Technology for Water

ENVIROCHEMIE

Whitepaper

Chemical-physical Water Treatment, Filtration and Flocculation

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Introduction

In water treatment plants chemical-physical processes play an essential part in the process chain. They are successfully employed in the pre- and post-treatment of waters of different origins, as well as of other process liquids. In this regard the removal of particles by filtration is a central step. Classical filtration processes are used for particles ranging from 1 µm to 100 µm, i.e. bacteria, yeast cells, sand. Smaller particles are separated by membrane processes, whereas larger ones are removed by screening, sedimentation or flotation.

As early as in 2000 BC the construction of a cistern with an added filtration was described. Rain water from roofs und rocks was collected and led into a basin. By covering the cistern, the water was kept clean of dirt and algae. In a sandwich-like stone wall filled with clay there was a wooden tube with a sleeve valve. Subsequently the water could be led over a bed of sand or gravel, and so it was filtered before being used. In special cases the filter bed was extended by a layer of carbon.

Filtration by means of granular materials is the oldest technical method of water purification. At first the filter material has to be chosen for the required filtration task by an expert. Apart from the suitable filtration process also the filter dimensions are important to optimize the life-cycle-costs.

Filtration

Choice of the Filtration Process

The choice of the appropriate filtration process mainly depends on the amount of suspended solids in the water, as well as on the particle size and the demanded purity of the filtrate.

High particle content, i.e. after precipitation reactions	Cloth Filter
Medium or high particle content	Volume Filter
Low to very low particle content	Surface Filter

If the filtration task consists of the separation of relatively high particle quantities from the water in the first place, a volume filtration will be preferred. If, however, the particle content is low and high safety filtration of the particles is required, a surface filtration according to the sieving principle is chosen. The cloth filtration separates the particles by passing the water through a fabric or filament material. With this method waters with high particle contents can be treated, but the application is restricted to particles over 10 µm.

Because of the practical importance of volume filters in industrial water treatment, this method is particularly described below.

Volume filters stand out by a very sturdy operating behavior, i.e. with a view to strong fluctuations of the suspended solids content. In industrial water treatment volume filters are designed as cylindrical vessels filled with granular filter materials as filter bed. For mere particle filtration inert filter materials are preferred. Crushed silica sand with a narrow grain size has proven to be the best choice. Such a fill brings about a relatively well defined pore volume, which occupies approximately one third of the filter bed. For larger solid loads the filter bed consists of layers with different filter materials of various grain sizes and densities.

The filter bed, generally passed downstream, does not fill the vessel completely so that a free board remains. The filter bed bottom is equipped with finely slotted filter nozzles (approx. 70 to 90 nozzles/m² filter cross-section), which hold back the filter material. In order to prevent the slots from blocking, the nozzles are embedded in a support layer of coarser gravel. This support layer also safeguards an even distribution of flushing water during filter backflushing.

Volume Filters: Dimensioning

Despite intensive research, there are no generally applicable calculation equations for the dimensioning of volume filters, as the filter materials and composition of waters vary considerably. Reliable design parameters can, however, be derived from operational experience. It makes a difference whether the water is filtered directly, i.e. without pretreatment, or whether a flocculation filtration with or without sedimentation is carried out.

Chart 1 Dimensioning of Volume Filters

Dimensioning parameters	Direct filtration	Flocculation filtration without sedimentation	Flocculation filtration with sedimentation
Filter velocity [m h^{-1}] Single layer filter	10 - 20	7 – 10	7 - 15
Filter velocity [m h^{-1}] Multilayer filter	15 - 25	10 – 15	10 - 20
Filter material grain size [mm] Single layer filter	0.7 – 1.25 or 1,0 – 2,2	1.0 – 2.2	1.0 – 2.2
Filter material grain size [mm] Multilayer filter	Hydroanthracite 0.8 – 1.6 / Sand 0.4 – 0.7 or Hydroanthracite 1.6 – 2.5 / Sand 0.71 – 1.25	Hydroanthracite 0.8 – 1.6 / Sand 0.4 – 0.7 or Hydroanthracite 1.6 – 2.5 / Sand 0.71 – 1.25	Hydroanthracite 0.8 – 1.6 / Sand 0.4 – 0.7 or Hydroanthracite 1.6 – 2.5 / Sand 0.71 – 1.25
Layer height [m] Single layer filter	1.5 – 2.5	1.5 – 2.5	1.5 – 2.5
Layer height [m] Multilayer filter			
Hydroanthracite	1.0	1.0	1.0
Sand	1.5	1.5	1.5

The essential key parameter for filter dimensioning is the filter velocity, calculated by dividing the volume flow (m^3/h) by the cross-section of the empty filter (m^2).

Volume Filters: Filter Backflushing

Due to the separation of particles, the pores of the filter material become blocked with increasing operation time, causing, at a constant volume flow rate, an increasing pressure loss across the filter bed (see fig. 1). This pressure loss exerts a very high force on the nozzle bottom, and is thus restricted to a max. value of 0.5 bar in most cases. When this value is reached, filtration has to be interrupted and the filter has to be backflushed.

A further consequence of the growing blocking of filter pores is an increasing flow velocity in the still free pores, when the filter plant is operated at a constant total volume flow rate. Due to rising filter velocity less and less particles are held back so that the concentration of particles, resp. turbidity substances in the filtrate increases from a certain filter load onwards (see fig. 1). Apart from the max. allowable pressure loss, the max. allowable concentration of solids in the filtrate is a further criterion to interrupt the filtration process and to start backflushing the filter.

That means the end of a filter cycle is either reached, when the turbidity surpasses the defined max. value or when the max. differential pressure is reached.

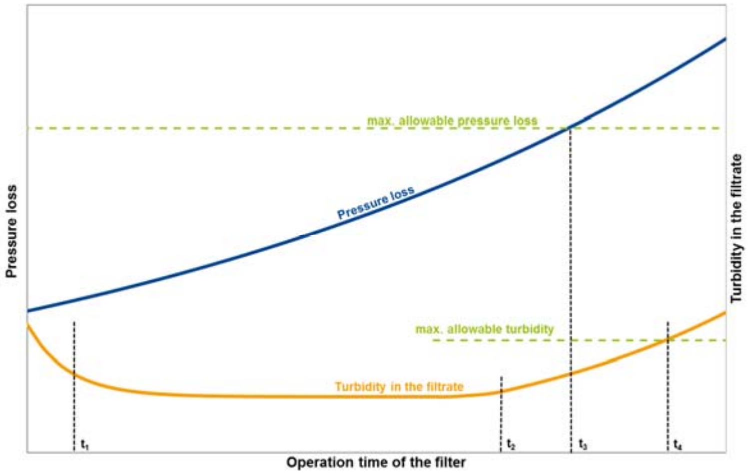


Fig.1 Particle concentration, resp. turbidity in the filtrate and pressure loss as a function of the operation time of a filter

The backflushing is done in opposite flow direction to the loading, i.e. from bottom to top, in order to rinse out the filtrated solid substances from the filter bed. The most frequent variants are backflushing only with water or flushing with water and air.

Plain water flushing needs very high water velocities, so that the flushing water consumption can be as high as 15 per cent of the produced filtrate. Air-water-flushing starts with an air flushing phase to break open the filter bed. In a second step all solid substances are rinsed out with water. The flushing water consumption is about 6 to 10 per cent of the filtrate.

The combined air-water-flushing consumes only 3 per cent of the gained filtrate and thus is very economical and effective. After a short preflushing with water, the water level in the filter is decreased to nearly the filter bed in order to get space for its expansion. Subsequently to the air flushing follows the combined air-water-flushing, which loosens and rinses out the solid substances by intensively moving the filter materials. In a final step flushing water drives out the filtered particles as well as the remaining flushing air.

Before starting a new filtration cycle the filtrate has to be led out for some minutes, as due to the backflushing some turbidities, which have sunk to the lower filter bed and would affect the filter quality, have to be rinsed out.

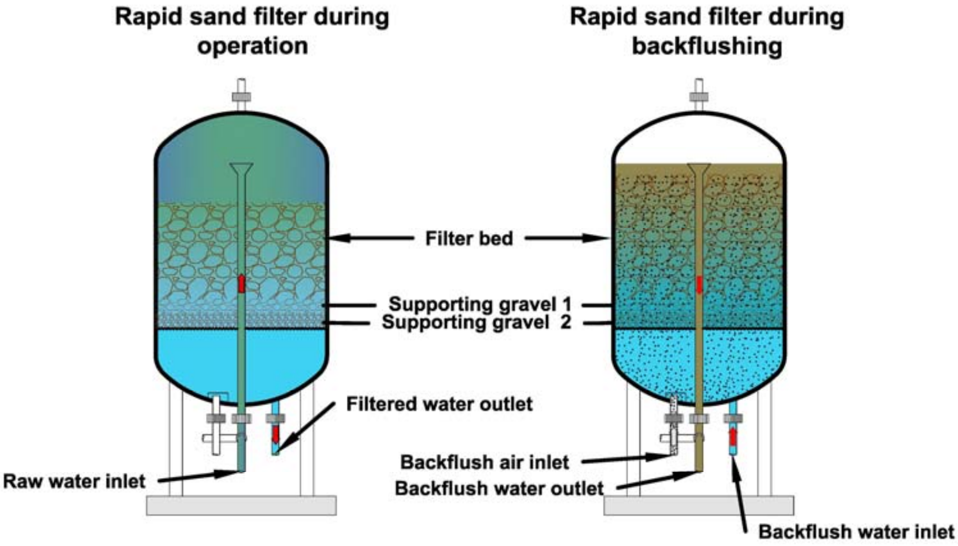
A good backflushing is only reached when the filter bed can expand. That is the case when there is an open space of 800 to 1000 mm (called free board) above the filter material. Due to the expansion of the filter bed the pores are enlarged. In the growing fluidized bed the filtrated particles are suspended again (as the filter grains rub against each other) and then flushed out with the backflushing water.

Chart 2 gives examples of backflushing programs for the combined air-water-flushing for single- and multilayer filters. The duration of the partial steps as well as the specific water, resp. the air volume flow rates are listed. In case of multilayer filters with very light filter materials the flushing with air and water should be made separately, so that the filter materials are not washed out by the flotation effect. For multilayer filters the washing out time of solid components should be long enough to remove the air from the filter and to ensure a classification of the filter materials.

Chart 2 Backflushing Programs for Volume Filters

Program step	Single layer filter	Multilayer filter
Pre-flushing, rinsing out deposits on the filter bed	Water, duration 3 min, 60 $m^3 m^{-2} h^{-1}$	Water, duration 3 min, 60 $m^3 m^{-2} h^{-1}$
Expansion of the filter bed	Air, Duration 1 - 3 min, 60 – 90 $m^3 m^{-2} h^{-1}$	Air, Duration 1 - 3 min, 60 – 90 $m^3 m^{-2} h^{-1}$
Suspending of the filtered particles	Air and water, Duration 3 to 5 min, Air 60 – 80 $m^3 m^{-2} h^{-1}$ Water 10 – 15 $m^3 m^{-2} h^{-1}$	Air and water, Duration 3 min, Air 60 $m^3 m^{-2} h^{-1}$ Water 10 – 15 $m^3 m^{-2} h^{-1}$
Removal of the filtered particles	Water, Duration 3 bis 5 min, 10 - 20 $m^3 m^{-2} h^{-1}$	Water, Duration 5 min, 40 - 90 $m^3 m^{-2} h^{-1}$
Purge of the initial filtrate	Duration ca. 5 min	Duration ca. 5 min

The backflushing water is led to a sludge treatment step, where the separated solid components are further thickened. The clear water stream from the sludge thickening is led back to the raw water.



Volume Filter: Filter Efficiency

The filter efficiency of volume filters, i.e. the probability that a particle is filtered out, depends mostly on its size (s. fig.3). For particles with a diameter in the range of 1 µm it is typical that they are hardly filtered out. For smaller dirt components the Van-der-Waals forces are dominant compared to the flow forces, causing particle accumulation onto the filter material. Larger particles are separated by the sieving effect of the pores. Fig. 4 shows a typical dependence between filter efficiency and particle size for a defined filter velocity.

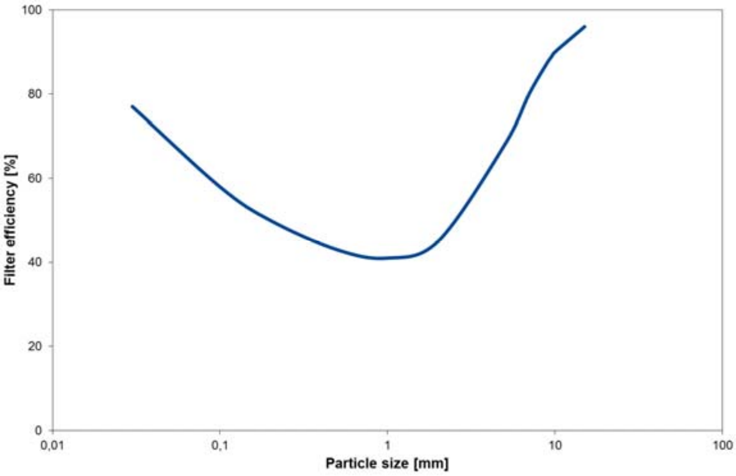


Fig. 3 Filter efficiency vs. particle size

If the filter velocity is reduced, the flow forces on the particles get weaker and the separation efficiency rises, i.e. with lower filter velocities a better filtration result is reached (s. fig.4).

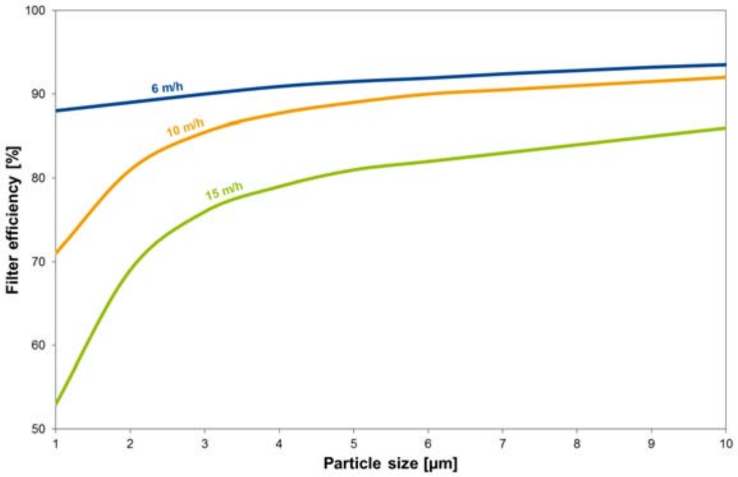


Fig. 4 Filter efficiency at different filter velocities

A lower filter velocity does not only mean an improved clear water quality, but also longer filter life-cycles, and thus a less specific flushing water consumption. If moreover wider pipe cross-sections are chosen, there is also a significantly lower consumption of electrical energy for the pumps. A reduction of the pressure loss by only 0.1 bar at a volume flow rate of 100 m³/h corresponds to savings of 1.500 kWh/a.

Fig. 5 Example of a plant with 2-layer-filter (EnviroChemie GmbH)

Continuously Operated Volume Filter

A continuously operated volume filter is cleaned during running filtration. The filter need not be switched off for backflushing (s. fig 6)

The raw water flows through the inlet pipe (double pipe system) and the radial inlet distributor from the bottom into the filter bed and rises to the top, countercurrent to the down streaming filter material. The filtrated clear water leaves the filter over the overflow weir at the outlet in the upper filter part.

The loaded filter material from the lower end of the filter cone is transported by a mammoth pump (air-lift pump) to the upper part of the filter. From there the filter material falls into the washer at the filter head, where it is cleaned in countercurrent direction with a small partial stream of the filtrate.

This flushing water stream, which can be adjusted by a weir, flushes the filtrated residues out of the filter. The cleaned filter material falls back onto the filter bed and is reused in the filtration process.

In the lower part of the filter there is a distributor cone installed, which secures a uniform velocity of the filter material over the whole filter cross-section.

Chart 3 Dimensioning parameter of continuously operated volume filters

Dimensioning parameters	Continuously operated volume filter
Operating limits ca.	25 - 100 m³ h^{-1}
Backflush water demand	3 - 5 m³ h^{-1}
Filter velocitiy	10 - 20 m h^{-1}
Filter material grain size	0.7 – 1.2 mm oder 1.0 – 2.0 mm
Layer height	1.5 m
Filter cross-section	5.0 m^2

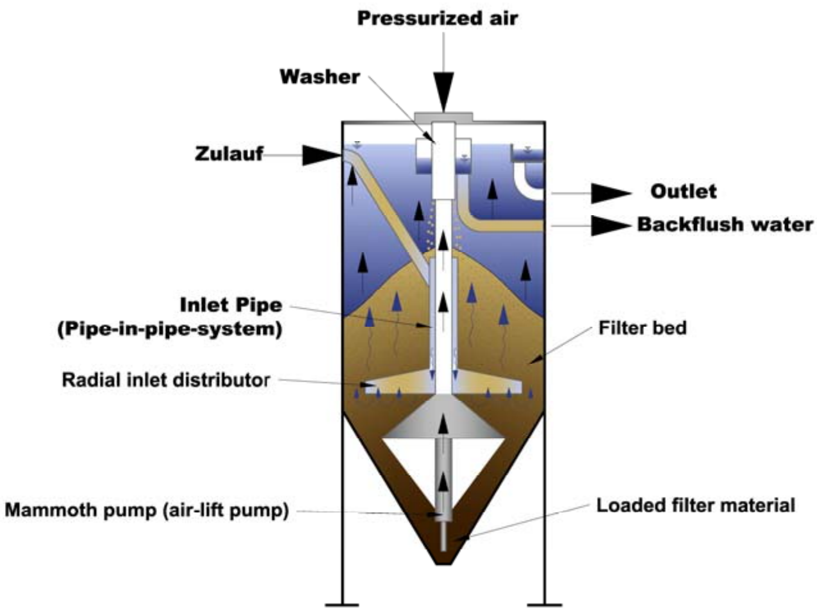


Fig. 6 Continuously Operated Volume Filter

Flocculation

The low filter efficiency of volume filters for particles with a grain size of ca. 1 µm often means a big problem, as on the one hand these particles can be hardly measured continuously, and on the other hand they accumulate in the subsequent process steps and can agglomerate. Furthermore, the size of many microorganisms is in this range.

A widely used method to improve filter efficiency is the transformation of smaller particles in filterable agglomerates by flocculation. For this purpose a specific property of turbidities is made use of. They have a negative surface charge in aqueous suspension, caused by adsorption of hydrogen carbonate ions onto inorganic particles and by organic acids onto organic suspensa.

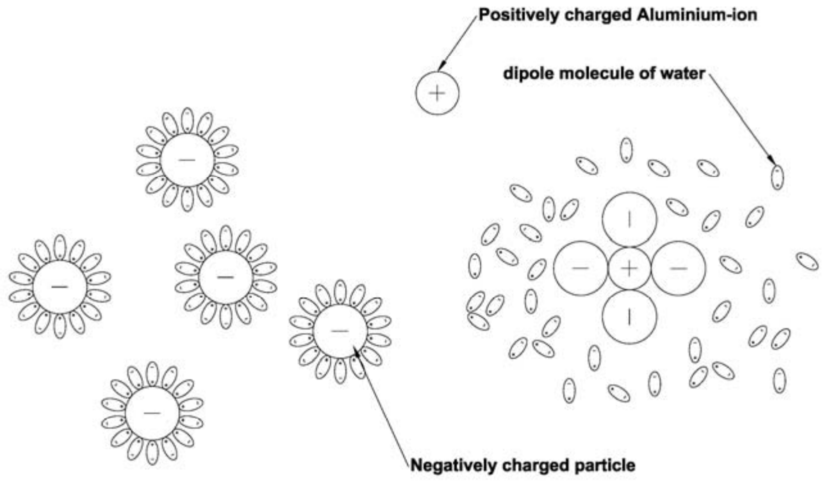


Fig. 7 Flocculation with aluminium ions

Physically seen the ionic charge strength of particles is stated by the Zeta potential, i.e. a higher numerical value means a heavier rejection of the particles. For pH-values within the neutral range, the Zeta potential is generally between -14 and -30 mV. By dosing coagulants into the water which are positively charged (flocculants), the negative charges of particles are compensated, and a so-called destabilization of the suspension is reached. In the subsequent coagulation the coagulants and the particles form flocs and agglomerate.

Flocculation = Destabilization + Coagulation

For this purpose the added quantity of flocculants need not be so high that the negative charges are completely compensated. On the contrary, if flocculants are overdosed, particles can become positively charged and dispersed again. The optimal Zeta potential for coagulation depends very much on the physic-chemical mechanism of flocculation. Therefore the type of flocculant and the needed quantity have to be defined for each application, directly at the concerned plant with the specific water to be treated.

For the destabilization of turbidities acid salts of trivalent aluminium or iron are applied as so-called primary flocculants. In aqueous surroundings hydrolysis takes place and, in simple terms, positively charged metal hydroxides and free acids are formed.

In application there is to make a difference between aluminium and iron salts.

Aluminium Salts

Aluminium-hydroxi-chloride

$Al_2(OH)_3Cl_3 + 3\ H_2O \Rightarrow 2\ Al(OH)_3 + 3HCl$

Aluminium sulphate

$Al_2(SO_4)_3 + 12\ H_2O \Rightarrow 2\ Al(OH)_3 + 6\ H_3O^+ + 3\ SO_4^{2-}$

$6\ HCO_3^- + 6\ H_3O^+ \Rightarrow 12\ H_2O + 6\ CO_2$

Because of the produced acids when hydroxides are formed, there is a change in the pH-value, which influences the chemical balance of the reaction. With a sufficient content of hydrocarbonate ions the resulting H_3O^+ ions are debuffered, otherwise alkalization agents as sodium hydroxide (caustic soda) or soda solutions have to be added to increase the pH-value. However, a pH-value above 7.5 causes an increased concentration of residual aluminium by forming $[Al(OH)_4]^-$. Optimal values for the flocculation of aluminium salts are in the range of pH 5.5 to 7.2. Due to residual solubility an aluminium content of 0.1 mg/L is unavoidable in technical plants.

Iron (III) Chloride

With regard to flocculation, iron (III) chloride shows the same behavior as aluminium sulphate, but the produced sludge flocs are more dense, have a higher sedimentation rate and cause a higher solids content in the thickened sludge. A further advantage of iron salts is the wide pH-value range for their application. From 3.3 up to the high alcaline range, i.e. pH-values of up to 11 as found in lime softening, iron salts are used. The optimal pH-value is from 5.5 to 7.5.

If at the same time manganese, oxidized in the alcaline range, has to be removed together with turbidities, iron (III) salts in the pH-range of 7 to 8 are also applicable in this case. Whereas humic acid compounds can be precipitated in the pH-value range of 5.5 to 6.5. The usual dosage for surface waters can be seen in the values of chart 4.

Chart 4 Flocculants and Dosage Recommendations

Trivial name	Flocculant	Application	Dosage	Optimum pH-Value
Aluminium sulphate	$Al_2(SO_4)_3x18H_2O$	Turbidity removal Humic substances	10 – 50 g/m^3 0.25 – 1.0 mg Al^{3+}/mg DOC*	6.5 – 7.0 5.0 – 6.5
Polyaluminium-chloride PAC	$[Al(OH)_xCl_{3-x-2z}(SO_4)_z]_n$	Turbidity removal Humic substances	10 – 50 g/m^3 0.25 – 1.0 mg Al^{3+}/mg DOC*	6.5 – 7.5 5.0 – 6.5
Iron (III) chloride	$FeCl_3 \cdot 6H_2O$	Turbidity removal Humic substances Manganese removal Lime softening	10 – 50 g/m^3 0.5 – 2.0 mg Fe^{3+}/mg DOC* 10 – 50 g/m^3 10 – 50 g/m^3	4.0 – 10.5 4.0 – 6.0 7.0 – 8.0 9.5 – 10.5
Iron (II) sulphate	$FeSO_4\ x \cdot 7H_2O$	Turbidity removal Humic substances Manganese removal Lime softening	10 – 50 g/m^3 0.5 – 2.0 mg Fe^{3+}/mg DOC* 10 – 50 g/m^3 10 – 50 g/m^3	4.0 – 10.5 4.0 – 6.0 7.0 – 8.0 9.5 – 10.5

*DOC= Dissolved Organic Carbon

The Process Technology of Flocculation

The flocculation process is realized in four steps:

- Dosage and mixture
- Destabilization
- Aggregation of micro-flocs
- Aggregation of macro-flocs

The task of dosing consists of admixing a relatively small flocculant volume flow with a large raw water flow quickly and completely. The admixing success is most important for the whole flocculation process. The destabilization happens spontaneously with high turbulence in the admix reactor. High shear gradients produce micro-flocs, which are easily filterable in volume filters, especially multilayer filters.

If instead of direct filtration after the flocculation, a sludge separation by sedimentation (in case of iron salts) or flotation (in case of aluminium salts) is intended, so-called flocculation aids are added in order to produce macro-flocs. Flocculation aids are mostly organic polyelectrolytes with cationic or anionic functional groups. There is the choice of polyelectrolytes with different ionic strengths and chain lengths. The optimal flocculation aid has to be adapted experimentally in situ to the chemical-physical properties of the water (i.e. pH-value), and to the already chosen flocculant.

After the flocculation aid has been added, only low shear forces may appear, so that macro-flocs are produced at higher retention times.

Chart 5 shows the most important reactor types for flocculation and its typical operational parameters.

Chart 5 Operating conditions of flocculation reactors

Basic type	Details
Agitator tank	• Retention time 2 – 60 min • Shear rate 10 – 100 s^{-1} • Two and more tanks in series with decreasing shear rate: Mixing tanks Retention time 2 – 5 min Stirrer peripheral velocity 4 – 5 m s^{-1} Flocculation tank Retention time 20 – 60 min Stirrer peripheral velocity 0,5 – 1,5 m s^{-1}
Static Systems	• Flow chambers with hydraulically effective installations. • Flow-dependent systems • Flow velocity 0,1 - 0,2 m s-1 • Simple realization
Pipes	• Fast floc formation in pipe lengths of more than 20 m • Limiting the maximum throughput
Fluidizes sludge bed	• Combination with sedimentation • Upstreaming water • Floc forming in in the fluidized sludge • Long retention times
Sludge recirculation	• Recirculation of sludge in the micro-flucculation step

Conclusions

Volume filters are excellently suited to separate suspended particles and turbidities from surface waters and process liquids. The separation efficiency, resp. the filtrate quality can be significantly improved by the combination with a flocculation step. Higher investment costs, due to larger filter dimensions implying lower filter velocities, enhance the filtrate quality and cut energy costs.

Author

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