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Recent developments in centrifuge technology

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Abstract

Centrifugation represents one of the main groups of mechanical particle-liquid separation processes. There are available various centrifuges for sedimentation and filtration, which are operating continuously or discontinuously. The tasks for centrifugal separation are very wide spread from liquid clarification and purification, particle thickening, solids demoistening, particle fractionating and sorting, solids washing, liquid–liquid separation to extraction of solids or liquids. Applications of centrifuges can be found in all kinds of industry, in environmental protection, water treatment, etc. In the centrifugal field mass forces are present during the separation process. This leads to specific advantages and disadvantages in comparison to competing separation processes. Research and development for centrifugal processes today has not coming to an end but several new ideas to use centrifugal forces for separation and new technical developments in this field can be observed. After description of some fundamentals and presentation of an overview of the technical variations some aspects of advantages and disadvantages of centrifuges in comparison to other separation techniques are discussed and examples for recent research and technical development as well as actual trends in the field of centrifugation are given.

Keywords: Solid–liquid separation; Centrifugation; Filtration; Sedimentation

1. Introduction

Centrifuges are representing one of the main techniques to separate particles from liquids. Looking to the scheme of physical principles of solid–liquid separation in Fig. 1, centrifuges are identified mainly for sedimentation and cake filtration. These processes are marked in Fig. 1 by white characters. Some very few exeptions are existing, e.g. centrifuges for sorting, where sedimentation and flotation are realized simultaneously or some centrifuges for classification, which are using a crossflow of liquid to separate a suspension into two fractions of different particle size. General informations about mechanical solid–liquid separation can be found in Refs. [1,2], about centrifugal separation in Refs. [3,4] and especially about decanter centrifuges in Ref. [5].

One example for a modern sorting centrifuge is given in Fig. 2. Plastic particles of different density can be separated by this special designed decanter centrifuge into a floating light fraction and a settling heavy fraction. The suspension liquid must have a density in between of the different solids.

Beside the physical principle of separation the task of separation in the centrifugal field can be defined very different, like demonstrated in Fig. 3. Centrifuges are especially well suited to separate molecularly inmiscible liquids, whereby frequently in addition solid particles are present. High centrifugal forces are allowing the separation of even very stable emulsions according to the density of the components involved.

Applications of centrifuges can be found in all kinds of industry, in environmental protection, water treatment, etc.

2. Centrifuges in combination with other separation aparatuses for process optimization

In most cases one single separation apparatus is not able to solve the separation problem in an optimal way. A combination of different apparatus then shows the best process results. One example is given in Fig. 4. The continuously operating pusher centrifuge definitively needs a concentrated feed due to the very short residence time of the solids in the process room. This can be guaranteed by a preconcentration of the slurry by graviational sedimentation. On the other side the screen of the centrifuge has to be as open as possible to avoid any clogging and reduction of its permeability. As a consequence the filtrate will become relatively turbid. To avoid solid losses and to get clear liquid, the filtrate is given back to the thickener, which is layed out for clear overflow.

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Nomenclature

a_c centrifugal acceleration
A area
c_v volume concentration
C centrifugal factor
F_c centrifugal force
g gravity
h height
h_{cap} capillary height
m_s, m_L solid, liquid mass
Δp_c centrifugal pressure differen
p_g, p_L gas, liquid pressure
r, R radius
V_L liquid volume
$x_{3,50}$ mean particle size

Greek letters
δ wetting angle
$\gamma_{L,g}$ surface tension
ρ_L liquid density
ω angular velocity

To avoid flooding of pusher centrifuges, to increase throughput and to be able to process even smaller particles, recently developed pusher centrifuges have not only an integrated pre-concentration zone (see Fig. 5) but in addition a pulsed feed [6].

The feed stream is pulsed, which means, that during back stroke of the pusher plate the slurry valve is open and during the dangerous forward stroke the feed valve is closed.

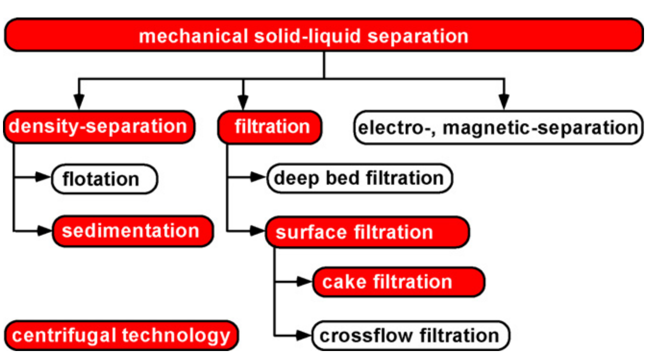

Fig. 1. Centrifuges in the scheme of solid–liquid separation techniques.

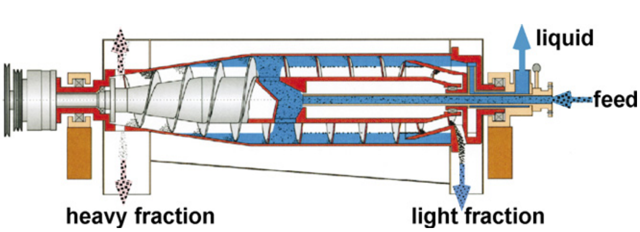

Fig. 2. Decanter centrifuge for sorting (type Flottweg).

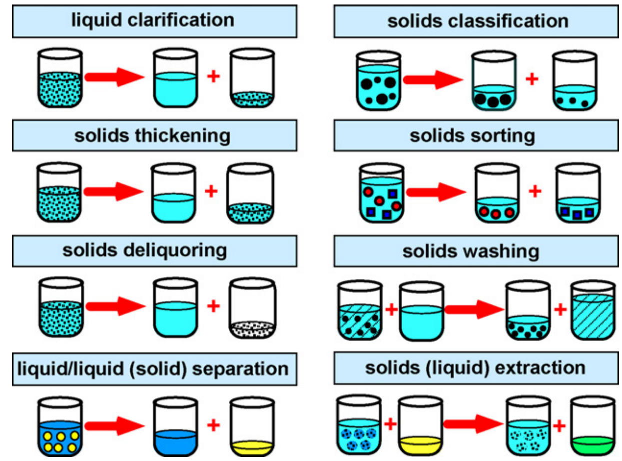

Fig. 3. Tasks for centrifugal separation.

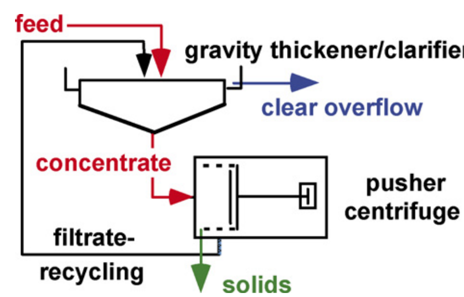

Fig. 4. Combination of pusher centrifuge and settling basin.

3. Centrifugal forces and consequences for the separation process

The use of mass forces in the centrifugal field for the separation process leads to specific advantages and disadvantages in comparison to competing separation processes using the same or other physical separation principles and other forces like gas differential pressure (vacuum pump, compressor), hydraulic pressure (slurry pump) or mechanical pressure (diaphragm, piston). In many cases not only the application of a centrifuge is possible, but there are competing techniques and a detailled discussion is necessary to select the optimal process. One example is given in Fig. 6 for the separation of very small particles in the micron and submicron range.

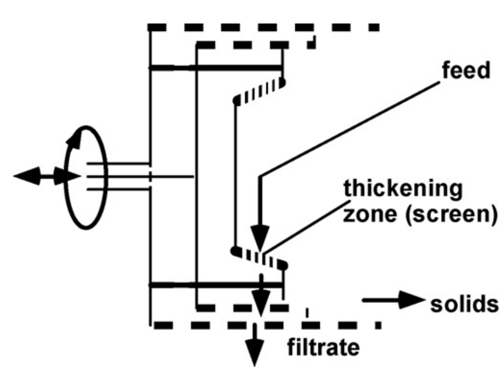

Fig. 5. Pusher centrifuge with integrated preconcentration zone (type Ferrum).

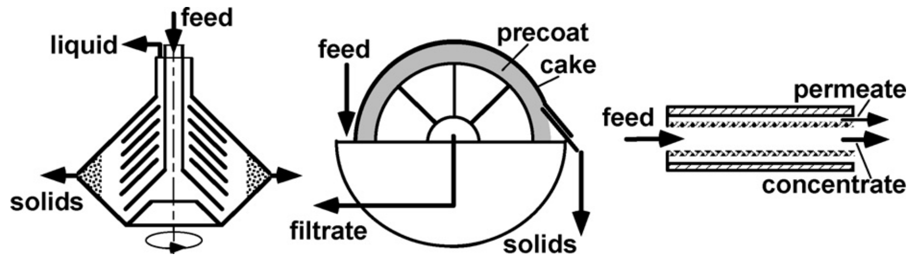

Fig. 6. Competition of disc stack separator, precoat drum filter and crossflow module.

The principle situation for centrifugal separation is shown in Fig. 7 and the calculation of the centrifugal force for sedimentation and filtration is given in Eqs. (1) and (2).

Sedimentation:

$$F_c = m_s a_c = m_s r\omega^2 = m_s C g \tag{1}$$

Filtration:

$$\Delta p_c = \frac{F_c}{A} = \frac{m_L C g}{A} = \frac{V_L \rho_L C g}{A} = \rho_L C g h \tag{2}$$

An undesired but not avoidable consequence of acting mass forces in sediments of centrifuges is the remaining concentration profile like to be seen in Fig. 8. The sediment layers at the bottom are highly compressed whereby the surface layer of the sediment remaines very loose packed. Concentration profile means moisture profile and different rheological behaviour of the sediment. The slippery upper regions of such sediment may cause problems during the transport by the screw in decanter centrifuges.

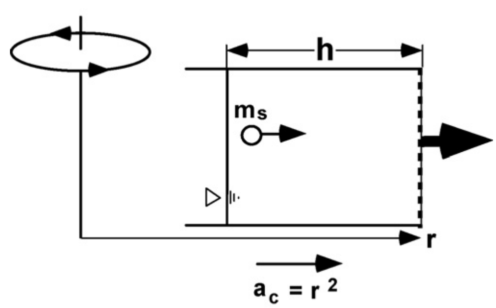

Fig. 7. Principle situation for particle separation in centrifuges.

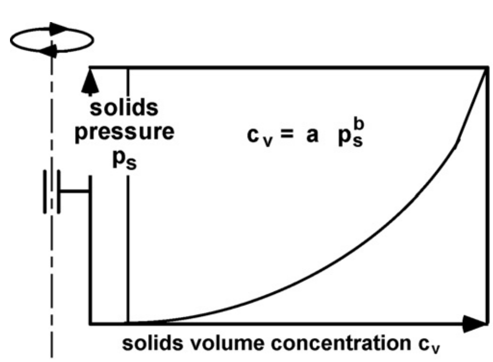

Fig. 8. Concentration profile in a sediment of a centrifuge in the equilibrium state.

To avoid solids transport problems decanter centrifuges with special designed sludge discharge systems have been developed (see Fig. 9) [7].

The sluge is compressed maximally at the largest radius of the double cone bowl and then transported by hydraulic pressure through the gap of a weir plate to the sludge outlet.

For centrifugal filtration processes one can distinguish between the phase of filter cake formation and the desaturation of filter cakes. Both of them show specific effects directly connected with the centrifugal forces. Parallel to filtration the mass forces are acting directly on the particles and therefore additional sedimentation is present in every case. The same phenomeneon is valid for vacuum or pressure filtration processes but in the case of filter centrifuges the sedimentation velocity is increased by the centrifugal factor and predominates in many cases the separation process. For peeler centrifuges some consequences have to be taken into account as can be seen from Fig. 10 [8].

The superimposed sedimentation leads in most cases to the formation of a clear liquid zone on top of the cake and this amount of liquid has to overcome the maximal filtration resistance during drainage through the previous settled particle system. This needs more time than to build up the cake by filtration only. In the case of a broad particle size distribution and relatively low slurry concentrations in addition a very disadvantagues classification effect occurs, which results in the formation of a fine particle layer on top of the filter cake. This layer, which

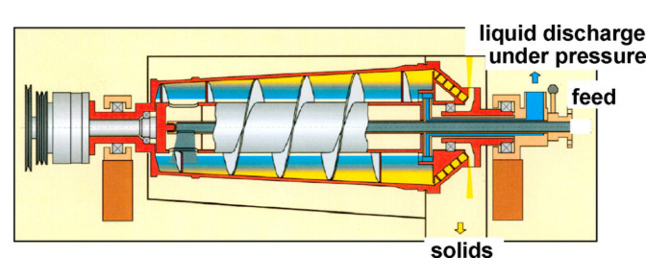

Fig. 9. Decanter centrifuge with special sludge discharge system (type Flottweg).

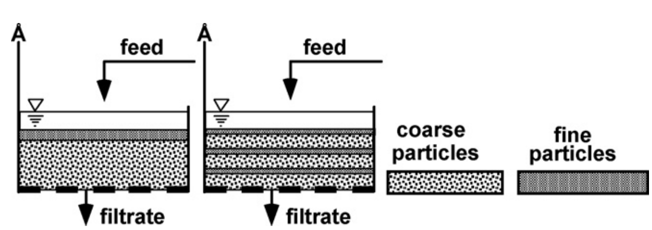

Fig. 10. Filter cake formation in peeler centrifuges.

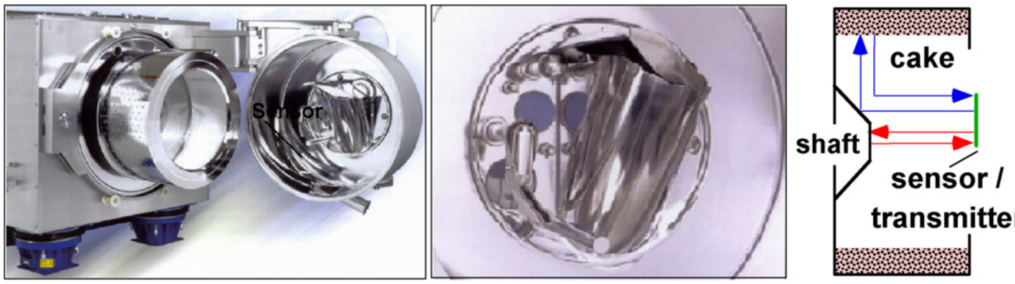

Fig. 11. Ultrasonic level control for peeler centrifuges (type KMP).

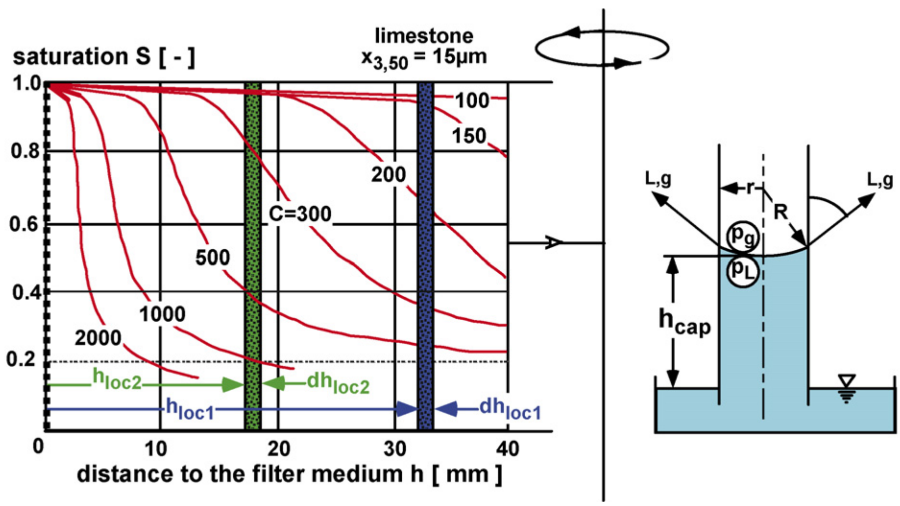

Fig. 12. Moisture profile in a filter cake after centrifugation.

can be seen in the very left part of Fig. 10, shows an extremely high filtration resistance. In most practical cases several shots of slurry are given into the centrifuge basket to get a reasonable cake thickness. In these cases, as can be seen in the more right hand drawing in Fig. 10, several fine particle layers can form and the cycle time increases significantly. As a consequence, the procedure of feeding a discontinuously operating filter centrifuge can influence very sensitive the process result.

To control the level of filling in the centrifuge basket, modern ultrasonic level controller have been developed for peeler centrifuges (see Fig. 11) [9].

The dewatering of the filter cake is also negatively affected by a fine particle layer on top of the cake due to the increased capillary pressure. So the best procedure is the reduction of filling velocity and the increase of the feed concentration to build up the cake homogeneously. Also for homogeneous filter cakes remarkable differences exist for the desaturation between vacuum and pressure filters on the one hand and filter centrifuges on the other hand. As can be seen in Fig. 12, in contradiction to the homogeneous demoistening in vacuum and pressure filters in centrifuges a moisture profile in the cake is remaining in the equilibrium state. At the cake surface the lowest moisture is found and completely saturated cake near the filter medium.

The zone of full saturation is determined by the capillary height h_{cap}, when the equilibrium state is reached. As can be seen from Eq. (2) the centrifugal pressure depends on the liquid height. During the demoistening of a capillary the local liquid height h_{loc} becomes smaller and thus the cake remaines more and more saturated in the direction to the filter medium.

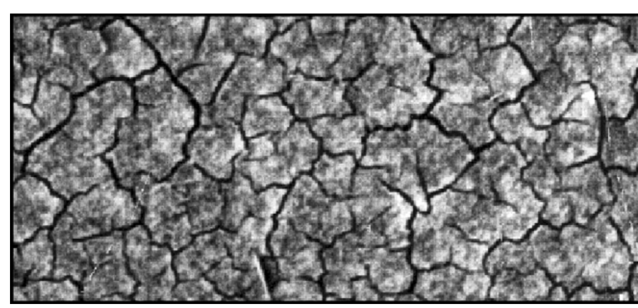

Fig. 13. Shrinkage cracks in a filter cake during desaturation.

One big advantague of centrifugal demoistening in comparison to vacuum or pressure filtration is the not existing gas throughput and very low tendency of cake cracking, which can be seen in Fig. 13 [10,11].

If there is some danger of shrinkage crack formation during desaturation or during washing, a filter centrifuge may be a better choice than a gas pressure filter.

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