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## Wastewater treatment plants

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Part 13: Chemical treatment — Treatment of wastewater by precipitation/flocculation

## National foreword

This British Standard is the UK implementation of EN 12255-13:2023. It supersedes BS EN 12255-13:2002, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/505/40, Wastewater Treatment Plants 50 PT.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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## Wastewater treatment plants Part 13: Chemical treatment - Treatment of wastewater by precipitation/flocculation

Stations d'épuration - Partie 13: Traitement chimique -  
Traitement des eaux usées par  
précipitation/floculation

Kläranlagen - Teil 13: Chemische Behandlung -  
Abwasserbehandlung durch Fällung/Flockung

This European Standard was approved by CEN on 24 April 2023.

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## European foreword

This document (EN 12255-13:2023) has been prepared by Technical Committee CEN/TC 165 "Waste water engineering", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard either by publication of an identical text or by endorsement, at the latest by January 2024, and conflicting national standards shall be withdrawn at the latest by January 2024.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12255-13:2002.

This is the thirteenth part prepared by Working Group CEN/TC 165/WG 40 relating to the general requirements and processes for treatment plants for a total number of inhabitants and population equivalents (PT) over 50.

The EN 12255 series with the generic title "Wastewater treatment plants" consists of the following parts:

- *Part 1: General construction principles*
- *Part 2: Storm management systems*
- *Part 3: Preliminary treatment*
- *Part 4: Primary treatment*
- *Part 5: Lagooning processes*
- *Part 6: Activated sludge process*
- *Part 7: Biological fixed-film reactors*
- *Part 8: Sludge treatment and storage*
- *Part 9: Odour control and ventilation*
- *Part 10: Safety principles*
- *Part 11: General data required*
- *Part 12: Control and automation*
- *Part 13: Chemical treatment — Treatment of wastewater by precipitation/flocculation*
- *Part 14: Disinfection*
- *Part 15: Measurement of the oxygen transfer in clean water in aeration tanks of activated sludge plants*
- *Part 16: Physical (mechanical) filtration*

NOTE Part 2 is under preparation.

Any feedback and questions on this document should be directed to the users' national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

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## 1 Scope

This document specifies the requirements for chemical treatment of wastewater by precipitation/flocculation for removal of phosphorus and suspended solids.

The application of polymers is not described in this document.

This document has not attempted to specify all available practices.

NOTE Chemical treatment can be performed in combination with primary and more commonly with secondary treatment, but it can also be performed as separate tertiary treatment, usually in combination with filtration (see EN 12255-16). Chemical treatment can provide a potential contribution to the **circular economy** through the recovery of materials, such as phosphorus, from wastewater or sludge.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12255-1, *Wastewater treatment plants - Part 1: General construction principles*

EN 12255-11, *Wastewater treatment plants - Part 11: General data required*

EN 16932-1, *Drain and sewer systems outside buildings - Pumping systems - Part 1: General requirements*

EN 16932-2, *Drain and sewer systems outside buildings - Pumping systems - Part 2: Positive pressure systems*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

### 3.1

#### **chemical treatment**

process involving the addition of chemicals to achieve a specific result

Note 1 to entry: For wastewater, typical chemical treatments comprise: coagulation/precipitation with metal salts (including lime) or organic polymers in order to remove inorganic and organic phosphorus compounds or suspended solids and colloids.

[SOURCE: ISO 6107:2021, definition 3.108 modified – Note 1 to entry added]

### 3.2

#### **chemical precipitation**

conversion of components dissolved in water into an undissolved form by chemical reaction with a precipitant

[SOURCE: EN 16323:2014, 2.3.5.8]



### 3.3

#### **precipitant**

chemical used to bring about precipitation

[SOURCE: EN 16323:2014, 2.3.5.45]

### 3.4

#### **coagulation**

destabilisation of undissolved and colloiddally dispersed matter to allow aggregation, usually by addition of coagulants

[SOURCE: EN 16323:2014, 2.3.5.9]

### 3.5

#### **coagulant**

chemical added to destabilise suspensions or emulsions

[SOURCE: EN 16323:2014, 2.3.1.21]

Note 1 to entry: A coagulant is normally based on an aluminium or iron salt (inorganic coagulant) but could also be a polymer (organic). In water treatment, the coagulant always has a positive charge

### 3.6

#### **flocculation**

formation of separable flocs by aggregation of small particles

[SOURCE: EN 16323:2014, 2.3.5.19]

Note 1 to entry: Micro-flocculation can be achieved by destabilization and coagulation/aggregation, macro-flocculation can be achieved by addition of bridge building polymers.

### 3.7

#### **destabilisation**

compensation of negative charges on the surfaces of particles by addition of positively charged bivalent or trivalent metal ions to achieve particle aggregation

Note 1 to entry: Destabilization is performed by reduction of the zeta-potential.

### 3.8

#### **tertiary treatment**

additional treatment processes which result in further purification than that obtained by primary and secondary treatment

[SOURCE: EN 16323:2014, 2.3.5.51]

### 3.9

#### **aerobic**

dissolved oxygen is present

[SOURCE: EN 16323:2014, 2.3.1.1]

Note 1 to entry: The terms oxic and aerobic are synonyms.

### 3.10

#### **anaerobic**

absence of dissolved oxygen, nitrate, nitrite and sulphate

[SOURCE: EN 16323:2014, 2.3.1.2]

Note 1 to entry: It can be important that other oxidising chemicals are also absent.

### 3.11

#### **anoxic**

absence of dissolved oxygen but presence of nitrite or nitrate

[SOURCE: EN 16323:2014, 2.3.1.3]

## 4 Symbols and abbreviations

### 4.1 Symbols

$C_{\text{Dos}}$	concentration of the dosed iron or aluminium salt ( $\text{kg}/\text{m}^3$ )
$C_{\text{P,in}}$	arriving P-concentration ( $\text{mg}/\text{l}$ )
$C_{\text{P,out}}$	remaining P-concentration ( $\text{mg}/\text{l}$ )
$L_{\text{P,rem}}$	removed phosphorus load ( $\text{kg}/\text{h}$ )
$Q$	wastewater flow ( $\text{l}/\text{s}$ )
$Q_{\text{Dos}}$	dose rate ( $\text{m}^3/\text{h}$ )
$\omega$	specific molar weight of the chemical ( $\text{g}/\text{mol}$ )
$\rho$	density of the chemical ( $\text{kg}/\text{m}^3$ )
$\beta$	ratio between the dosed precipitant (e.g. iron) to the stoichiometrically required precipitant for the phosphorus to be removed

### 4.2 Abbreviations

ADP	adenosine-di-phosphate
ASP	activated sludge plants
ATP	adenosine-tri-phosphate
DS	dry solids
EBPR	enhanced biological phosphorus removal
FPD	flow proportional dosing
FST	final settlement tanks
P	phosphorus
TSR	tertiary solids removal

## 5 Requirements

### 5.1 General

Chemical treatment of wastewater can be divided into two processes:

- a reaction phase, that consists of precipitation of dissolved phosphates, desorption of colloids and the formation of flocs; and
- a separation phase, in which the flocs are separated from the water.

The reactors and floc separators (sedimentation tanks, flotation or filtration units etc.) for the chemical treatment can be integrated with the other parts of the wastewater treatment plant (pre-precipitation as part of primary treatment, simultaneous precipitation as part of secondary treatment, see 5.5.2.1 and 5.5.2.2) or be a separate part of the treatment plant (post precipitation, direct precipitation, i.e. tertiary treatment, see 5.5.2.3, or direct precipitation).

The water level in the chemical reactors and tanks may be controlled by fixed or adjustable weirs. It is particularly important where there are multiple parallel reactors.

The design of the process shall take into account variations in flow and load as stipulated in EN 12255-1 and EN 12255-11.

### 5.2 Regulation

National or local regulations or the relevant authority can set requirements for phosphorus removal, recovery and re-use. This might also include a limit for the metal (iron or aluminium) used in the precipitation/flocculation of phosphorus in its various forms.

Limits would typically be on the remaining concentration of cations and anions (e.g. chloride, sulfate or aluminium) in the final effluent or its pH range. The mechanism and risk of over-dosing should be considered in the design phase.

### 5.3 Phosphorus removal strategies

#### 5.3.1 General

Phosphorus can be removed by primary treatment followed by biological or chemical treatment and may require tertiary (solids and phosphate removal) to meet tighter consents.

The Total Phosphorus permit limits imposed on sites can typically range from 2 mg/l down to 0,1 mg/l. The recommend strategy for achieving these permits varies depending on a number of factors:

- the total Phosphorus permit;
- the site's biological treatment stage;
- the site's final effluent solids removal performance;
- the precipitant chemical chosen to achieve Phosphorus removal;
- the means by which the precipitant is added and mixed;
- the characteristics of the influent (e.g. organic load, pH, industrial discharges etc)

Table 1 outlines an approach for sites with new total phosphorus permits which have not previously had final effluent total phosphorus permits and do not have existing tertiary solids removal (TSR) e.g. through effluent filtration:

**Table 1 — Recommended strategies for meeting required total phosphorus permits**

Biological treatment stage	Total phosphorus permit			
	≥ 1 mg/l	0,75 mg/l to 1 mg/l	0,5 mg/l to 1 mg/l	< 0,5 mg/l
Activated sludge plant	Single point dosing	Single point dosing with TSR optional	Dual or single point dosing with TSR optional	Dual or single point dosing with TSR
Trickling filters		Single point dosing	Single point dosing	

NOTE 1 Table 1 assumes good performance of existing final clarifiers and humus tanks with respect to solids removal.

NOTE 2 The total P concentrations in Table 1 are based on the yearly average of 24-h composite samples as common in most EU countries. However, other national regulations can exist.

### 5.3.2 Primary treatment

In primary treatment, phosphorus associated with settleable particles is removed (typically 5 % to 15 % of the total influent phosphorus depending on the character of the wastewater).

### 5.3.3 Biological treatment and enhanced biological phosphorus removal

In the biological treatment a certain amount of phosphorus is consumed at the microbial synthesis of new cellular material (10 % to 30 % of the influent phosphorus). By introducing anaerobic zones in activated sludge systems where phosphates are released an increased biological removal of total phosphorus can be reached without addition of chemicals (40 % to 70 % of the influent concentration). The uptake of Phosphorus in the anoxic and aerobic zones is thus increased (so-called luxury uptake). This additional process in activated sludge systems with incorporated anaerobic zones is called “enhanced biological phosphorus removal” (EBPR).

Chemical precipitation of orthophosphate PO<sub>4</sub>-P requires the addition of chemical at single or dual dosing points.

### 5.3.4 Tertiary treatment

If an assessment of the site indicates that final effluent suspended solids is high (>10 mg/l on average), TSR technology shall be considered at less stringent total phosphorus permits than Table 1 recommends.

Where the existing phosphorous or solids removal performance of the plant is poor, or the permit has been made more stringent, refurbishment of assets to improve the performance should be considered as an alternative option to the installation of new TSR technology. This review should consider data from as long a period as possible.

Tertiary solids removal (e.g. by sedimentation, flotation or filtration) may be required downstream of the final settlement tanks (FSTs) to meet permit requirements. This assessment must be made by the designer on a case by case basis.

## 5.4 Design considerations

### 5.4.1 Chemical

The reactions involved in the precipitation of phosphate shall be considered in light of the many competing reactions and the associated equilibrium constants.

Various parameters (e.g. pH value, alkalinity or the solids concentration in the final effluent), affect a plant's ability to meet a total phosphorus permit and shall therefore be considered. Appropriate means to prevent overdosage of chemicals shall be provided.

At the commencement of any projects involving chemical phosphate removal, it is essential to establish the level of total phosphorus within the wastewater to be treated. If high levels of phosphorus are present (greater than 20 mg/l), an audit to understand the source(s) should be undertaken to establish if source reduction offers a better option.

Jar tests can be performed early in the design to establish if chemical precipitation is feasible for the site and which chemical precipitant gives optimum performance. These tests should be conducted under a range of flow conditions to ensure the widest range of influent P concentrations and shall also consider metal concentrations and pH values. Jar tests will have limited significance for complex activated sludge processes.

For works with low or very low total phosphorus permit limits, onsite trialling of precipitant dosing should be considered.

Industrial discharges can affect the effectiveness of wastewater treatment plants and their units. This shall be considered during design. Where the quality of considerable portions of the raw wastewater differs from the characteristics of common municipal wastewater, pilot testing of treatment systems over a representative time period is recommended.

#### 5.4.2 Interchangeability

Tanks need to have external fixings to foundations. EN 12255-1 contains requirements for interchangeability of tanks.

Other design requirements can be found in EN 12255-1.

### 5.5 Chemical background and process options

#### 5.5.1 Chemical process

Most, but not all phosphorus in the raw wastewater is in the form of phosphates, generally orthophosphate. Industrial effluents may contain more or less other phosphorus forms. Biological wastewater treatment may transform other forms to orthophosphate because this is the form bacteria can take up. The phosphorus in cells is predominantly in the form of adenosin-di- and adenosin-tri-phosphate (ADP and ATP). The latter serves as an energy reservoir. While the bacteria have sufficient substrate and oxygen, they build up their ATP reservoir, but when they are under stress, they reduce it and release phosphate. For this reason surplus sludge shall be removed from aerobic or anoxic zones.

In order to obtain precipitation and coagulation a cationic chemical shall be added to the wastewater. Most commonly this is a salt of aluminium or iron. Lime can also be used. When using lime an additional neutralization after precipitation will be needed. If improvement/enhancement of flocculation is required, a polymeric flocculant can be added.

Precipitants react not only with phosphate but also with other substances (e.g. iron reacts with sulphide). For this reason, a surplus of precipitants needs to be dosed, i.e. more than the stoichiometric ratio relative to the phosphate concentration. The ratio is described with a factor  $\beta$  which is usually between 1,2 and 2,0.

The addition of magnesium hydroxide ( $Mg(OH)_2$ ) can be used for promoting a controlled phosphate precipitation as struvite, in liquids containing high concentrations of phosphate and ammonium (e.g. return flow from digested sludge dewatering or anaerobically digested sludge).

Salts of  $Fe^{2+}$  (e.g.  $FeSO_4$ ) or  $Fe^{3+}$  (e.g.  $FeCl_3$ ) or of  $Al^{3+}$  (e.g.  $AlCl_3$ ) or of polyaluminium can be used as precipitants and coagulants. If  $Fe^{2+}$  is used as a precipitant it will be oxidized to  $Fe^{3+}$  in aerated reactors therefore increasing the oxygen consumption.

Phosphorus can be present in the wastewater in the following forms:

- a) organically bound phosphorus,
- b) inorganic phosphorus,
  - orthophosphate,
  - polyphosphate,
  - nonreactive phosphorus compounds.

Polyphosphates are eventually converted to orthophosphates and the organically bound phosphorus can be converted to orthophosphate during biological treatment.

In the chemical precipitation, a precipitation agent (such as aluminium sulphate, polyaluminium chloride, ferric and ferrous chloride, ferric chloride sulphate, ferric and ferrous sulphate, ferric chloride and blends of aluminium and iron salts or calcium hydroxide) is added to the wastewater. Orthophosphate is precipitated as metal-orthophosphate.  $Al^{3+}$ ,  $Fe^{2+}$  and  $Fe^{3+}$  are multivalent ions which act as coagulants by destabilization. The solubility of the precipitates is pH-dependent.

Organic polyelectrolytes are used as flocculation agents for colloidal and suspended matter.

Chemical precipitation and coagulation can be carried out in three different ways:

- pre-precipitation upstream of primary treatment,
- simultaneous precipitation as part of secondary treatment,
- post-precipitation after secondary and as tertiary treatment.

Dosing ratios  $\beta$  (molar ratio metal:phosphorus) vary depending on the type of biological treatment phosphorus content in the water to be treated and the effluent requirement.

Exceptionally high molar ratios  $\beta$  have been observed as high as:

- Biological trickling reactor – up to 6 : 1.
- Activated sludge plants (ASP) – up to 4 : 1.

To achieve a P concentration below 1 mg/l in the effluent of activated sludge systems, a  $\beta$  ratio of about 1,5 is usually sufficient. More stringent requirements require higher  $\beta$  ratios. The dosage of precipitants can be reduced by dosing it at several points in the treatment process, e.g. with a  $\beta$  of 1,0 to 1,2 into the activated sludge process and another  $\beta$  of 1,2 upstream of an effluent filter. This is usually necessary where very stringent effluent limits of e.g. < 0,5 mg P/l are required.

Dosing at the molar ratios given above has shown that, in some cases, plants can achieve a total phosphorus concentration in their final effluent of close to 0,5 mg/l final effluent, particularly for ASP plants, where the metal dosing has been optimized and the average suspended solids concentration in the final effluent is below 10 mg/l.

Multi-point dosing is more complex but has the following advantages:

- lower residual phosphorus concentrations can be achieved;
- overall  $\beta$  can be reduced, i.e. less chemicals are needed. For very low total phosphorus permits (<0,5 mg/l) a secondary or even a tertiary dose point is usually required.

The addition of metal salts reduces the alkalinity of the wastewater and its pH. To prevent inhibition of nitrification, the remaining alkalinity should not be below 1,5 mmol/l.

It may be necessary to raise the alkalinity, e.g. by addition of sodium hydroxide (caustic soda) or calcium carbonate. The consumption of alkalinity depends on the metal/anion ratio and the residual free acid of the precipitant. Therefore partially neutralized products like basic aluminium salts will have a lower impact on the alkalinity

Organic polyelectrolytes or polymers are used as flocculants for colloidal and suspended matter.

They can be added after precipitation/coagulation to form larger and stronger flocs and thus increase solids and phosphorus removal (e.g. in filters).

## 5.5.2 Precipitation processes

### 5.5.2.1 Pre-precipitation

Pre-precipitation takes place in the primary treatment stage. For pre-precipitation, precipitant is dosed immediately upstream of the primary settling tank. Precipitants based on aluminium or iron can be used except those based on  $\text{Fe}^{2+}$ . It serves for dual point precipitation. It is especially useful where the inflow concentration of ortho phosphate is high. By pre-precipitation not only phosphates are removed but also organic load. This results in a significant relief of the aerated biological process (lower demand for aeration) and an increase of the organic load of the primary sludge. Consequently, this can boost the biogas production in the anaerobic digesters.

### 5.5.2.2 Simultaneous precipitation

Simultaneous precipitation can be used in wastewater treatment plants with biological treatment using the activated sludge process.

With simultaneous precipitation precipitant should be added upstream of the aeration tank, upstream of the secondary clarifiers or into the return sludge.

The mixed biological and chemical sludge is separated in the secondary settlement tank. The return sludge, the surplus sludge and the mixed liquor suspended solids contain a larger proportion of inorganic material as compared to activated sludge plants without P-removal.

Where trickling filters are used, dosing occurs upstream of the clarifier.

### 5.5.2.3 Post-precipitation

Precipitation upstream of effluent filters or other units for tertiary treatment is normally a complement to biological phosphorus removal or to pre-precipitation and/or simultaneous precipitation. The chemical is added into the channel or pipe leading to the tertiary treatment unit, e.g. a filter. Effective mixing after the dosing point is required

Post-precipitation can be added to wastewater treatment plants with biological treatment such as activated sludge, trickling filter etc.

To achieve sufficient mixing and flocculation for post-precipitation, precipitants should be added to a mixing tank, or to a channel or pipeline with turbulent flow, between secondary and tertiary treatment.

Floc formation takes place in a flocculation reactor followed by a final clarification tank where the chemical sludge is separated. Alternatively flotation or filtration can be used for separation.

### 5.5.2.4 Multipoint precipitation

The effectiveness and efficiency of the precipitation may be increased by adding the chemicals at two or three different points, e.g. grit chamber, aeration tank, and upstream of effluent filters.

### 5.5.3 Selection of precipitation chemicals

The coagulation and flocculation performance and the breakthrough risk of metal salts is influenced by the following factors:

- pH of the wastewater;
- dose;
- mixing;
- buffer capacity;
- dosing point location.

Iron salts are often preferred due to their wider availability and the more relaxed final effluent permit limits related to the lower environmental toxicity, however aluminium metal salt selection shall be considered if there are problems associated with iron salt usage (e.g. the formation of colloidal iron, the cost or supply of iron salts etc.). Iron also assists in sulfide removal in anaerobic digestion.

When considering alternative chemicals the following shall be taken into account:

- water quality before treatment
- residual final effluent limits (e.g. phosphorous concentration, pH, alkalinity, metal concentration, suspended solids);
- additional sludge production;
- alkalinity consumption;
- cost and availability of the chemicals including the impact on alkalinity and the need for correction.
- increasing anion concentration (e.g. chloride and sulfate)
- the system compatibility (e.g. when changing from Fe to Al salts, the higher corrosive effect could attack fittings/fixtures).

Guidance on commonly used chemicals is provided in Annex A. Some waste products or by-products and products ready for use can be used as precipitation and coagulation chemicals.

Careful consideration of the heavy metal concentration and other pollutants is necessary.

**NOTE** Details about heavy metal limits can be obtained from relevant national and European regulations and standards (e.g. EN 888, EN 889, EN 890, EN 891, EN 17034, DWA 202 etc.).

The different precipitation chemicals have different pH-optima (see Annex A). The addition also influences the pH of the waste water.

Type and dose of the chemical is dependent on the type of wastewater and its alkalinity. They should both be determined in a precipitation test. This test should be done on the specific wastewater in beakers equipped with stirrers with variable velocity or in pilot or full-scale trials. Such tests are not useful for simultaneous precipitation, but they are useful for precipitation during primary and tertiary treatment.



## 5.6 Storage preparation and dosing of chemicals

Most of the chemicals are hazardous. Additional information on requirements for storage, preparation and dosing equipment, along with any environmental specifications, can be found in national or local regulations. Storage, preparation and dosing equipment shall additionally meet the requirements of the relevant authority.

Information concerning commonly used chemicals is given in Annex A.

The suppliers' directions shall be observed.

The following items shall be considered:

- type of storage, as a solid or liquid (e.g. lime can be stored as solid CaO or liquid Ca(OH)<sub>2</sub>; FeSO<sub>4</sub> is usually stored as a solid, FeCl<sub>3</sub>, FeCl<sub>2</sub>, Fe(NO<sub>3</sub>)<sub>3</sub>, Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, AlCl<sub>3</sub> as a liquid, Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> as a solid or as a liquid);
- any required pre-treatment of the chemicals before dosing (e.g. slaking CaO to Ca(OH)<sub>2</sub>, or dissolving solid FeSO<sub>4</sub>);
- maximum storage time of the chemical;
- safety precautions in handling chemicals (e.g. personal protective equipment);
- safety precautions to contain leakage of full tank volume;
- double pipelines with leak sensors;
- climatic conditions.

Regular cleaning of the storage tanks may be required as per the manufacturer's requirements or the need for periodic inspection. The design of the storage should consider the options available for safe and effective cleaning.

For safety precautions see also EN 12255-10.

## 5.7 Dosing equipment

Storage, preparation and dosing equipment shall meet the requirements of national or local regulations or the relevant authority. Other environmental requirements specified by national or local regulations or the relevant authority shall also be met.

Unless otherwise specified, the dosing system shall have some form of back-up, either built in or held in storage.

Where automatic controls are used, the system shall be designed to change into safe state (fail safe mode) in case of failure.

The product shall be dosed at points where fast mixing is guaranteed. The reaction between the chemicals and the wastewater ingredients is extremely rapid. It is therefore important, in order to reduce competitive reactions, that the chemical is distributed uniformly. This can be done in many ways, e.g. with injection into turbulent flow or into mixing chambers.

The design shall include provisions for cleaning of the dosing system, including provision for the removal of scale.

There is a danger of dosing pipe clogging. Therefore, the pipework shall be designed for easy cleaning and consideration should be given to:

- constant circulation;
- a flushing system;
- rodding.

Dosing lines and dosing pumps shall be corrosion resistant, even if the chemical of choice should not be corrosive, in order to permit use of other more corrosive chemicals.

The speed of the dosing pump shall be controlled manually or automatically depending on the control system (see 5.10).

In most countries it is also required that pumps and pipelines or hoses for hazardous chemicals are installed within an external pipeline that conveys leaking fluid towards a water-tight basin with a leak sensor.

### 5.8 Silos, tanks and pipes

Most chemicals are supplied and dosed as liquids from a tank. Other chemicals are supplied as solids and require dissolving in a tank with a stirrer. Excellent mixing can also be achieved by intermittent air injection.

The dissolving tank shall be made of plastic material. In some cases, a concrete tank, internally coated with a plastic material, can be used. Stainless steel tanks are not recommended.

It is possible to store solid chemicals in a silo and to supply batches of the solid chemicals and water to a dissolution tank. The dosing of chemicals and water can be automatically controlled depending on the level in the dissolution tank. The mass of added solid chemicals is controlled by the operation time of the feeder (e.g. a conveyer screw or a cellular wheel sluice). Addition of water is usually controlled via the liquid level in the dissolution tank. The concentration in the dosing tank should be kept well below the saturation concentration to prevent precipitation, e.g. resulting from changing temperature.

Silos for solid chemicals shall remain dry. Bridging of solids can be prevented by vibration. If introduction of compressed air is used to prevent bridging, the air must be dry.

The silos or storage tanks should be placed as near to the dosing point(s) as possible. Pipe length should be as short as possible, and the pipework should be designed without any stagnation zones or sharp bends, especially when lime slurries are used.

A leakage monitoring system for silos, tanks and pipes is required.

Silos and tanks shall be protected against mechanical damage, e.g. collisions with tankers.

The tightness shall be checked before commissioning the dosing and protecting pipes.

In most countries it is required that tanks for hazardous chemicals are installed within a water-tight basin that has the same volume as the largest tank and is provided with a leak sensor.

## 5.9 Mixing

The chemicals shall be rapidly mixed into the wastewater.

Provision should be made for easy removal of mixing devices without emptying the tank. The choice of the device depends on the characteristics of the chemicals used.

When selecting the dosing point, the following requirements should be used to determine the best location:

- mixing requirements;
- chemical contact time;
- operational access;
- distance from bulk storage or day tank;
- required pumping head and dosing flow rates;
- location of other supply pipes made of less resistant materials.

Mixing of the chemical into the wastewater shall be as rapid as possible to achieve an even concentration. The choice of the correct dosing point will be crucial in order to avoid / reduce competitive reactions. A mixing power of at least  $100\text{W}/\text{m}^3$  is recommended.

After dosing micro-flocculation occurs. The power input for flocculation shall neither be too low (insufficient mixing) nor too high (destruction of flocs). A power input between  $2\text{W}/\text{m}^3$  and  $4\text{W}/\text{m}^3$  is recommended.

The mixing powers may be generated with a mechanical mixer, static mixer or by hydraulic means, e.g. by dosing immediately upstream of a centrifugal pump, a venturi nozzle or an overflow weir.

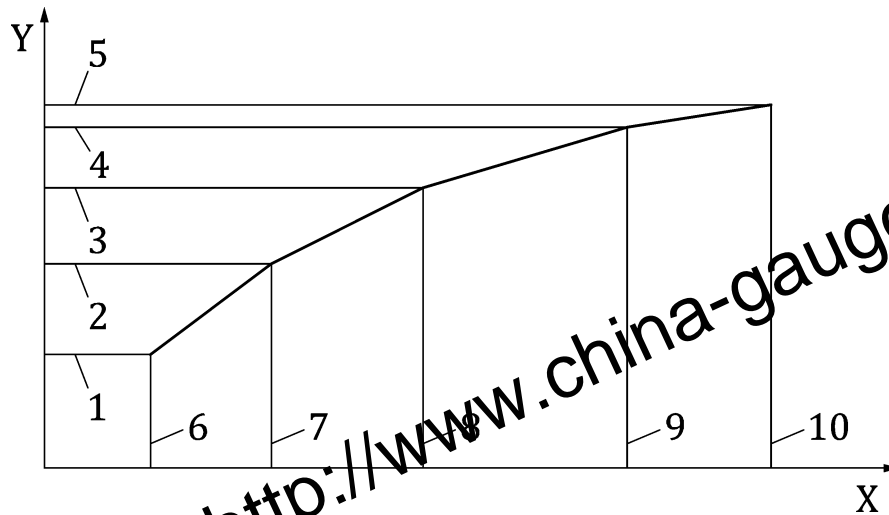
## 5.10 Control systems for dosing of chemical

### 5.10.1 General

Typically the control of chemical dosing will be similar to one of the following. In order to standardize on a single system it is possible to have a single system that can operate in one of the four modes below dependant on local circumstances and equipment constraints.

### 5.10.2 Flow proportional dosing (FPD)

Flow proportional dosing (FPD), whereby the dose rate increases as the sewage flow increases according to flow/dose set point pairs. Figure 2 illustrates an example of flow proportional dosing trigger points



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**Key**

- X Flow in l/s or Depth in mm
- Y Dose Rate in l/h
- 1 Dose Rate 1
- 2 Dose Rate 2
- 3 Dose Rate 3
- 4 Dose Rate 4
- 5 Dose Rate 5
- 6 Minimum wastewater Flow or Minimum wastewater Level
- 7 Wastewater Flow 2 or wastewater Level 2
- 8 Wastewater Flow 3 or wastewater Level 3
- 9 Wastewater Flow 4 or wastewater Level 4
- 10 Maximum wastewater Flow or Maximum wastewater Level

**Figure 2 — Example dosing algorithm based on the wastewater flow (source Wessex Water plc)**

NOTE The P-concentration is not proportional to the flow. The P-load of domestic sewage depends on the urine flow which varies over time. The flow depends on other factors, such as surface water or infiltration water.

**5.10.3 Load proportional dosing**

- a) Total phosphate load proportional dosing, whereby the dose rate shall be calculated as the product of the incoming flow and its measured phosphate concentration.
- b) Profile controlled load proportional dosing, whereby the dose rate shall be calculated as the product of the incoming flow and an phosphate concentration value taken from a predetermined profile (see Figure 2).
- c) Fixed flow profile controlled load proportional dosing, whereby the dose rate is independent of the flow rate and taken from a time dependent phosphate load profile.

#### 5.10.4 Phosphorus load calculation

The removed phosphorus load can be determined as:

$$L_{P,rem} = \frac{Q \cdot (C_{P,in} - C_{P,out}) \cdot 1000}{3,6} \text{ [kg/h]} \quad (1)$$

where

- $L_{P,rem}$  Is the removed phosphorus load (kg/h)  
 $Q$  is the wastewater flow (l/s);  
 $C_{P,in}$  is the arriving P-concentration (mg/l).  
 $C_{P,out}$  is the remaining P-concentration (mg/l).

The dose rate is determined as:

$$Q_{Dos} = \frac{L_{P,rem} \cdot \beta \cdot \omega}{(C_{Dos} \cdot 31)} \text{ [m}^3\text{/h]} \quad (2)$$

where

- $Q_{Dos}$  is the dose rate (mg/h);  
 $\beta$  is the dimensionless ratio of dosed chemical to its stoichiometric requirement.  
 $\omega$  is the specific molar weight of the chemical (g/mol); the molar mass of Fe is 56 g/mol and that of Al is 27 g/mol.  
 $C_{Dos}$  is the concentration of the dosed iron or aluminium salt (kg/m<sup>3</sup>);

NOTE 1 31 (g/mol) is the molar mass of phosphorus.

NOTE 2 The factor  $\beta$  is needed because precipitants react not only with phosphate but also with other substances (e.g. sulphide). For this reason, a surplus of precipitants needs to be dosed, i.e. more than the stoichiometric ratio relative to the phosphate concentration. The necessary factor  $\beta$  is usually between 1,2 and 2,0.

#### 5.10.5 Other control concepts

In addition to the control concepts described, “knowledge-based” controller systems are available according to the state of the art, of which the Model Predictive Control (fuzzy) controllers are the best known. These are able to model more complex relationships and also process derived variables (e.g. consumption in the aeration tank). In addition, the control of these solutions is defined in the form of verbally formulated, Model Predictive Control (fuzzy) rules. Assuming a manageable number of these rules, this results in control solutions that are generally characterized by transparency and good traceability. The transfer behaviour of a Model Predictive Control (fuzzy) controller can be interpreted as a nonlinear map.

#### 5.11 Flocculation reactors

Where flocculation reactors are needed, the hydraulic design shall minimize short circuiting. The distance between the flocculator and the separation unit (sedimentation tank, flotation) shall be short.

It is important that the water leaving the flocculation process should not be subjected to greater shear forces than encountered in the flocculation process. Therefore, the flocculation unit should be situated directly adjacent to or in the sedimentation tank.

The retention time in flocculation reactors should not be less than 20 min and agitation should occur with a specific power consumption of about 5 W/m<sup>3</sup>.

## 5.12 Sedimentation tanks

### 5.12.1 General

The sedimentation tanks shall adequately separate the chemical and biological sludge solids from the effluent and provide a concentration zone for withdrawal of sludge. The separation performance affects the quality of the final effluent.

Sedimentation tanks may be of upward flow type, horizontal flow type or a lamella separator.

### 5.12.2 Chemical sludge wasting

Sludge wasting is the removal of chemical sludge formed during the precipitation process together with the biological sludge and separated from the effluent.

The weight and volume of sludge to be wasted, depends primarily on the pollution load and the type of chemical used.

Sludge wasting shall be done continuously or quasi-continuously taking into consideration further sludge thickening and/or treatment.

For sludge pumping the choice of centrifugal or positive displacement pumps should be considered depending upon the sludge viscosity and the head to be achieved. Typically such pumping is intermittent.

General construction principles according EN 12255-1 shall be considered for design of the sludge wasting system. EN 16932-1 and EN 16932-2 provide guidance on pumping installations.

## 5.13 Flotation

In flotation tanks air is used to float particles to the surface, where they can be separated as sludge. The flotation should be of the dissolved-air flotation type. The surface sludge is usually collected using a scum scraper. In addition, there should be a collection system for the heavy sludge settled on the bottom of the tank.

Flotation is also described in EN 12255-4.

## 5.14 Physical filtration

Filtering is normally used as a complement to sedimentation or flotation in order to provide better suspended solids removal. However, some types of filters are designed to be able to serve as the only separation stage for chemical treatment of wastewater.

Where physical filters are used, there should be primary and secondary treatment before tertiary treatment. Where lime is used as a precipitant, physical filtration is not appropriate.

Physical filtration is described in EN 12255-16.

## 5.15 Sludge

### 5.15.1 Sludge production

Chemical precipitation with metal salts produces a sludge containing mixed metal phosphates and hydroxides and organic components from biological treatment. Chemical sludges containing iron and aluminium can be more difficult to process than biological sludges. The impacts of the estimated additional chemical sludge production on the existing sludge processing and storage assets shall be considered on a site-by-site basis. The addition of iron or aluminium into a wastewater treatment plant leads to a sludge containing more iron/aluminium.

The COD load of the sludge can also increase as a result of the enhanced precipitation / flocculation process. More organic substances will also be removed from the wastewater and incorporated into the sludge phase.”

Chemical treatment results in the following additional chemical sludge production:

- 4 g DS per 1 g Al;
- 2,5 g DS per 1 g Fe;
- 0,7 g DS per 1 g Ca.

In practical operation the additional chemical sludge production can be different. It may be determined by precipitation tests.

#### 5.15.2 Sludge characteristics

All sludge flocs are fragile and should not be subjected to high shear stress. This should be considered when pumps are selected.”

Iron-phosphate flocs have better settling and thickening characteristics than aluminium-phosphate flocs and form a more compact sludge. Calcium-phosphate sludge settles rapidly and forms a compact sludge. In order to improve sludge thickening and dewatering, polymers may need to be added.

**Annex A**  
(informative)

**Precipitation chemicals**

**A.1 Aluminium, calcium and iron salts**

Aluminium, calcium and iron salts suitable for chemical precipitation of phosphorus are summarized in Table A.1 and design considerations for their application are summarized in Table A.2.

**Table A.1 — Common phosphate-precipitants (coagulants) in wastewater treatment**

Product	Chemical formula	Delivered state <sup>c</sup>	Typical product data		Applicable standards
			Density (20°C) g/cm <sup>3</sup>	Concentration %(Al, Fe)	
Ferric Chloride	FeCl <sub>3</sub>	liquid	1,42	13,7	EN 888
Ferrous Chloride	FeCl <sub>2</sub>	liquid	1,33–1,37	8,7–14	-
Ferrous Sulphate	FeSO <sub>4</sub> ·7H <sub>2</sub> O	solid	1,0 <sup>a</sup>	17,8	EN 889
	FeSO <sub>4</sub> ·H <sub>2</sub> O	solid	1,4 <sup>a</sup>	30	
	FeSO <sub>4</sub>	liquid	1,2 <sup>b</sup>	7 <sup>b</sup>	
Ferric Sulphate	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	liquid	1,47	11,8	EN 890
Ferric Chloride Sulphate	FeClSO <sub>4</sub>	liquid	1,52	12,3	EN 891
Polyaluminium Chloride	Al(OH) <sub>a</sub> Cl <sub>3-a</sub>	liquid	1,35–1,40	9	EN 17034
Sodium Aluminate	NaAl(OH) <sub>4</sub>	liquid	1,5	10–13	EN882
Aluminium Sulphate	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·nH <sub>2</sub> O n = 0, 16 or 18	solid	0,9–0,97 <sup>a</sup>	7,2–9,1	EN 878
		liquid	1,32	4,25	
Aluminium Chloride	AlCl <sub>3</sub>	liquid	1,3	5,8	EN 17034
Calcium salts	CaO	solid	0,8–1,2 <sup>a</sup>	-	EN 12518
	Ca(OH) <sub>2</sub> · H <sub>2</sub> O	liquid	1,06–1,28		

<sup>a</sup> Bulk density.  
<sup>b</sup> Saturated solution at 10°C  
<sup>c</sup> Description as liquid here means in aqueous solution,



**Table A.2 — Common phosphate-precipitants (coagulants) in wastewater treatment - application and containment materials**

Product	Recommended materials	Suitable dosage points		
		Pre-precipitation.	Simultaneous precipitation.	Post-precipitation.
Ferric Chloride	Corrosion resistant (rubber, plastics)	x	x	x
Ferrous Chloride	Corrosion resistant (rubber, plastics)	(x)	x	
Ferrous Sulphate	Corrosion resistant (rubber, plastics)	(x)	x	
Ferric Sulphate	Corrosion resistant (rubber, plastics)	x	x	x
Ferric Chloride Sulphate	Corrosion resistant (rubber, plastics)	x	x	x
Polyaluminium Chloride	Corrosion resistant (rubber, plastics)	x	x	x
Sodium Aluminate	Corrosion resistant (stainless steel, rubber, plastics)	x	x	x
Aluminium Sulphate	Corrosion resistant (rubber, plastics)	x	x	x
Aluminium Chloride	Corrosion resistant (rubber, plastics)	x	x	x
Calcium salts	(Stainless) steel	x <sup>a</sup>		x <sup>a</sup>

<sup>a</sup> due to the high pH-values (pH-optimum 9,3–11,2) a subsequent neutralization is required. Therefore, the use of calcium salts in simultaneous precipitation is not possible.

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