Mechanical Solid–Liquid Separation, Introduction

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1. General Considerations

Mechanical solid–liquid separation is a cross-sectional technology for particle sizes from some millimeters (particles) to some nanometers (molecules). As explained in Figure 1, the separation of particles from liquids touches nearly every industrial process, our personal life, and the environment.

Solid–liquid separation must be mastered for many applications, a broad range of slurry and process properties, and manifold required separation results. If hygienic issues play a significant role, apparatuses must be designed appropriately, or single-use equipment must be installed [2]. For exceedingly abrasive conditions, wear protection is required (pasted ceramic plates and hard facing). A careful analysis of the specific separation problem is essential to find the best solution for a desired result [3, 4]. Today, some thousands of solid–liquid separation apparatuses are available, and consistently, new developments can be recognized [5, 6]. Comprehensive overviews of solid–liquid separation principles as well as apparatuses and machines can be found in [1, 7–13].

To characterize and design mechanical solid–liquid separation processes, several experimental methods and theoretical approaches exist. In addition, advanced sensor and data-transfer technology allows remote process monitoring and result-dependent control and regulation. With multiscale simulations, shortcut models can be derived that enable the whole separation process to be simulated in seconds or even faster [14, 15].

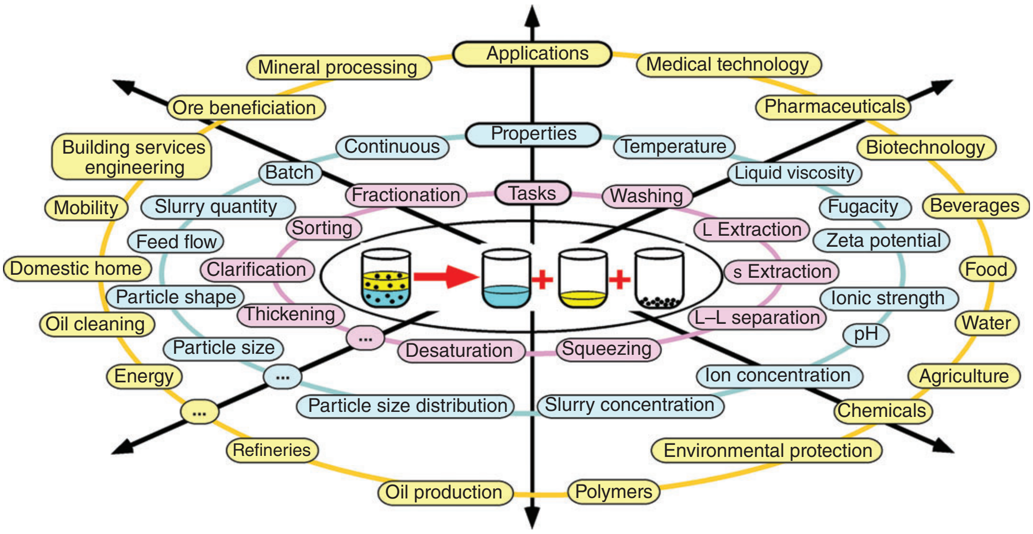

Figure 1. Uses, conditions, and applications for solid–liquid separation processes [1] (L = liquid; L–L = two immiscible liquids; s = solid)

The separation of a suspension into the continuous liquid and disperse solid phases can be realized by mechanical or thermal means [16]. Generally, a first mechanical liquid-removal step is advantageous, because it is less energy intensive than thermal methods, and often, undesirable product stress is avoided. After mechanical liquid separation, an unavoidable residue of liquid remains in the particle structure, which can only be removed thermally. Besides individual processes, hybrid mechanical–thermal processes are available, which are characterized by energy saving, low product losses, and simplified process design.

2. Physical Principles of Solid–Liquid Separation

2.1. Sedimentation

Sedimentation (→ Sedimentation) in liquids means particle movement in the direction of gravity or a centrifugal field to concentrate a suspension or separate particles as sediments. It is generally applicable for most solid–liquid separation problems if the solid density is greater than the liquid density. A physical limit for sedimentation in the earth's gravitational field is set for a particle size of about 1 μm, because thermal convection and Brownian motion keep smaller particles in stable suspension. Nevertheless, by means of agglomeration, even the smallest particles can be made accessible to gravity or centrifugal sedimentation. If a change in suspension properties by flocculation is forbidden, acceleration (mass forces) must be increased for compensation.

The velocity and phenomenology of particle motion depend essentially on density difference, acceleration, particle size, size distribution, particle shape, concentration in the liquid, and liquid viscosity. In highly diluted and stable slurries, particle settling is unhindered and individual according to their size. A slight increase in concentration leads to hydrodynamically induced formation of particle clusters, which settle faster than the individual particles. If the particle concentration is increased further, the particles increasingly hinder each other, and the settling behavior changes to swarm and finally zone sedimentation [17, 18]. A sharp and self-stabilizing particle-settling front forms at a critical slurry concentration, and all particles settle with more or less the same velocity. Finally, the particles touch each other in the sediment and are only able to move further downward by consolidation.

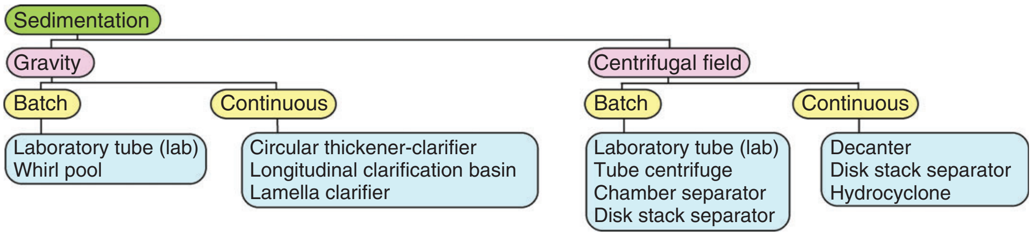

Figure 2. Sedimentation apparatuses and machines [1]

Figure 2 gives an overview of the basic sedimentation apparatuses and machines.

2.2. Froth Flotation

Froth flotation (→ Flotation) uses gas bubbles to sort particle mixtures of different wettability or to concentrate particles [19].

Gas bubbles adhere to hydrophobic particles, and the two float together. Hydrophilic particles are not affected and settle downward. The particle wettability can be adjusted by adsorption of special surfactants [20]. Mainly three kinds of surfactants are used for froth flotation. Collectors hydrophobize particles, depressants hydrophilize them, and frothers prevent coalescence of gas bubbles. The optimal particle diameters for flotation are in the range between 40 and 150 µm for solids with a density of more than 3000 kg/m^3.

Flotation is used particularly in the beneficiation of mineral raw materials and coal to sort particle mixtures of minerals and tailings, in paper recycling, for pulp deinking, and as energetically favorable and low-cost process for total separation of organic particles, e.g., for sewage water treatment or to harvest algae.

Figure 3 illustrates different methods of bubble generation and slurry mixing.

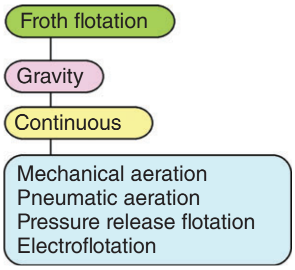

Figure 3. Flotation apparatuses [1]

2.3. Depth Filtration

Depth filtration (→ Filtration, 2. Equipment) is used preferably if low-concentration liquids that contain very small particles in the few-micrometer or sub-micrometer range must be clarified. The particles are separated inside a highly permeable porous filter layer (collector). The particles must be much smaller than the pores of the filter medium. The filter cycle ends when either a critical value of the pressure loss or an inacceptable turbidity of the filtrate is exceeded. The solids concentration in the filter feed must not exceed a critical maximum value in order to avoid blockage of the filter surface. Further deliquoring of the separated particles is not possible. The separated solids are removed more or less efficiently by backflushing of the filter layer or completely together with the filter layer.

Packed-bed filters consist of discrete disperse particle layers (filter aid), which are regenerated after the filtration by backflushing or exchange. These filters are used frequently for water purification [21]. Alternatively, the filter medium can consist of a premanufactured fibrous filter sheet [22]. Flex-bed filters use small fibrous balls of a few centimeters diameter as collector elements, which can be adjusted in pore size by mechanical compression [23].

Precoat filtration can be realized for cake filters, such as candle, leaf, and vacuum drum filters. An auxiliary particle layer is formed on a filter medium before the actual product is filtered. For batchwise-operating filters, the entire precoat layer is discharged after reaching the limit of the dirt-holding capacity. During

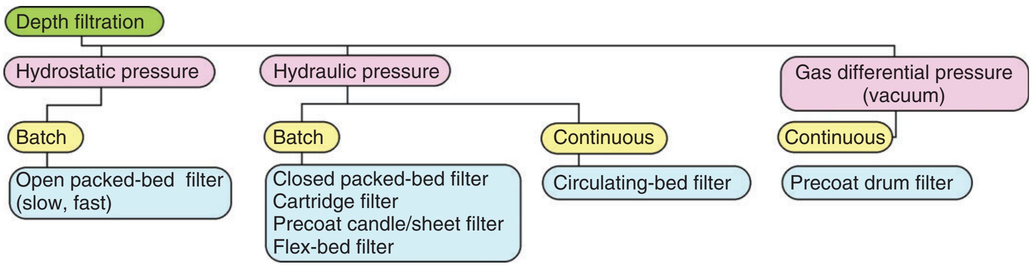

Figure 4. Depth filters [1]. Höflinger [22]

precoat filtration with continuous vacuum drum filters (e.g., to separate baker's yeast), a very thin layer of down to ca. 100 µm is permanently peeled off from the surface of the precoat of initially ca. 10 cm in thickness. This was previously clogged by separated particles after one drum revolution. After peeling, a clean precoat surface appears and is immersed again into the suspension. After reduction of the precoat to a safety layer of some millimeters, a new precoat must be built up.

The preceding formation of the precoat layer can be avoided by direct mixing of the filter aid with the suspension to be separated (body feed filtration). The particles of the filter aid form a stable network into which the target particles are incorporated.

Filter aid materials are of mineral or organic origin. Diatomaceous earth, perlite, coke, starch, wood flour, extract-free cellulose, and ultrapure cellulose among others are applied. Materials such as activated charcoal and ion-exchange resins are able to bind in addition dissolved molecules. The costs for filter aid acquisition and disposal play an important role besides separation characteristics and purity requirements. In particular, organic filter aids have advantages in comparison to mineral materials, such as low bulk density, biological degradability, nearly ash-free combustibility, and low abrasiveness.

Figure 4 shows the different types of depth filters.

2.4. Cross-Flow Filtration

Cross-flow filtration (shear-stress filtration and dynamic filtration; → Filtration, 2. Equipment) serves to separate very small particles of a few micrometers down to colloids and dissolved molecules of a few nanometers. It is realized in the simplest case by pumping a suspension parallel to the surface of a microporous membrane through a fixed filter module [24]. The liquid permeates the filter medium (membrane) and is discharged as filtrate (permeate). Particles try to follow the liquid and build up a cake on the filter medium, but the tangential flow of the suspension detaches most particles from the membrane surface by shear and lift forces (larger particles) or by diffusion (smaller particles) if they are greater than the adhesive forces. The unavoidable particle layer at the membrane surface should be kept as thin and stable as possible over time. The slurry is consecutively concentrated but must finally remain flowable.

The shear gradient to realize the cross-flow effect can be produced alternatively by a filter cell, which is connected with a torsion rod and oscillates at the resonance frequency. The liquid, as inertial mass, cannot follow the oscillation, and gentle and energy-saving shearing originates directly at the membrane.

Thirdly, the shear forces are generated by a rotating stirrer or partly overlapping and counterrotating membrane disks. With the stirrer, very high shear forces and very high final concentrations can be reached, because suspensions often exhibit a shear-thinning effect.

The type of membrane depends among others on the size of the substances to be separated. For micro- and ultrafiltration, membranes made from ceramics, polymers, and others are used. A convective flow through real pore channels takes place. This technique competes with high-speed centrifuges, e.g., disk-stack separators and tube centrifuges, and depth

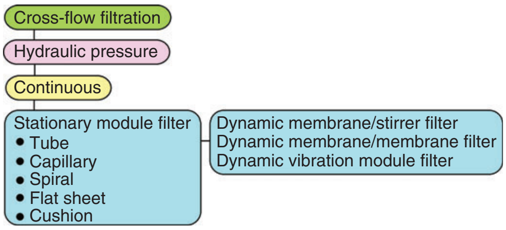

Figure 5. Cross-flow filters [1]

and precoat filters. Nanofiltration and reverse osmosis are realized with "poreless" polymer membranes to separate small molecules by diffusion. This technique competes with thermal evaporation and is used, e.g., for water desalination. Due to successive blockage or fouling of the membrane pores, the filter media must be periodically regenerated by backflushing and/or various washing procedures.

During a batchwise operation, a defined volume of suspension is concentrated by permanent filtration and recycling of the concentrate until the target concentration is reached. The processable suspension volume can be increased by the fed-batch procedure. Concentrate is fed back likewise, but the removed filtrate is replaced by fresh suspension until the total volume of the feed tank has reached the final concentration. Continuously operating cross-flow filtration requires several membrane modules in a series (cascade), because the residence time of the concentrate during one module passage is not sufficient to reach the target concentration.

Diafiltration (→ Bioseparation) is a cross-flow procedure for dilution washing to rinse molecules through the membrane, which are dissolved in the feed suspension. One example for this technique is blood washing in artificial kidneys (dialysis).

Membrane elements can be designed in various shapes. Figure 5 gives an overview of the different cross-flow filters.

2.5. Cake Filtration

Cake filtration (→ Filtration, 2. Equipment) leads to a particle layer from a few millimeters to several decimeters, which is formed on the surface of a filter medium such as fabric, needle felt, sintered ceramic, and polymer membranes [25]. The liquid penetrates the filter medium, whereas the particles are held back. The necessary filtration pressure is generated pneumatically, hydraulically, mechanically, or by a centrifugal field. Particle size and slurry concentration must be great enough to enable cake formation in a reasonable time. Otherwise, the process may be physically possible but will not be economical or cannot be realized at all technically. The processable particle spectrum ranges from several hundred micrometers down to a few micrometers. The lower limit can be often extended by particle agglomeration. Cake filtration offers the possibility of solids post-treatment, e.g., cake permeation washing and deliquoring.

Figure 6 gives a rough overview of the basic cake filter types [26, 27].

2.6. Sieve and Blocking Filtration

Single particles approach individually the filter medium and are either able to pass (sieving) or plug single pores (blocking). During sieve filtration, particles must be hindered to clog sieve pores by mechanical vibration of the sieve or ultrasound. The pores of a blocking filter are clogged successively, and after reaching a critical pressure loss, regeneration of the filter medium must be carried out by backflushing, brushes, or other measures. In the case of very small particles, often only very thin filter cakes can be formed, which cannot be blown off by gas in a gaseous atmosphere but are rinsed from the filter media by backflushing with liquid.

Sieve and blocking filtration are used for suspensions with quite low concentrations and a broad particle spectrum from the millimeter to the micrometer range. Among others, many applications can be found in the metalworking industry for regeneration of cooling lubricants. Sometimes only the separation of oversized particles is aimed at in order to protect a subsequent separation apparatus. Such strainers are installed, e.g., in the feed pipe of hydrocyclones or disk-stack separators, to protect their concentrate-discharge nozzles from blockage.

Figure 7 compiles the basic types of sieve and blocking filters.

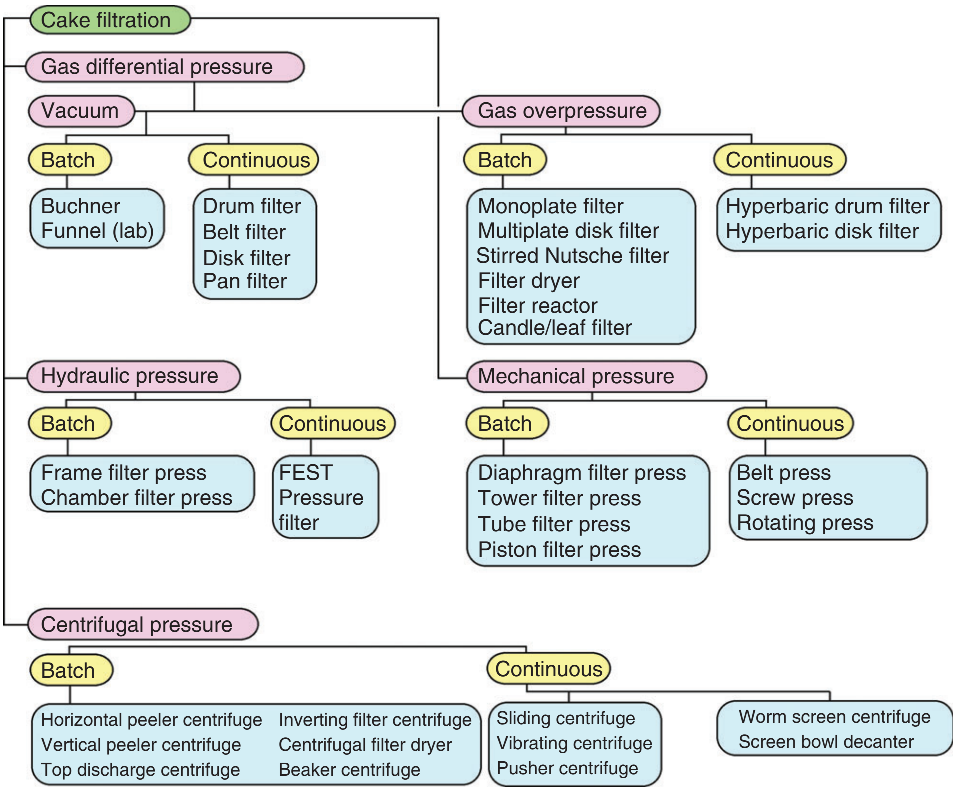

Figure 6. Cake filters [1]. Based on Dickenson [26] and Gasper et al. [27]

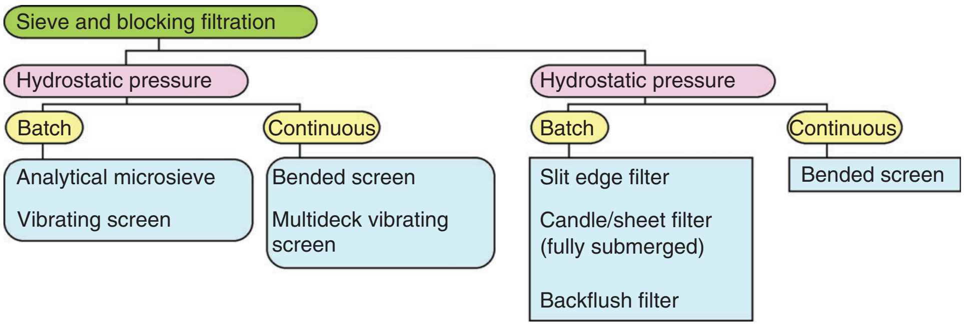

Figure 7. Sieve and blocking filters [1]

2.7. Electrofiltration

Electrofiltration (→ Electrostatic Separation) enhances the performance of conventional filtration processes by means of an electric field in the process room. If particles in liquids carry an electric charge, they will move toward the countercharged electrode. For example, in a diaphragm filter press, the particles can be kept away from the filter medium, which leads to comparatively high filtration velocity [28–31]. Besides electrophoresis, electrolysis of the electrodes, including the formation of hydrogen and oxygen gas bubbles, as well as slurry heating due to the electrical resistance of the system must be considered.

2.8. Magnetic Separation

Magnetic separation (→ Magnetic Separation) uses magnetized paramagnetic particles and their deposition on metallic collectors. High-gradient magnetic separators use a network of metal wires to deform the magnetic flux lines. This increases the magnetic forces on the particles [32–35]. Particles are separated highly efficiently in an open structure with minimal flow resistance. If the magnetic field is switched off, the particles detach from the wires and are discharged from the filter by rinsing. Besides magnetic separation for sorting of minerals, in biotechnology specially coated magnetic beads are used to separate selected molecules from fermentation broths (magnetic fishing).

3. Uses of Mechanical Solid–Liquid Separation Processes

3.1. Thickening

Thickening (concentration) is defined as removal of only a certain part of liquid from a dilute suspension to reach a required final solids concentration, to relieve following apparatuses, or to make them applicable at all. After concentration, a suspension is still able to flow. Thickening can be realized by static or centrifugal sedimentation, flotation, membrane cross-flow filtration, backflushing filters, regenerable depth filters, and others.

3.2. Clarification

Clarification (polishing) produces preferably particle-free liquid. Clarification and thickening are often supported by particle agglomeration. In principle, the same equipment as for thickening can be used. In addition, nonregenerable depth filters are well suited. Completely particle-free liquid can be generated by absolute filters, which hold back even the smallest particles in the suspension.

3.3. Washing

Washing (purification) of previously separated solid particles is a measure to remove residual original liquid (mother liquor) and therein-dissolved molecules by a molecularly miscible liquid [36–38]. If crystals are separated from a saturated solution, clean saturated solution can be used as wash liquid or a liquid (e.g., alcohol) that is molecularly miscible with the mother liquor (e.g., water), but in which the solids are much less soluble. Washing is not flushing [39]. During flushing, the mother liquor is displaced by a nonmolecularly miscible liquid against capillary forces.

Dilution washing requires alternating particle separation and resuspending with wash liquid and can be realized for any density-separation or filtration apparatus.

Permeation washing is only possible for filtration. An ideal pure wash liquid originates if a cold filter cake is exposed to hot steam, which condenses at the cake surface or inside already emptied cake pores.

Cocurrent application of fresh wash liquid takes place in several steps consecutively to the contaminated particle system and can be realized for dilution and permeation washing. As a result, a relatively large amount of relatively low-concentration wash liquid is produced.

Countercurrent washing saves wash liquid and increases its concentration of soluble substances, which makes this procedure more efficient. Fresh wash liquid is applied only once at the location where the particle system is already nearly completely purified. This wash liquid is loaded to a slight extent with soluble substances and can be reused again upstream, where the particle system is more enriched. For this procedure, all processes of dilution and permeation washing in serial connection (cascade) are suited. Only a few apparatuses are well suited to realize countercurrent washing in a single unit, e.g., vacuum belt filters, to some extent vacuum and pressure drum filters, vacuum pan filters, and FEST rotary pressure filters.

3.4. Deliquoring

Deliquoring of sediments or filter cakes is realized by squeezing (compression and consolidation) or desaturation. Deliquoring is physically limited, and a certain amount of residual liquid cannot be removed at all by mechanical means [40].

Compressible sediments or filter cakes exhibit after formation a porosity gradient across their height. During sedimentation, the weight of the upper particles compresses the lower particle layers. This leads to a relatively loosely packed surface and a maximally consolidated bottom layer (static thickeners, decanter centrifuges, disc stack separators, and tube centrifuges). In sedimentation processes, no further forces can be applied, and even in the equilibrium stage, a porosity gradient remains across the sediment height. All pores of the sediment remain fully saturated with liquid. During cake filtration, the same phenomena can be observed, but the liquid flow additionally transfers friction forces to the particle structure. After cake formation, the asymmetric cake structure can be reduced to the minimal possible porosity through squeezing by a diaphragm (diaphragm filter press), between two filter belts (double-belt press), by a transport screw with narrowing channel cross section (screw press), or by pumping additional slurry into a process room that is already filled with cake (chamber filter press and frame filter press).

Incompressible filter cakes show no porosity gradient across their height and allow liquid displacement by the hydrostatic pressure of the liquid inside the cake (batchwise-operating filter centrifuges such as peeler and inverting filter centrifuges and continuously operating machines such as pusher, worm screens, sliding centrifuges, and screen-bowl decanters), vacuum behind the filter medium, or gas overpressure above the filter cake (batchwise-operating filters such as candle, leaf, cartridge, stirred Nutsche filters, and filter dryers and continuously operating apparatuses such as drum, belt, disk, and pan filters). A precondition for liquid displacement is the overcoming of the capillary pressure in the filter cake pores by the applied pressure [41]. The smaller the pores, the higher the capillary pressure becomes.

3.5. Three-Phase Separation

Three-phase separation includes solid particles and two molecularly nonmiscible liquids, e.g., in olive oil production. In most cases, an organic liquid is emulsified as light phase in an aqueous matrix liquid as heavy phase. Often, such emulsions are difficult to separate, and strong centrifugal forces are needed (specialized decanters, disk-stack separators, and batchwise-operating solid-bowl centrifuges).

3.6. Extraction

Extraction removes molecules dissolved in a matrix liquid selectively by an extraction agent. In the case of aqueous solid–liquid or pure liquid systems, an emulsified organic solvent is used [42]. Initially, the extraction agent must be intensively mixed with the slurry or liquid and emulsified. A favorable droplet size of the extraction agent for centrifugal separation is ca. 100 µm. Secondly, the extraction agent must be enriched with the target molecules. Finally, the enriched extract must be separated from the degraded slurry. Often, several extraction steps are arranged in series to maximize the yield. Countercurrent extraction is particularly efficient, because it leads to comparatively high extract concentrations and low extractant consumption.

Applications can be found among others in the pharmaceutical industry, e.g., penicillin production and extraction of medicinal herbs.

3.7. Sorting

Sorting separates particles of different materials that exhibit different density or wettability in a slurry. The liquid density can be chosen or adjusted in such a way that the lighter particles float, while the heavier particles settle. This is realized among others in specialized sorting decanters for plastics recycling [43].

Besides different densities, different wettability can be used for sorting. If both particle fractions settle but exhibit different wettability, froth flotation can be applied (see Section 2.2).

3.8. Classification

Classification (sizing, grading, and fractionation) separates particles into fractions of different sizes by sieving (screening

→ Screening) or flow classification. Vibrating multiscreens enable the production of several fractions in one process step. Furthermore, sieving is an analytical method to characterize particle size distributions down to particle sizes of a few micrometers [44]. Besides screening, sedimentation of particles can be used for particle size analysis, because particles of different sizes settle with different velocities, which are measured and correlated with the particle size. If particles are exposed to a liquid flow contrary to the settling direction, as in special upstream classifiers, static circular settling basins with adjusted overload, or in the centrifugal potential vortex of hydrocyclones, smaller particles can follow the flow, and coarser particles settle in the opposite direction [8]. Alternatively, a cross-flow process can be chosen, in which particle settling and liquid flow are perpendicular to each other. Particles of different sizes are transported to different places and can be discharged separately. Cross-flow classification for two fractions is technically realized in decanter or tube centrifuges with adjusted overload. Several fractions can be produced in a multichamber separator [45]. If particles of different densities and different sizes are present in the suspension, a small particle of high density settles with the same velocity as a larger particle of low density. Here, classification is not possible, unless sorting took place before.

There are manifold applications for this process, from coarse materials in the sand and gravel industry by screening to fine particle fractionation of limestone by overloaded decanter centrifuges or hydrocyclones.

4. Enhancement of Solid–Liquid Separation Processes

4.1. Mechanical–Thermal Hybrid Processes

Mechanical–thermal hybrid processes can be realized by thermal drying of solids inside various filters. This is interesting for hygienic production and minimization of product losses. A first possibility consists of passing hot gas through the previously desaturated filter cake (stirred Nutsche filters and filter centrifuge dryers). A second possibility uses contact drying via heating the apparatus walls (stirred Nutsche filters with jacket). A third possibility is vacuum drying (diaphragm filter presses). The squeezed filter cake is heated by heating plates between the filter chambers, and vacuum is applied to the filtrate outlet pipes to lower the boiling point. Special synergetic effects occur in steam pressure filtration [46, 47] (continuously operating pressure disk and drum filters and inverting filter centrifuges). Here, pressurized gas is replaced by hot steam. Steam pressure filtration is much more energy efficient than a combination of pressure filter and separate thermal dryer.

4.2. Mode of Operation

4.2.1. Discontinuous Operation

In discontinuous (batch) processes, each single process step can be adjusted in a time-independent manner. The separation apparatus can be adapted to the process requirements with maximal flexibility, but throughput is limited due to cake production exclusively during filtration time. Quasi-continuous operation can be realized by parallel installation and time-shifted operation of several batchwise-operating units or installation of a sufficiently large buffer tank for the feed suspension, which must correspond to the capacity of the separation apparatus.

4.2.2. Continuous Operation

The significant characteristic of a continuously operating apparatus is the permanent slurry feed. All process steps are coupled with each other, and the time for each process step is set by the common transport velocity and the geometrical length of the respective process zone. Time adjustment in relatively narrow limits is possible. The throughput of continuously operating apparatuses is comparatively high due to permanent generation of products. It is possible to separate continuously in a batch process either by installation of a sufficiently large buffer tank for the feed suspension or by periodical shut down of the separation apparatus.

4.3. Apparatus Combination

4.3.1. Function Separation

The entire separation process is divided into individual steps, which are assigned to an optimally suited apparatus, e.g., wastewater treatment with coarse screening, separation of sand, sludge agglomeration and thickening, and sludge deliquoring.

4.3.2. Function Integration

Several process steps, e.g., agglomeration, separation, washing, deliquoring, and drying, are integrated in a single apparatus. This is of interest if product losses must be avoided as far as possible and/or highly hygienic conditions are required. Examples are filter reactors, stirred Nutsche filters, and centrifugal dryers. In most cases, only mechanical separation and thermal drying are combined with each other.

4.3.3. Serial Connection

Identical separation apparatuses are installed in a series (cascade). This intensifies the process result. Examples are washing, extraction, and sorting in several consecutive and repeated steps to maximize the separation results.

4.3.4. Parallel Connection

Parallel connection of separation apparatuses increases the throughput. One large apparatus instead of several smaller units in parallel is not always appropriate. For example, the throughput of hydrocyclones increases with increasing cyclone diameter, but the cut size rises likewise. If a small cut size is required and a large feed flow must be handled, several small hydrocyclones must be installed in parallel. A further aspect may be the greater reliability and easy scaleup.

4.3.5. Cross-Connection

Here, the respective strength of each apparatus is of benefit for the products, whereby their weaknesses compensate each other internally. An example is the combination of static sedimentation basin (thickener) and pusher centrifuge. The thickener can be optimized to produce a particularly particle-free liquid. The still-flowable concentrate is supplied to the pusher centrifuge for maximal solids deliquoring. The separated liquid of the filter centrifuge often has unacceptable turbidity. This filtrate is sent back to the thickener. As a result, the process result is a particularly clear liquid and dry solids.

4.4. Slurry Pretreatment

4.4.1. Preconcentration

Preconcentration (thickening) serves to withdraw a notable fraction of clear liquid with minimal possible effort from the feed to relieve the following separation equipment. Static and centrifugal sedimentation, cross-flow filtration, backflushing, and gravity filters are normally used for this purpose.

4.4.2. Agglomeration

Sedimentation and filtration of small particles in the size range of a few micrometers are often facilitated by agglomeration. Agglomerates settle faster than single particles. Undesired sedimentation of single particles (except classification) can be transformed into swarm sink behavior. Particle segregation is prevented, and the necessary clarification area decreases remarkably. In filtration processes, agglomeration leads to more permeable filter cakes, filtrate pollution can be reduced, and particle segregation avoided.

If van der Waals attractive forces between particles are used, the process is named coagulation [48]. In most cases, particles in liquid carry homopolar electric surface charges and repel each other. To enable van der Waals adhesion, the electrostatic repulsion must be reduced sufficiently. The balance between attractive and repulsive forces is described by the Derjaguin–Landau–Verwey–Overbeek (DLVO) theory [49, 50]. Favorable conditions for coagulation can be adjusted by the pH value and/or the ion concentration of the suspension [51].

Alternatively, particles can be agglomerated by soluble polymers, which is named bridging flocculation. The preparation of the flocculant solution, the dosage, and mixture with the suspension and the controlled floc formation constitute an own step in the process chain and must be carefully controlled [52]. However, if the addition of external substances is forbidden, as is often the case for foods or pharmaceuticals, alternatively, the driving forces must be increased.

4.4.3. Body Feed Filtration

The filtration properties of problematic suspensions are improved by mixing with relatively coarse mineral or organic filter aids. Compared with depth filtration, suspensions of higher solids concentration can be separated, and an additional stirred vessel for precoat preparation can be saved. On the other hand, some of the particles to be separated can enter the filtrate during the initial cake formation.

4.4.4. Preclassification

The smallest or largest particles of a suspension must be removed if they disturb the subsequent separation process. Coarse particles can be removed, e.g., by strainers or bended screens (degritting), and fine particles by hydrocyclones or upstream classifiers (desliming). Ultrafiltration or reverse osmosis for separation of molecules can be protected from disturbing particles by depth or micro cross-flow filters.

4.4.5. Defoaming

Defoaming by chemical or mechanical means is sometimes necessary for trouble-free process operation. Foams develop during froth flotation and in particular in the presence of organic substances, e.g., proteins. Foam destruction by chemical means is in most cases undesired due to product pollution, and mechanical foam suppression by water spray or special defoaming turbines is preferred.

5. Economic Aspects

Figure 1 demonstrates the enormous variety of applications for solid–liquid separation technology and thus the economic significance for the global market of separation equipment. In principle, there is nearly no solid–liquid separation problem today that cannot be solved somehow. However, the final question in nearly every case is how much it costs. Thus, the challenge is to find an effective, sustainable, and finally economical solution. This is motivation not only to look for the best-suited state-of-the-art technology to get the desired separation result but also to search for the most cost-efficient solution. This includes not only the focus on the separation step itself but also needs to consider the whole process chain. If a solid–liquid separation follows a crystallization step, the question may be asked whether the crystals could be made a little bit larger to relieve the separation step and make it cheaper. Then, perhaps, a costly filter press may be replaced by a comparatively cheap vacuum filter. If a thermal dryer (rotary kiln) must be installed after a rotary vacuum filtration with insufficient cake moisture content, a comparatively much smaller hyperbaric pressure filter can replace both the vacuum filter and the thermal dryer. A similar aspect is given for cheap preconcentration (e.g., static sedimentation) of a dilute slurry to make the following highly efficient separation equipment (e.g., pusher centrifuge) smaller and thus cheaper. Agglomeration can reduce the size of all separation apparatuses due to improved separation properties of the slurry. If a body feed is chosen to enhance the separation, a decision must be made between mineral and organic filter aids. Minerals, e.g., diatomaceous earth, may be a bit cheaper than organic materials such as extract-free cellulose, but less apparatus wear, less transport, and landfill costs may justify the higher price for the latter. Last but not least, one must consider that in most cases alternative techniques are in principle able to solve a specific separation problem. Investment costs for apparatus, peripherals, installation, and buildings, among others, and operating costs for energy, maintenance, repair, and service staff, among others, must be compared for alternative separation concepts.

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