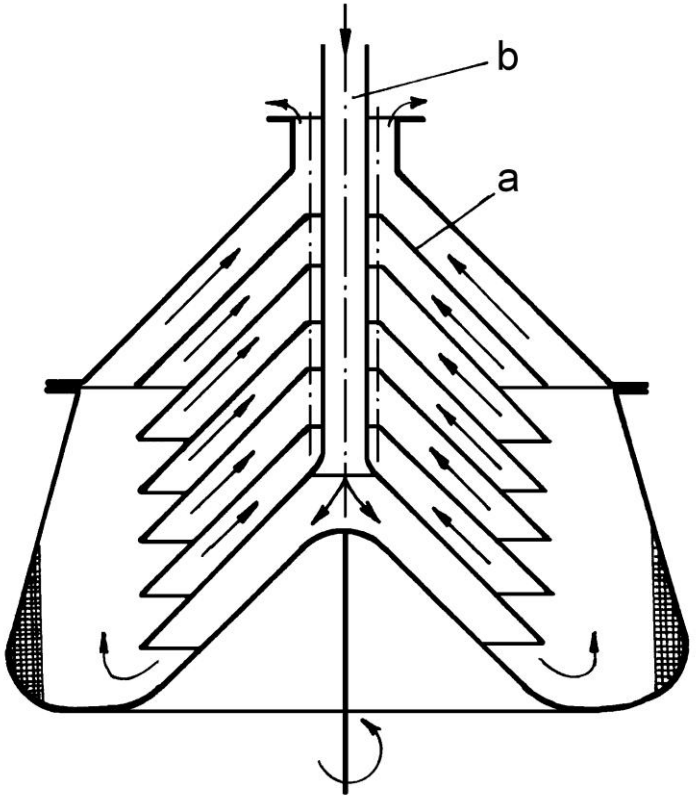


- concentric vertical compartments
- accelerated sedimentation
- increase of residence time
- from 2 up to 6 chambers
- classification effect
- application for removal of fine particles

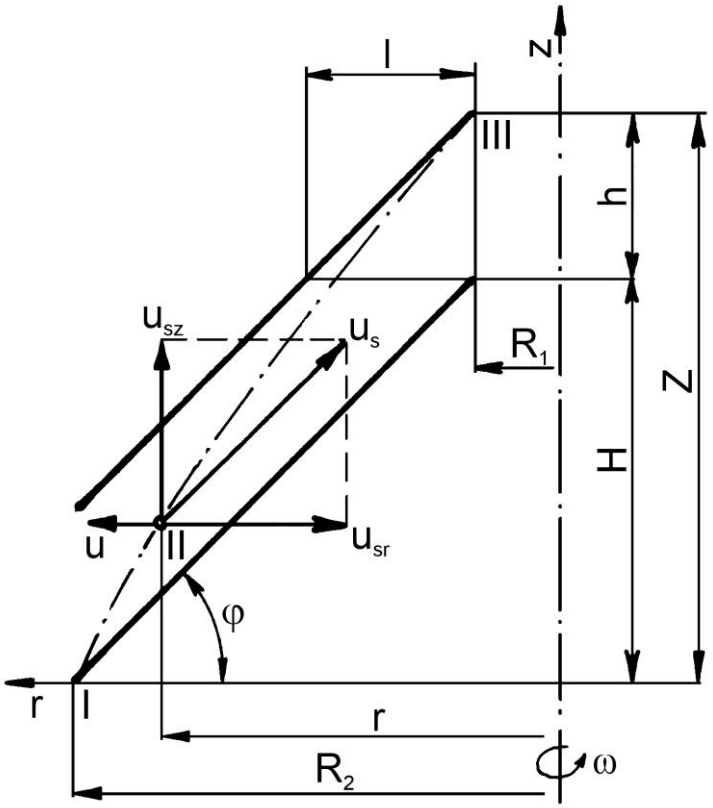


Disc-bowl centrifuges

Bowl with cone discs and slurry space



Trajectory of sedimentation particle in slurry space

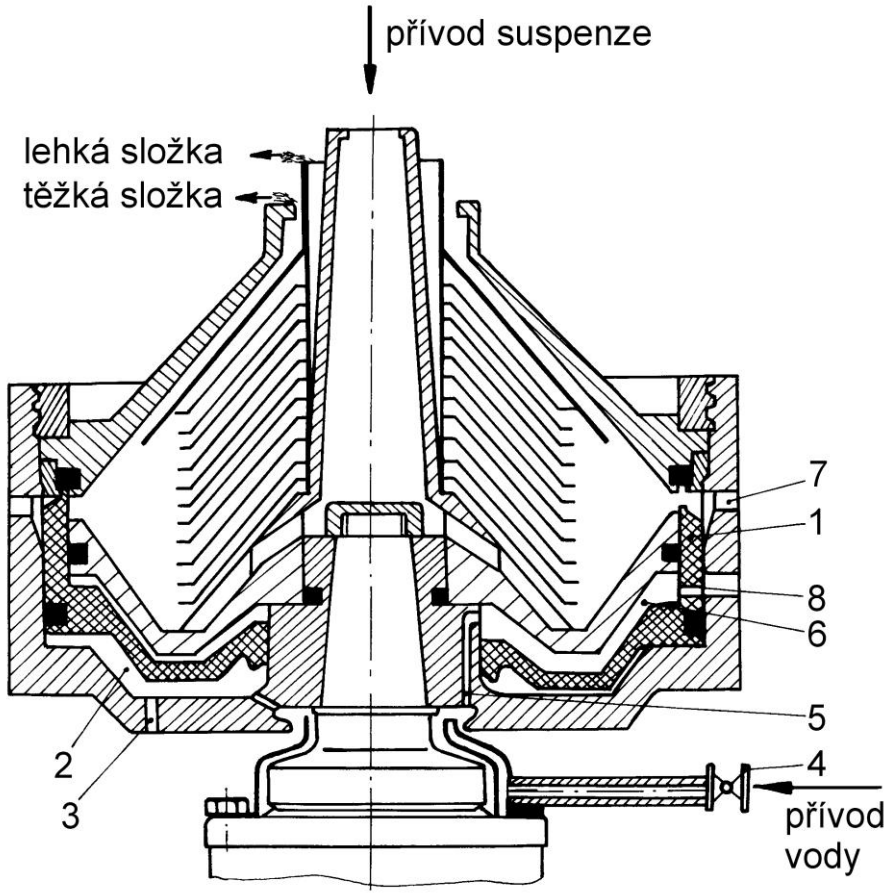


a *– conical disc,* ***b*** *– slurry feed inlet*

Modern types of disc-bowl centrifuges

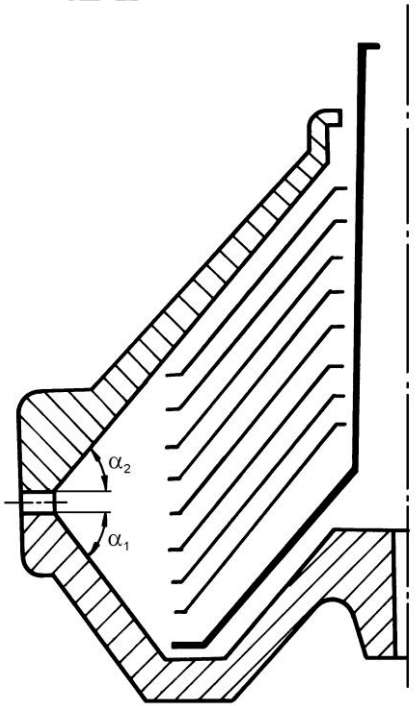
automatic or continuous discharge of sediment (slurry)

With automatic gate discharge

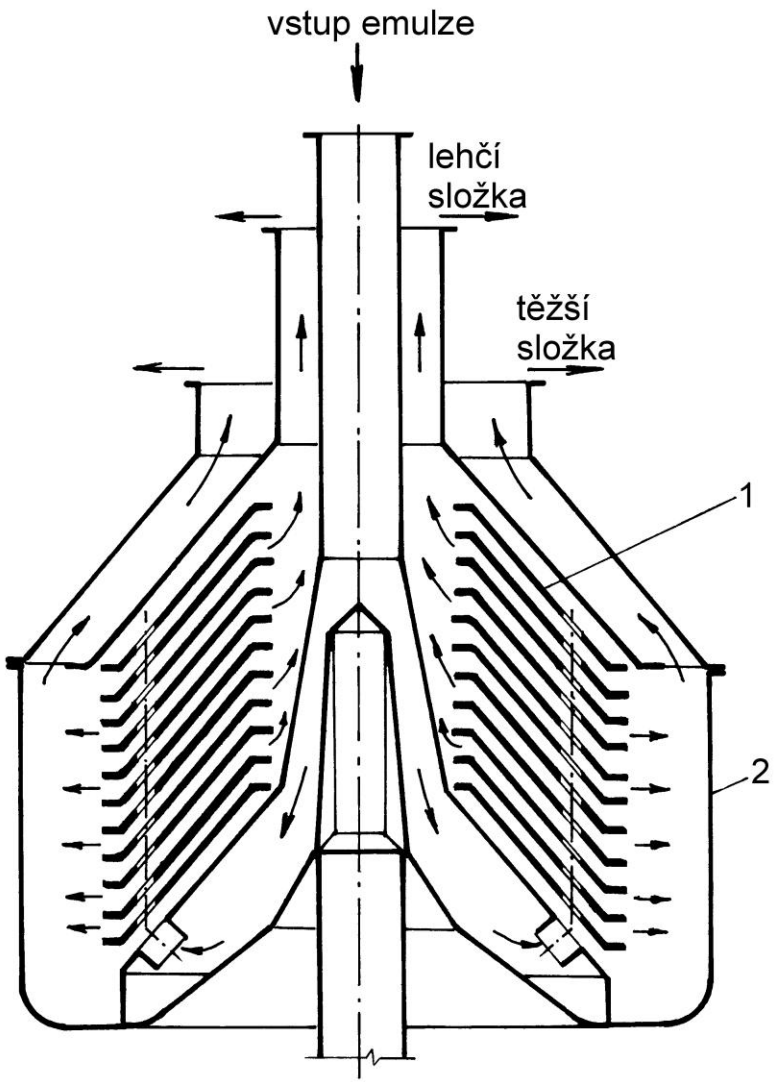


***1** – pístové šoupátko, **2** – prostor pro uzavírací kapalinu, **3** – přepadový otvor, **4** – přívodní kohout, **5** – přívodní kanálek, **6** – prostor pro kapalinu, **7** – otvory pro výstup kalu, **8** – otvor pro výstup ovládací kapaliny*

With nozzle discharge of slurry



- continuous discharge
- angle of cone has to be smaller than angle of friction



Bowl of centrifuge for emulsion separation

***1** – discs, **2** – bowl shell*

- discs with holes for inlet of emulsion (suspension)
- position of holes by densities and contents of both components
- great density and little heavy component – holes toward periphery

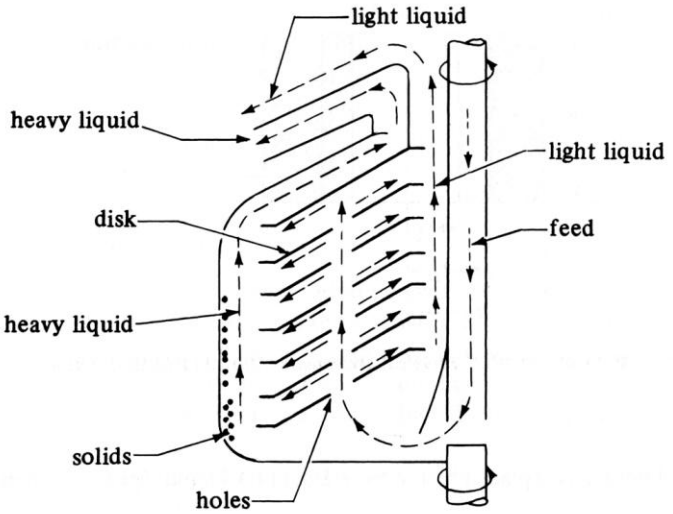
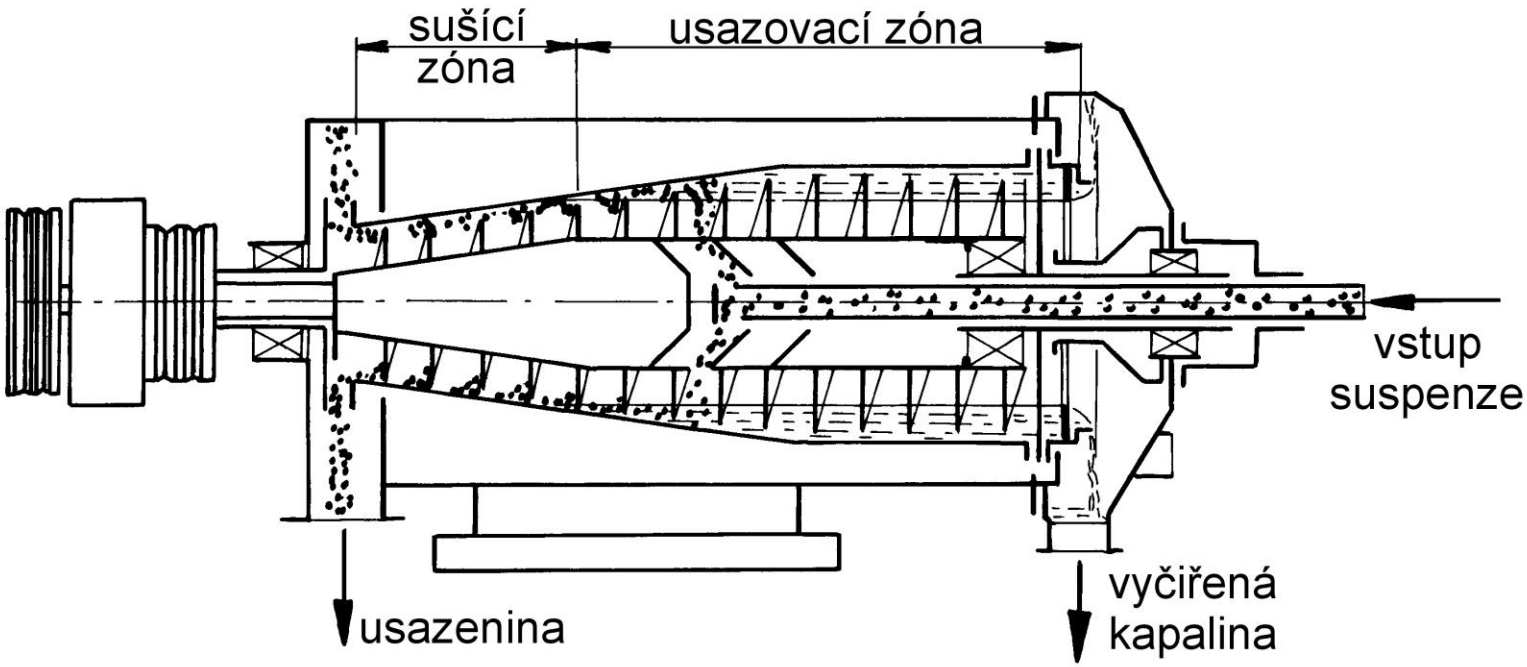
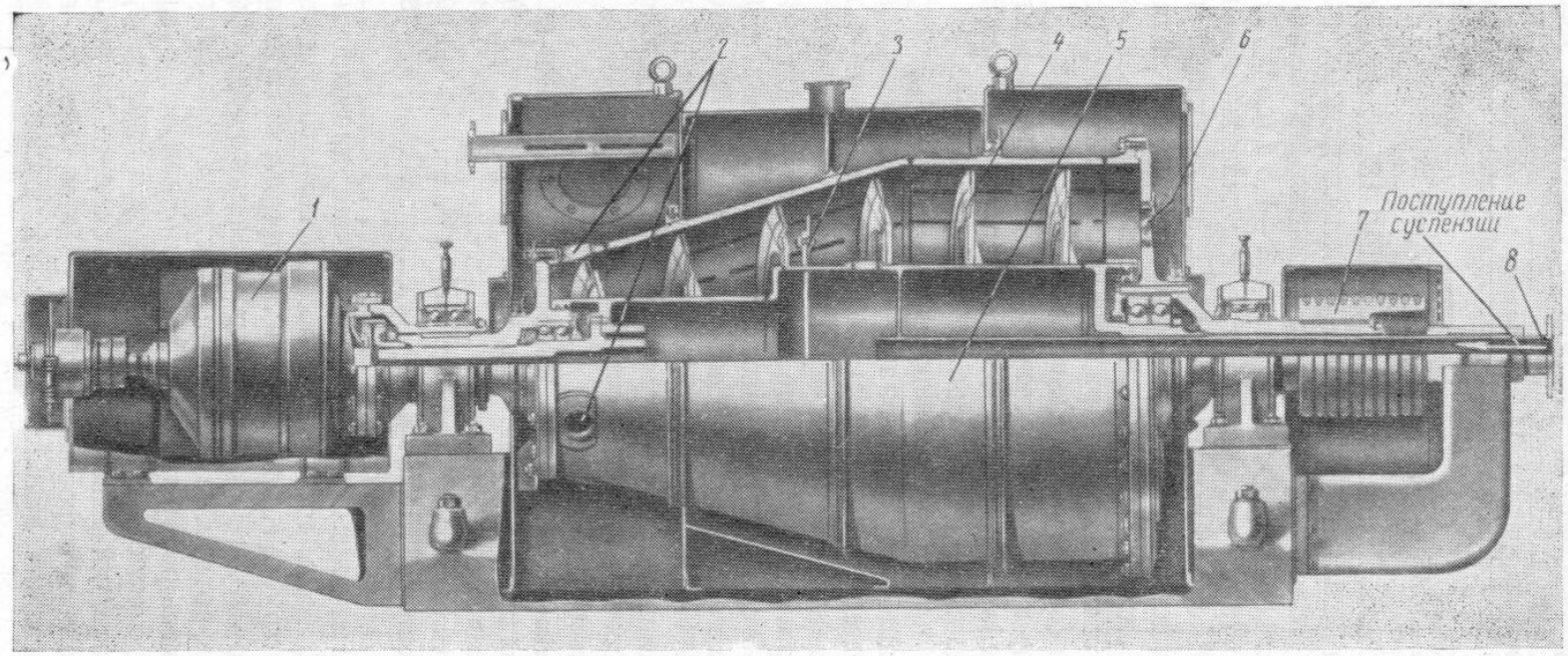
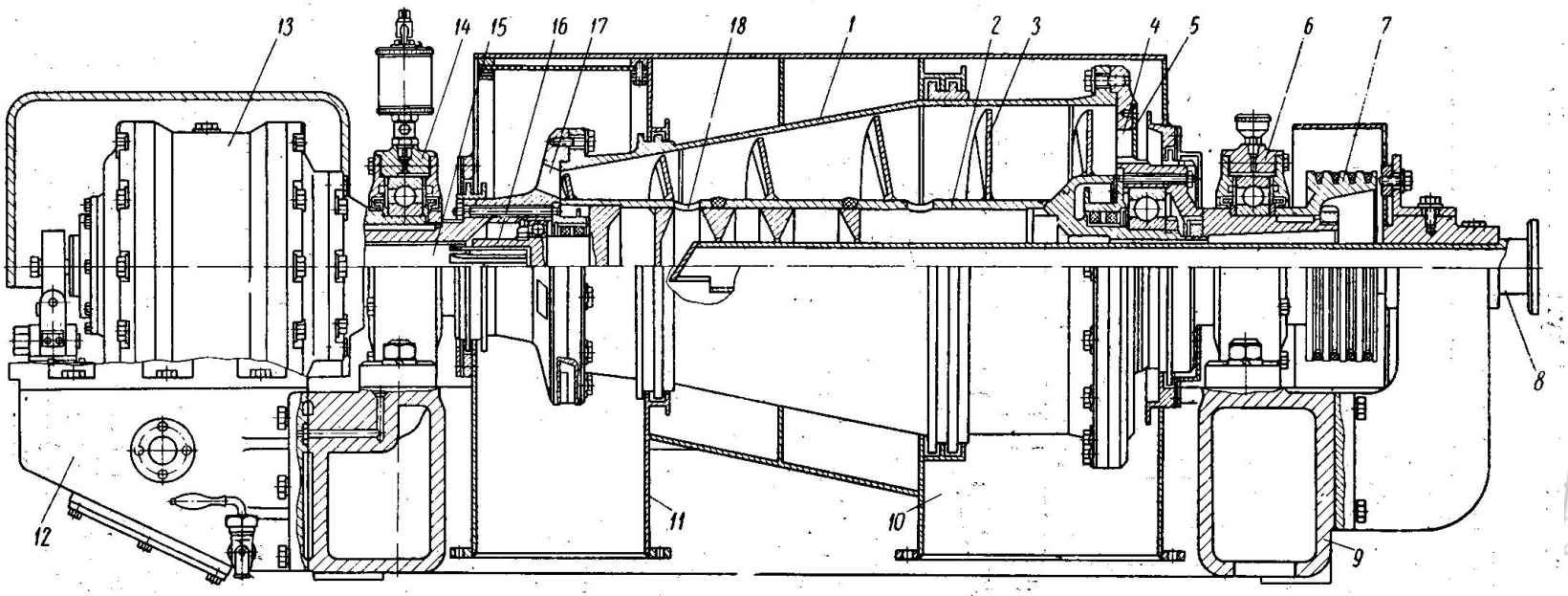


FIGURE 14.4-4. *Schematic of disk bowl centrifuge.*

Continuous horizontal bowl centrifuges with screw discharge




1
2
3
4
5
6
7
8
Поступление суспензии


13
14
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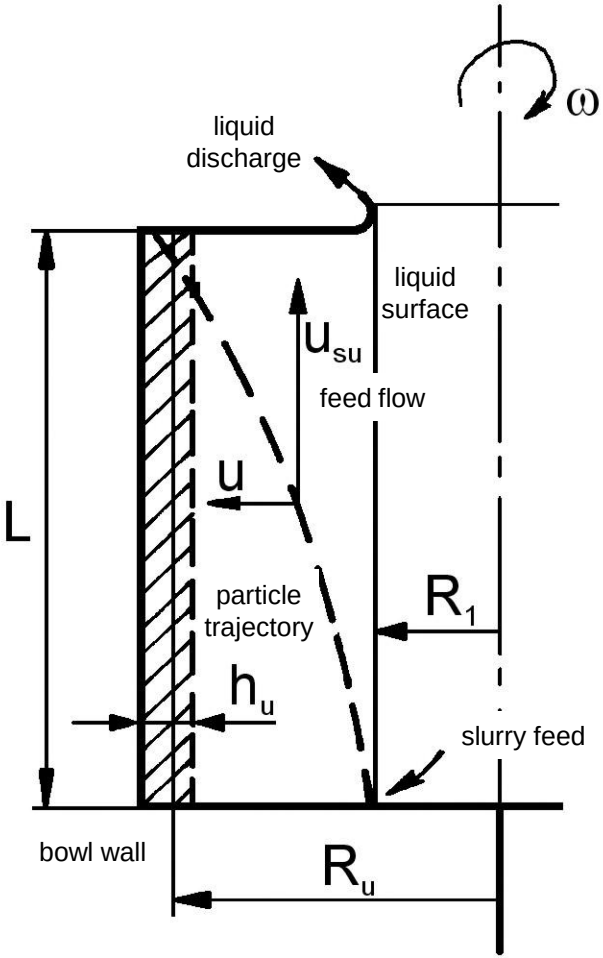
9

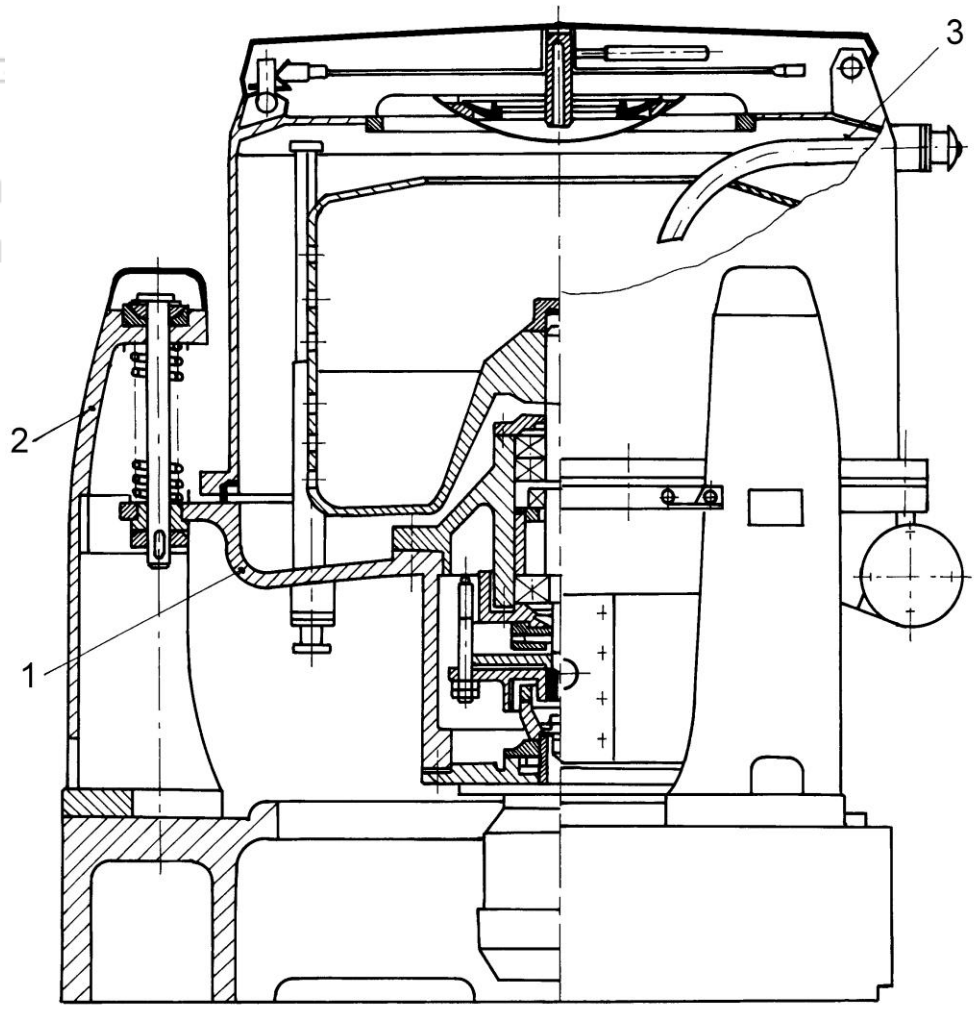
EXAMPLE: Semi-batch centrifuge

Determine volumetric capacity of semi-batch bowl centrifuge for separation of sodium crystals greater than 50 μm (density 1460 kg·m^{-3}) from liquid detergent (with density 800 kg·m^{-3} and viscosity 0.1 Pa·s). Rotational speed of bowl is 1500 rpm and inside diameter is 300 mm and height is 500 mm. Clear liquid is discharge from overflow with radius 80 mm. Maximal height of particle layer sediment on bowl wall is 35 mm and layer has porosity 0.28. Volumetric concentration of sodium particles greater then 50 μm in feed slurry is 1 %. Handling time is approximately 10 min.



Filtration centrifuges

Column centrifuge with upper discharge



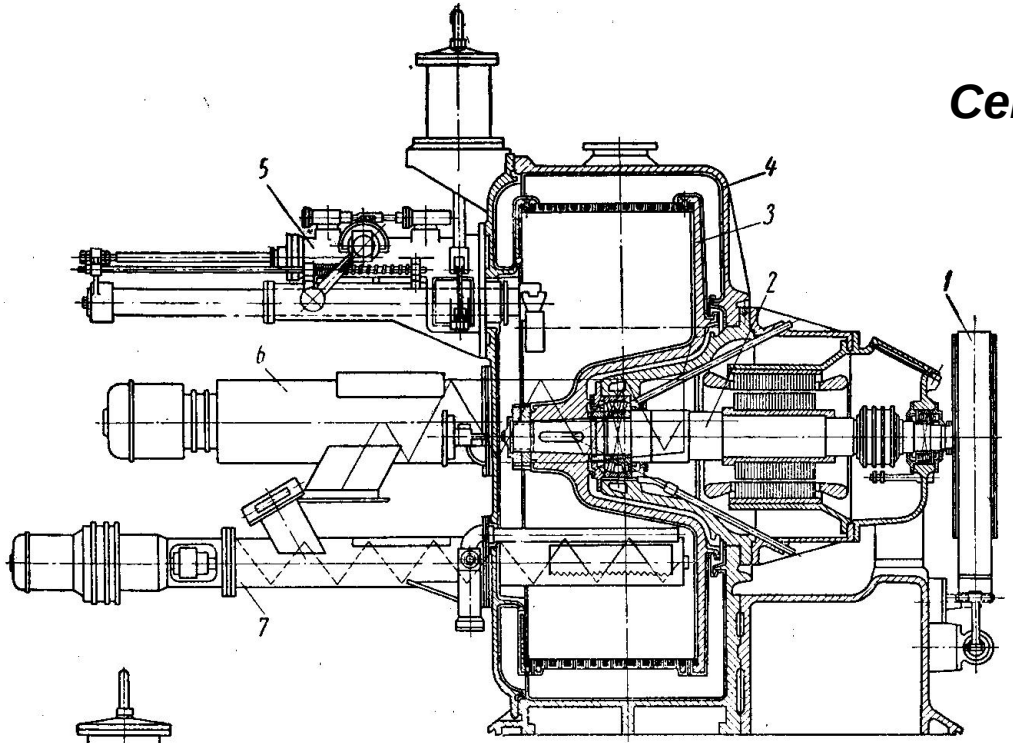
***1** – odstředivka s pohonem, **2** – stojan, **3** – přívod suspenze*

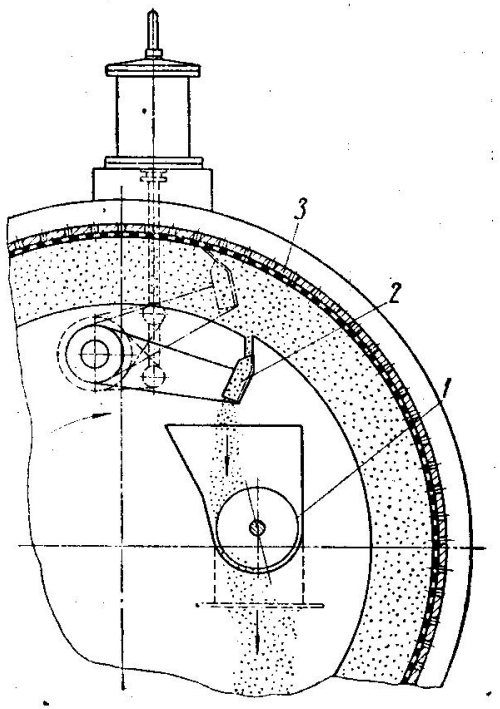
Working cycle of filtration

- filling
- filtration
- drying
- cake discharge

- batch with manual discharge – laborious
- for small capacities
- frame is hanged on three columns

Centrifuges with knife discharge





- horizontal or vertical
- automatic cake discharge by hydraulic driven knife to inclined partition connected

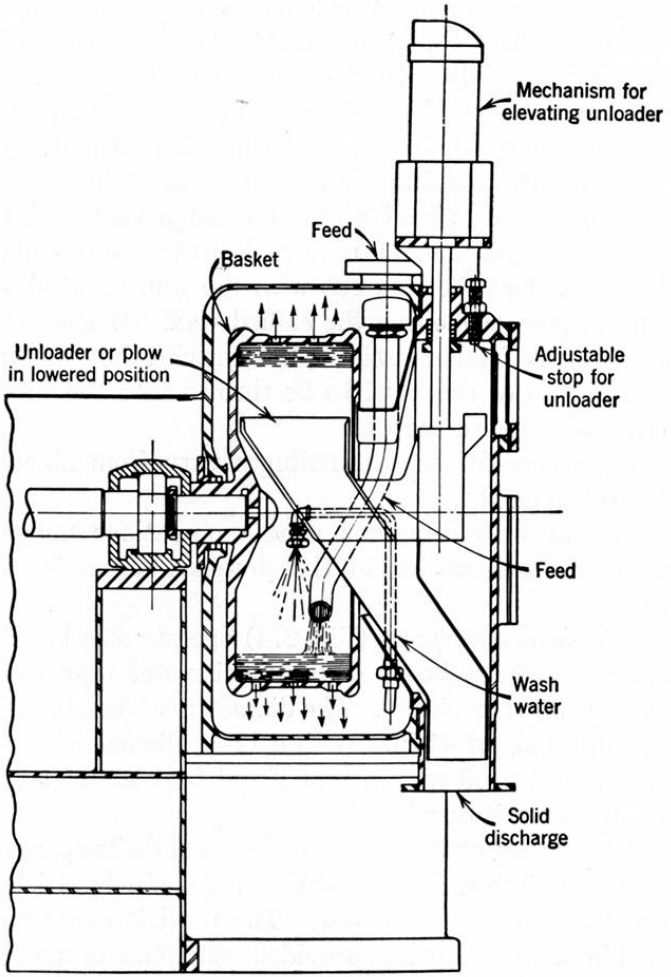
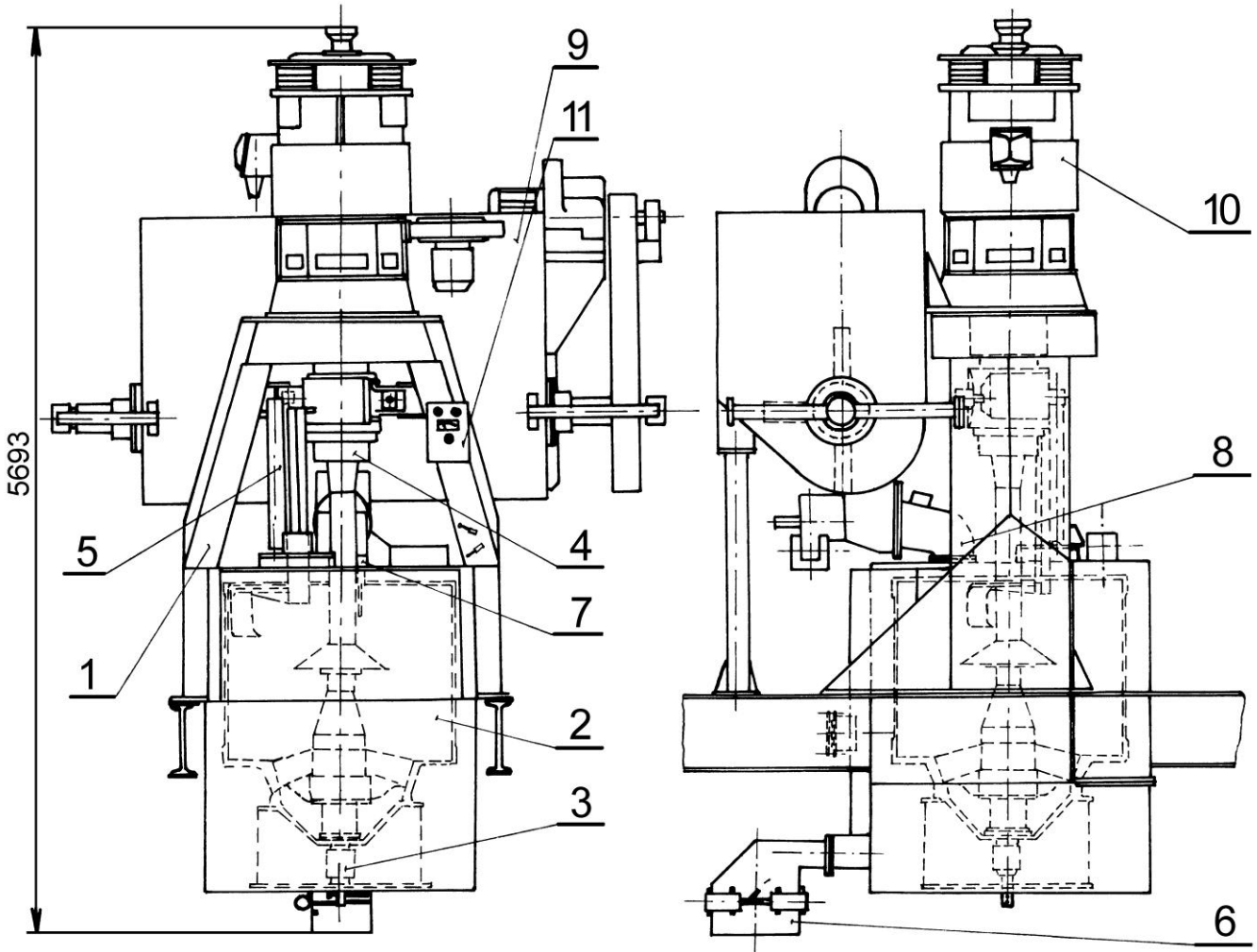


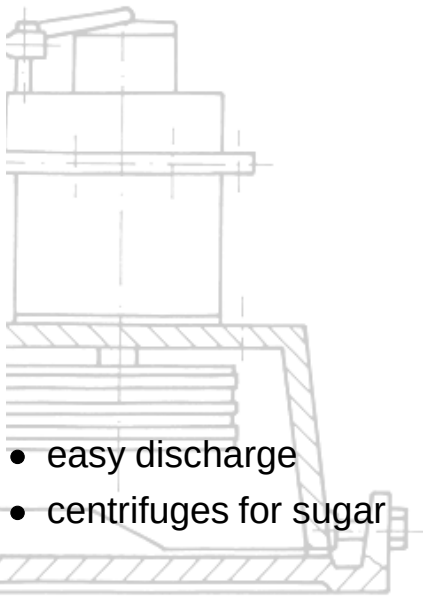
FIG. 271. Sectional drawing of an automatic batch horizontal centrifugal. (*Baker Perkins, Inc.*)

Top suspended centrifuge with lower discharge

ARO 1500 – ZVU Hradec Králové



1 *– stojan,*
2 *– buben*
3 *– uzávěr bubnu*
4 *– závěs uložení hřídele bubnu*
5 *– vyhrnovač*
6 *– dělič sirobů*
7 *– čidlo napouštění*
8 *– napouštěcí mechanismus*
9 *– rozdělovací žlab na suspenzi*
10 *– poháněcí stejnosměrný elektromotor*
11 *– ovládací panel*



- easy discharge
- centrifuges for sugar

Pracovní frekvence otáčení je 1200 min^{-1} nebo 1500 min^{-1}, plnící frekvence otáčení $200 \div 300$ min^{-1}, vyhrnovací frekvence otáčení $30 \div 80$ min^{-1}, počet pracovních cyklů se pohybuje od 6 do 24 za hodinu. Maximální výkonnost u typu ***ARO 1500*** s vnitřním průměrem bubnu 1370 mm (s maximální náplní bubnu 1500 kg) je až 790 t cukroviny za den, štítkový výkon poháněcího elekromotoru činí 260 kW. Provoz odstředivky je automaticky programově řízen, při zkoušení cyklu je možné ruční řízení.

Continuous filtration centrifuges

Reciprocating conveyor centrifuge

cake is removed by reciprocating pusher rotating with basket

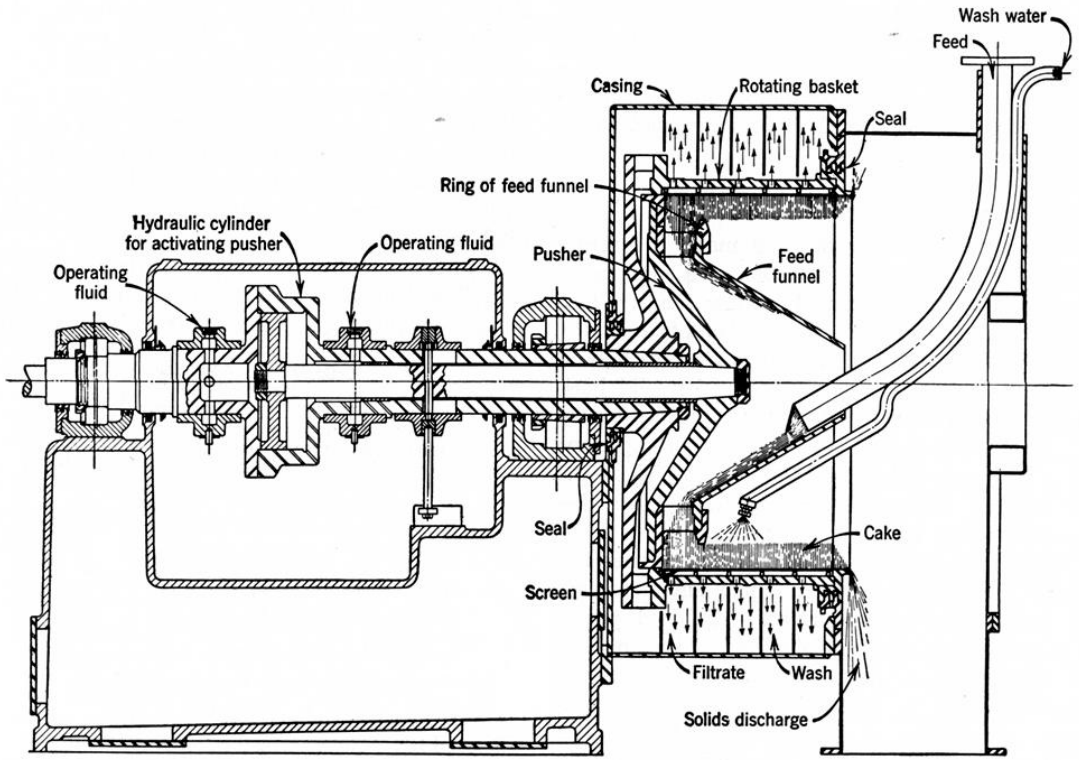
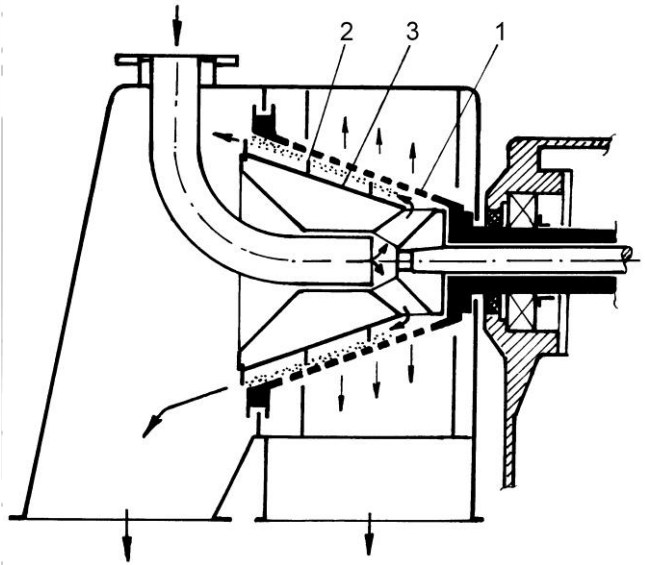


FIG. 270. Sectional drawing of a continuous perforate-basket centrifugal with pusher discharge. (*Baker Perkins, Inc.*)

Helical conveyor filtration centrifuge



1 *– buben odstředivky,* ***2*** *– šroubové nože,* ***3*** *– vynášecí buben*