Im Auftrag des:

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit

MINISTRY OF NATURAL RESOURCES AND ECOLOGY OF THE RUSSIAN FEDERATION

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Peculiarities, procedures, techniques, and problems of wastewater disposal

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Tartu 2021

Content

1 Wastewater generation and composition

1.1 Municipal wastewater

1.1.1 Availability and quality of input data

In many cases only some of the available measured data can be used when designing a new wastewater treatment plant. The input values required for dimensioning must be carefully collected/measured and checked. Existing data must be inspected for reliability and informative value and as far as possible, for plausibility and wastewater related peculiarities (for e.g., by comparing them with the number of connected inhabitants and their specific water consumption, by examining typical correlations between different parameters and balancing material flows, etc.) [1].

The following aspects and commonly associated problems are to be particularly addressed:

- *Scope of input data:* often, only a few baseline values are available, rendering assumptions necessary for the missing data.
- *Quality/reproducibility of the data:* in addition to the sampling conditions, the analytical method used to determine the wastewater parameters is often not specified.
- *Reference size of data:* the form of sampling as random or composite samples as well as the preparation of composite samples with flow-proportional or time-proportional samplers is often unclear; statistical unambiguously determined data, e.g., the daily pollutant loads used as design parameters, which are undercut on 85 % of the days (see table below), are usually not available.
- *Verifiability of input data:* missing information on specific features in the wastewater inflow, e.g., proportions of industrial wastewater or extraneous water, make a plausibility check difficult.
- *Probability of predicted data:* forecasts of ambitious growth, for e.g., in connection rates and water volumes.

The internationally differing sampling and analysis methods must also be considered (e.g., different determination of COD with potassium dichromate or potassium permanganate, use of homogenised or filtered samples, use of different filters). It is strongly recommended to record the type of sampling and analysis method when collecting measurement data [1].

Different wastewater compositions, resulting, for e.g., from local water consumption, or high inflow of extraneous water, can lead to specific concentration values in each case. Furthermore, the connection rate of the population is often unclear. Therefore, the plausibility check must consider that, for e.g., the approach of specific loads of 60 g BOD_5/(I-d) and 120 g COD/(I-d), which has proven itself in Central Europe, cannot be applied in many other countries [1].

The definition of the expansion size of wastewater treatment plants via load-specific population equivalents (e.g., $PE_{BOD,60}$ with the above-mentioned specific load of 60 g BOD_5/(I-d)), which is common in Germany (see table below), is often not used in other countries. In these countries, the expansion size is specified via the wastewater inflow Q_d (average daily flow in m³/d). Since the dimensioning of the biological stages is primarily dependent on the pollutant loads to be treated, the specification of load-specific population equivalents remains useful for the quick classification of the expansion size of a wastewater treatment plant [1].

Table 1.1.1.1: Population-specific loads in g/(I·d), which are undercut on 85% of the days, without taking sludge liquor into account (for Germany, adapted from [2])

Parameter	Raw Wastewater
BOD_5	60
COD	120
DM	70
TKN	11
P	1.8

1.1.2 Specific wastewater generation (country-specific)

If, in a specific design case, no measured values are available for individual input variables, these must be estimated appropriately.

When estimating the values, the inflow conditions, which differ significantly from Central European conditions in some cases, must be considered. Table 1.1.2.1 shows an international overview with exemplary influent values of wastewater treatment plants in different countries. The values are plant-specific and cannot be generalised for their respective countries. However, they do give an indication of the range of inflow data [1].

Although the values, apart from the water temperatures, are overall within the typical range of Central European plants, they deviate considerably in individual cases. This reflects the site-specific boundary conditions, such as heightened degradation processes in the inflow due to higher temperatures, deviating disposal paths for food residues, discharges from septic tanks or inflows of extraneous water. A transfer of assumptions and standard values, which have proven themselves for Central European plants, must therefore be questioned very critically in individual cases. The wide range of COD/BOD_5 ratios also makes it clear that the ratio value of 2, which is frequently used in Germany, often does not apply. Therefore, in the absence of inflow COD data for the application of COD-based design approaches, a simple conversion from any available BOD_5 values without verification of the measurements is not advisable [1].

Table 1.1.2.1: Examples of different inlet qualities in different countries (adapted from [1], [3] and [4])

Location	Wastewater temperature (°C)		Average concentrations in the influent (mg/l)						COD / BOD_5	BOD_5 / N
	Min.	Max.	COD	BOD_5	DM	N	NH_4-N	P		
Oslo, Norway	6	16	380	120		30		3	3.2	4.0
Prilep, Macedonia	8	16	500	250	290	45	32	9	2.0	5.6
Klodzko, Poland	9	20	400	170	170	37	24	4	2.4	4.6
Batumi, Georgia	11	22	240		150	26		5		
Invercargill, New Zealand	3	24	330	230	290	39	26	8	1.4	5.9
Konya, Turkey	8	24	820	430	430	87		13	1.9	4.9
Adana, Turkey	14	25	475	240	265	44	31	9	2.0	5.5
Nabeul, Tunisia		25	1.17	470	610	57		13	2.5	8.2
Santa Cruz, Bolivia	12	26	680	290	370	67	44	12	2.3	4.3
Sevilla, Spain	8	28	590	350		57	43	9	1.7	6.1
Adama, Ethiopian	13	28	930	360	420	67	43	11	2.6	5.4
Haikou, China	21	28	260	100	250	26	19	5	2.6	3.8
Teheran, Iran	17	29	460	260	180	48	37	7	1.8	5.4
Nashik, India	23	30	280	250			30		1.1	
Aguas Blancas, Mexico	23	33	340	150	120	45			2.3	3.3
Dubai, UAE	30	33	580	250	250	48	34		2.3	5.2

Location	Wastewater temperature (ºC)		Average concentrations in the influent (mg/l)						COD / BOD_5	BOD_5 / N
	Min.	Max.	COD	BOD_5	DM	N	NH_4-N	P		
Managua, Nicaragua	30	34	770	380	400	39	18	7	2.0	9.7
Sanhur al M., Egypt	20	35	1.3	650	760	120	83	19	2.0	5.4
Fujairah,UAE	23	35	580	350	260	50	29	7	1.6	7.0
Minimum	3	16	240	100	120	26	18	3	1.1	3.3
Average	16	27	570	290	320	51	35	9	2.1	5.6
Maximum	30	35	1.3	650	760	120	83	19	3.2	9.7
Germany	8	20	400-800	200–400	250-500	40-80	25-50	6-12	2.0	5.0
Note: Minimum and maximum values are coloured blue and orange, respectively.										

1.1.3 Daily hydrographs of influent parameters

The WWTP design approaches in the Federal Republic of Germany are based on discharge requirements which are subject to the daily mean values. For processes with short residence times of only a few hours, special peak value considerations may be necessary if the comparative uniformity of the inflow in the sewer system or in the upstream treatment stages is low. This applies even more in warm climates, where load peaks can have a stronger impact due to comparatively smaller dimensioned plants [1].

In such cases, peak value observations must be carried out for sensitive parameters on the basis of individual peak values or the inflow's daily hydrographs. For e.g., the effects of minimum inflows on the flushing power of trickling filters or the consideration of maximum values by the impact factor of the nitrogen load (f_N) for the dimensioning of nitrogen elimination in activated sludge plants and trickling filters [1].

The results of random or mixed samples of the inflow parameters are usually best available when planning new or upgrading existing systems. Daily hydrographs (e.g., by means of 2-h composite samples or online analyses) are not available in most cases. This applies especially to new construction measures with sewage systems that have not yet been completed [1].

Figure 1.1.3.1 shows exemplary hydrographs for the wastewater inflow and the inflow concentrations of COD, N and P in the wastewater for a wastewater treatment plant in Germany (100,000 P.E) [1].

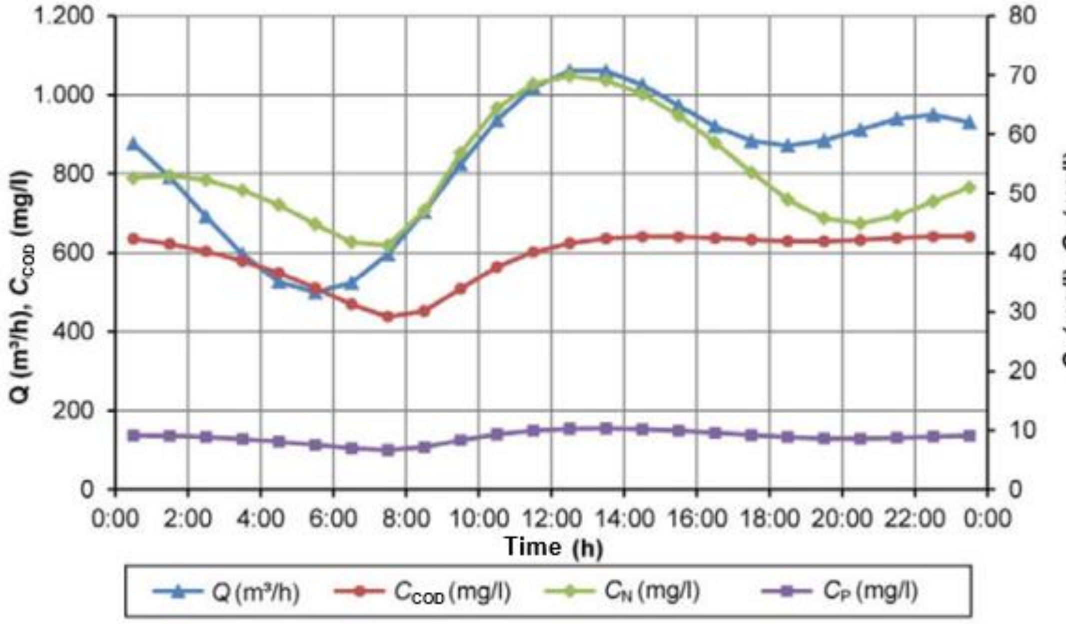

Figure 1.1.3.1: Exemplary daily hydrographs of the wastewater inflow and selected inflow concentrations for a wastewater treatment plant with 100,000 P.E. (adapted from [1] and [5])

As can be observed from the figure above, wastewater volumes and loads are lower during hours of minimal human activity, i.e., between 00:00 and 6:00, and reach peak values during the day – in this case, at around noon.

1.1.4 The ATV-DVWK-A 198: Standardization and derivation of design values for wastewater systems

The ATV-DVWK-A 198 deals with definitions, the collection, evaluation, and verification of data, as well as the derivation of design values for wastewater treatment plants and drainage systems based on these data. Subsequently, forecast data for different time periods can be derived from measured data. The aim of this Code of Practice is to standardise the derivation of values for the design of drainage systems and municipal wastewater treatment plants and the abbreviations for the design values as far as possible and appropriate for all ATV-DVWK Codes of Practice [6].

This Code of Practice introduces:

- a uniform system for abbreviations,
- a new approach for determining the combined sewer outflow (Q_M) for the interface between sewer and wastewater treatment plant,
- the concentration of COD, which has to be determined frequently, as a guide parameter and ratios to the other parameters required less frequently (e.g., BOD_5, filterable substances, nitrogen and phosphorus), in order to keep the costs of chemical analyses within reasonable limits,
- a computational determination of the dry weather discharge independent of weather records for hydraulic calculations.

The sewer system and the wastewater treatment plant should be operated for the same wastewater discharge. Due to the different planning horizons, the sewage system can be dimensioned for a different discharge than the wastewater treatment plant. Until now, the permissible combined sewer outflow was primarily determined according to the design data or the hydraulic capacity of the wastewater treatment plant. To optimise the permissible load of the treatment plant and the dimensioning of stormwater tanks, this Code of Practice recommends an approach involving a range of permissible combined sewer outflows [6].

During self-monitoring of wastewater plants, data that can form a valuable basis for planning extensions or optimisations of both drainage systems and wastewater treatment plants is collected. Unfortunately, in the past, data collection and evaluation were often carried out unilaterally, either only for sewage treatment plants or only for sewer systems. Terms and symbols were not always coordinated, often the same abbreviations with different meanings were used in different worksheets. This was partly due to the lack of clear guidelines [6].

Since more and more municipalities and other operators manage databases in which a lot of basic data for water management planning is stored, a clear definition and uniform further processing of this data is of particular importance [6].

It is recommended that the planning of wastewater facilities be based on measured values. Since the planning processes for the expansion of existing wastewater plants or new construction measures in individual districts usually take several years, this time should be used to broaden the data base, if necessary. This is a basic prerequisite for ecologically and economically sensible planning, construction, and operation of wastewater facilities [6].

1.2 Industrial wastewater

1.2.1 Wastewater from milk processing

The organic portion of cow's milk consists of approximately equal parts of fat, proteins, and lactose. Depending on the product range and production process, these organic substances are also found in varying proportions in the process wastewater, where they mainly enter through losses and cleaning processes [7].

Additionally, minerals (salts) are also present in milk and thus also in wastewater from milk processing. Wastewater from the milk processing industry, in contrast to wastewater from most other branches of the food and beverage industry, contains a significant amount of nitrogen (from the proteins) and phosphorus (an essential component of the minerals in milk) [7].

1.2.1.1 Wastewater generation and composition

Process wastewater generated by a milk-processing plant originates directly from production (rinsing milk, drip losses, contaminated vapor condensates, etc.), from pretreatment of milk (sludge from cleaning and sterilization separators) and from cleaning processes (used cleaning and disinfection solutions from CIP cleaning, washing water) [7].

Table 1.2.1.1: Daily values for specific wastewater generation, wastewater concentrations and loads in Germany (adapted from [7] and [8])

Loads	Unit	Range
Specific wastewater load	m³/1,000 kg Milk	0.5 – 2.5
Specific COD load	kg/1,000 kg Milk	0.8 – 5
COD	mg/l	800 – 4,500
Filterable substances	mg/l	150 – 1,000
NO_3-N	mg/l	10 – 120
NO_2-N	mg/l	0 – 2
NH_4-N	mg/l	0 – 20
KN	mg/l	10 – 150

Loads	Unit	Range
N-total	mg/l	20 – 250
N-total/COD	g N/g COD	0.02 – 0.06
P-total	mg/l	20 – 140
P-total/COD	g P/g COD	0.01 – 0.035
pH value	-	3.5 – 13
Low volatile lipophilic substances	mg/l	50 - 500

To avoid high concentrations of organic substances in wastewater, milk and whey losses should be prevented as far as possible, especially since milk has a COD of about 210,000 mg/l and whey about 70,000 mg COD/l [7].

Table 1.2.1.1 summarizes daily values for wastewater generation and wastewater load of milk-processing plants. The high N/COD and P/COD ratio values compared to other wastewater from the food industry are striking. Nitrogen is present in milk proteins. This explains the relatively low NH_4-N concentrations compared to Kjeldahl nitrogen (KN). However, a large proportion of the total nitrogen can also be present as nitrate. Nitric acid is often used in CIP cleaning, and sodium and potassium nitrate are frequently used in cheese production. Particularly in process wastewater from cheese production, and milk and whey powder production, the N/COD ratio is in the upper range and N/g COD ratio values of up to 0.06 g, which are decisive for the design case, can occur [7].

The phosphorus in the process wastewater comes almost exclusively from the milk itself. Here, too, especially in milk and whey powder production plants, and in cheese dairies, higher values of around 0.03 g P/g COD can be expected [7]

Salts in whole milk, in the whey produced and in wastewater streams from the production process (example in the German context – adapted from [7] and [9]).

Table 1.2.1.2: Salts in whole milk, in the whey produced and in wastewater streams from the production process (example in the German context – adapted from [7] and [9])

Parameter	Whole milk	Saline whey	Whey	Process water
	mg/l	mg/l	mg/l	mg/l
Sodium	414	21	440	543
Potassium	1,410	1,770	1,560	105
Calcium	1,485	2,450	610	80
Magnesium	100	160	77.5	12
Chloride	1,020	20,280	1,065	114
NO_3-N	0.18	-	0.18	8
Phosphorous	678	640	367	94

In addition to phosphorus, raw milk is also rich in other minerals (salts), particularly potassium, sodium, and calcium. Salts also enter the wastewater from milk-processing plants via cleaning agents and possibly via cheese plants. Table 1.2.1.2 shows an exemplary composition of salts (ions) in whole milk, in whey and in wastewater streams from the production process. The concentration of sodium and chloride is considerably higher here due to the saline whey, which greatly increases the ratio between sodium and the other cations in the process wastewater compared to whole milk. This can also be attributed to the caustic solution used for plant cleaning [7].

1.2.1.2 Measures to reduce wastewater load and volume

Extensive explanations of measures to reduce the wastewater load and volume can be found in the "BAT Reference Document in the Food, Drink and Milk Industries”, European Commission 2018. The main points are summarized below, with the focus on reducing wastewater pollution [7].

Measures to reduce wastewater loads

- collect leaked or spilled input materials and partially processed materials,
- separate collection and disposal of waste milk,
- complete collection of whey that cannot be further processed,
- integrated salt management in cheese production to reduce salt loads in wastewater,
- minimization of product losses,
- ongoing optimization of cleaning processes (cip systems) to save on chemicals and reduce salt loads, such as by re-using cleaning solutions,
- use of suitable systems to automate workflows, such as detection of the transition between product and water phases,
- carrying out dry cleaning and collection of solid residues, spilled products, and excess salt with subsequent separate recycling or treatment as waste,
- equipping drains with strainers and/or catch basins to prevent solids from entering wastewater,
- restricting the use of cleaning agents and disinfectants to the minimum necessary for operational purposes and replace chlorine-containing agents with oxygen-splitting or thermal disinfection agents,
- replacement of agents containing edta/nta with more environmentally friendly agents or water softening as an alternative.

Measures to reduce wastewater volumes

- analysis of water consumption in order to eliminate leaks,
- installation and monitoring of water meters at all major operating sites (water volume balance),
- use of high-pressure cleaning equipment, water-saving valves, and smaller-diameter hoses,
- use of condensate for cleaning purposes and as boiler feed water, as well as in heat and cold generation,
- cooling circuits instead of continuous flow systems,
- reduction of cooling water by heat recovery in heat exchangers,
- reuse of heated water from heat exchangers for cleaning purposes.

2 Wastewater quality requirements

2.1 Legal background

Water bodies are a (drinking) water resource, habitats, and wastewater sinks. These utilisation interests are balanced by means of regulatory law, partly supported by economic control instruments [7].

Many regulatory requirements in Europe stem from EU directives that must be transposed into national law. The Water Framework Directive (WFD) is the most important of these, with its daughter directives containing specific provisions. In addition to the requirements of the water law, the law of plant-related environmental protection, chemical safety and many more also have a connection to water and wastewater. This makes describing of the legal requirements for water management and industrial wastewater discharge difficult [7].

In the following, only the aspects relevant to industrial water use are presented and their interaction is discussed specifically with regards to industrial wastewater.

2.1.1 European legal framework

The European Water Framework Directive (WFD)

The broad protection approach of the Water Framework Directive, 2000/60/EC WFD, includes the protection of surface waters, transitional waters, coastal waters, and groundwater. The central objective is maintaining a good condition of all waters in community areas. In addition to improving the condition of aquatic ecosystems, this objective also includes preventing their further deterioration. The WFD pursues the strategy of sustainable water use based on long-term resource protection. This approach to water protection has quantitative and qualitative dimensions and combines an ecologically driven qualitative approach with a water management quantitative approach [7].

Particularly important for wastewater dischargers is the list of priority pollutants (Annex X of the WFD), which contains a selection of substances and groups of substances that pose a significant risk to or through the aquatic environment. For these substances, measures to limit the inputs of these priority substances as well as quality standards for their concentration must be established [7].

For the industrial and commercial sector, the requirements for wastewater dischargers are increasingly determined by EU regulations. The Industrial Emissions Directive 2010/75/EU from 2010 (IED) stipulates that the permitting and operation of the industrial plants listed in Annex I of the IED must be carried out in an integrated and cross-media manner in accordance with the best available techniques (BAT). This means that the separate consideration of air pollution control, water protection and waste prevention/recycling is replaced by the concept of precautionary production-integrated pollution prevention and control. A shift of environmental pollution into other environmental media such as air or soil, contrary to the state-of-the-art technology, is to be avoided. The central instrument for achieving this goal is the application of BAT in the approval of industrial plants [7].

BAT, according to Art. 3 IED, is defined as follows:

"Best available techniques" are the most efficient and advanced stages of development of activities and corresponding methods of operation which make certain techniques practically suitable to serve as a basis for emission limit values and other permit conditions in order to prevent emissions into and effects on the environment as a whole or, if this is not possible, to reduce them. In this context:

- "**Best**": the techniques that are most effective in achieving a generally high level of protection for the environment as a whole.
- "**Available techniques**" means those techniques that are developed at a scale, which, considering the cost/benefit ratio, make their application under economically and technically viable conditions in the industrial sector concerned, whether or not such techniques are used or produced within the Member State concerned, provided that they are available under reasonably accessible to the operator.
- "**Techniques**" means both the technology used and the way, the installation is designed, constructed, maintained, operated, and decommissioned [7].

For all important industrial sectors, the EU Commission continuously publishes BAT findings, which are legally binding and must be implemented in the EU within four years [7].

2.1.2 Wastewater Management in Germany – Quality Requirements vs Emission Requirements

In Germany, the combined approach of precautionary technology requirements (BAT) and the requirements related to the protected goods (WFD) has proven itself well. State-of-the-art emission standards ensure a continuous reduction in load, reduce the pollution of downstream areas and in the oceans, and allow proportionality aspects to be taken into account. Environmental quality standards (EQS) indicate the level that must be permanently maintained to protect humans (drinking water, irrigation water) and the environment (ecology and biodiversity) [7].

Compliance with environmental quality standards may require emission limitations beyond the application of BATs. The introduction of binding management objectives (EQS) for water bodies has strengthened the importance of the protected goods and provided clear guidance but has not called into question the need for precautionary load reductions of hazardous substances [7].

Basics of the assessment of wastewater discharges

When assessing wastewater discharges and wastewater treatment plants, the following aspects must generally be examined by the water authority:

1. Compliance with the requirements of water protection in relation to the objects to be protected, water management and wastewater disposal (§§ 5, 6, 12, 27, 47 and 55 WHG).
2. Compliance with precautionary technology-related requirements for the discharge of wastewater (section 57 WHG).
3. Compliance with the requirements for wastewater facilities (section 60 WHG).

The permit is revocable (section 18 (1) WHG). It grants the authority to use a body of water for a specific purpose in a manner determined by its nature and extent (section 10 (1) WHG). The permit specifies the purpose of the use of the water body. The type and extent of use are defined there by the listing of the planning documents, the description of the wastewater facilities, and by the content and ancillary provisions, especially the conditions for wastewater discharge. Accordingly, the purpose and scope of use must be described sufficiently and verifiably in the permit application [7].

Discharge permit based on Federal Water Act (WHG)

According to the Federal Water Act (WHG), the discharge of substances into a body of water constitutes a use. This also applies to the direct discharge of treated wastewater, as it of treated wastewater, because it contributes to the pollution of the water body. An official permit is required for this (section 8 WHG). Wastewater discharges into a water body are therefore generally prohibited. However, this prohibition may be lifted by the competent water authority in individual cases by means of a permit upon application of a clearance certificate (repressive prohibition with exemption reservation) [7].

There is no legal entitlement to the permit, as it is subject to the management discretion of the competent authority (section 12 para. 2 WHG). Since 1976, minimum requirements for the discharge of wastewater into water bodies and thus for wastewater generation, prevention and treatment have been set nationwide. The minimum requirements are laid down in section 57 (discharge of wastewater into water bodies, so-called direct discharge) of the WHG. Since 1996, these minimum requirements have been based on the state-of-the-art technology (see Annex 1 to the WHG). The permissible pollutant load is determined by how emissions to water can be minimised for the respective sector while adhering to technically and economically feasible advanced processes. These minimum requirements according to the state-of-the-art technology apply regardless of the local situation of a discharger [7].

Compliance with the requirements for wastewater facilities (Section 60 WHG)

While the requirements for wastewater discharge under section 57 WHG are aimed at compliance with the permissible quantity and harmfulness of wastewater, section 60 WHG defines the framework of requirements for the wastewater facilities required for this purpose. In addition to the construction and operation of the facilities, their maintenance is also covered [7].

It must be ensured that the requirements for wastewater disposal are met. The generally recognised rules of technology must be observed, and it must be ensured that wastewater treatment plants within the meaning of section 60(3) sentence 1 no. 2 WHG are constructed, operated and maintained in accordance with the state-of-the-art technology in order to have some correspondence to the "Best Available Techniques" as defined in the IED [7].

2.1.3 Wastewater Ordinance – Compliance with the Requirements for Wastewater Discharge

In the Wastewater Ordinance (AbwV), the federal government has defined general requirements and emission limit values for 53 source areas (municipal wastewater and 52 industrial and commercial sectors), which correspond to the state-of-the-art technology and are to be understood as minimum requirements. Annex 1 to the AbwV applies to domestic and municipal wastewater, the other annexes concern individual sectors of trade and industry [7, 10].

For most of the annexes, there are notes and explanations (background papers) issued by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the water Working Groups of the Federal States, in which the technical background is presented, and the requirements explained [7, 10].

The annexes of the AbwV, which are oriented towards wastewater types or sectors, contain concrete prevention and treatment measures as minimum requirements for the discharge of wastewater into water bodies. Since the amendment of the Wastewater Ordinance of 2 September 2014 (and most recently by the 7th amendment of the Wastewater Ordinance of 8 June 2016), the respective updated annexes of the

Wastewater Ordinance also contain all requirements for the water-related BAT of the EU. Discharge permits are only granted if the wastewater discharger implements the minimum measures described in the relevant annex of the AbwV to prevent and reduce wastewater emissions in accordance with the state-of-the-art technology [7].

The wastewater discharge operation can be analysed and assessed holistically sector by sector, as in the EU BAT findings, and prevention and reduction measures can be optimised more easily [7].

Particularly for hazardous substances (e.g., cadmium, mercury), requirements may also be laid down prior to mixing with other wastewater in the partial flow or at the point of transfer to the public sewer system (indirect discharge). Through the sectoral reference (e.g., metal, textile industry, food, paper production) and through a selection of the parameters to be limited, especially lead or sum parameters (e.g., TOC, TN_b, BOD_5, filterable substances) and active parameters (i.e., bioassay e.g., using fish eggs, daphnia, duckweed, luminescent bacteria), the measurement and monitoring effort can be kept within viable limits. In line with the idea of sectors or types of wastewater, requirements for dischargers are not usually set for specific individual substances, but rather wastewater source areas or sectors are determined, for which the state-of-the-art technology (which corresponds materially to European BAT) must be applied. The requirements are laid down at European level in the BAT findings (BAT-S) and - after updating - in the corresponding annexes to the AbwV [7].

Permit requirements and requirements for the discharge of wastewater into public and private wastewater systems (indirect discharges) are specified in the federal regulations of Sections 58 and 59 WHG in conjunction with the Wastewater Ordinance. In addition, the Federal States may, by means of their own legislation, lay down further-reaching permit requirements for the indirect discharge of wastewater [7].

2.1.4 IZÜV - Industrial Wastewater Treatment Plant Approval and Monitoring Ordinance

The implementation of the IED in the field of water protection led not only to changes in the WHG and the AbwV but also to the new Industrial Wastewater Treatment Plant Approval and Monitoring Ordinance (IZÜV). The scope of application of the IZÜV includes the granting of permits for water uses by industrial plants subject to the IED as well as the granting of permits for independently operated industrial wastewater treatment plants (6.11-plants according to Annex I of the IED) [7].

The scope of application extends not only to industrial wastewater treatment plants - as the title of the ordinance suggests - but rather also to discharges from IE plants. The long title of the IZÜV expresses this more clearly: "Ordinance regulating the procedure for the approval and monitoring of industrial wastewater treatment plants and water uses". Previous regulations of the Federal States for water uses by IPPC plants in state water laws or independent ordinances for IPPC plants no longer apply. Essentially the requirements correspond to those of the 9th BImSchV, i.e., the Ordinance on the Approval Procedure and other regulations of the BImSchG, i.e., the Federal Immission Control Act [7].

The scope of application of the IZÜV covers both the granting of permits or authorisations (Part 1) and their monitoring (§§ 7 to 10 IZÜV); the latter also covers the monitoring of indirect discharges (according to §§ 8 to 10 IZÜV) [7].

Part 1 of the IZÜV contains procedural provisions, more than 90% of which are otherwise regulated in the BImSchG. The procedural provisions refer to non-bundled (cf. section 13 BImSchG) permits for direct discharges from IE plants and to so-called 6.11 plants (according to Annex I IED). The procedural requirements of the IZÜV do not apply to indirect dischargers [7].

A permit according to IZÜV refers to the "process-specific contaminated wastewater". For e.g., this means that precipitation water from the roof of an IE plant does not require an IZÜV permit, but a normal permit for discharge [7].

The IZÜV thus expands the already customary authorisation procedures for discharges into water bodies to include the procedural requirements of the IED. Decisive for the practical relevance of the first part of the IZÜV (procedural requirements) is whether a BImSchG permit is already required for an IE plant and a wastewater treatment plant or discharge is also approved there as an ancillary facility (concentration effect of section 13 BImSchG regarding approval) [7].

What is new compared to the previous discharge permit are public participation, and monitoring requirements and obligations. Thus, if a licensing authority carries out an on-site visit at a facility, all relevant licensing facts are part of the inspection. The licensing authority can then call in a representative of the water authority.

2.1.5 Wastewater Levy Act

The amount of the levy is determined by the quantity and harmfulness (see Table 2.1.5.1) of certain discharged substances. Thus, direct dischargers must compensate at least part of the costs of using the environmental medium (implementation of the polluter-pays principle). The wastewater levy (AbwAG) is the first nationwide environmental levy with a steering function. The Wastewater Levy Act also implements the WFD requirement that environmental and resource costs must also be internalised in order to cover costs [11, 7].

Table 2.1.5.1: Annex to Section 3 AbwAG - Pollutants and Pollution Units under the Wastewater Levy Act [11]

Assessed pollutants and pollutant groups	The following full measuring units correspond to one damage unit	Thresholds by concentration	Thresholds by annual quantity
Oxidisable substances in chemical oxygen demand (COD)	50 kg Oxygen	20 mg/l	250 kg
Nitrogen as the sum of the individual determinations of nitrate nitrogen, nitrite nitrogen and ammonium nitrogen.	25 kg	5 mg/l	125 kg
Phosphorus	3 kg	0.1 mg/l	15 kg
Organic halogen compounds as adsorbable organically bound halogens (AOX)	2 kg halogen, calculated as organically bound chlorine	100 µg/l	10 kg annual amount
Metals and their compounds			
Mercury	20 g	1 µg	100 g
Cadmium	100 g	5 µg	500 g
Chromium	500 g	50 µg	2.5 kg
Nickel	500 g	50 µg	2.5 kg
Lead	500 g	50 µg	2.5 kg
Copper	1,000 g Metal	100 µg	5 kg/l
Toxicity to fish eggs	6,000 m^3 wastewater divided by G_{Ei}	$G_{Ei} = 2$	

The levy per pollution unit was increased in several steps to € 35.79 until 1997 but has not been adjusted since. The AbwAG provides for reductions in the levy rate in cases where the levy payer meets certain minimum requirements. In addition, certain investments to improve wastewater treatment can be offset against the levy. The wastewater levy is payable to the federal states. It is earmarked for water pollution control measures [7].

2.2 Indirect discharge

2.2.1 Leaflet DWA M115

Commercial and industrial wastewater (i.e., non-domestic wastewater) is often discharged into the public sewer system together with domestic wastewater and treated in the public wastewater treatment plant. Therefore, there are requirements regarding the quantity and quality of commercial and industrial wastewater from indirect discharges.

Part 1 of DWA Code of Practice 115 "Indirect Discharges of Non-Household Wastewater" deals with the legal basis for the use of the public wastewater system by indirect dischargers and gives advice on the appropriate design of the local drainage statutes, which enables the operator of the public wastewater system to monitor indirect dischargers efficiently and effectively [12, 7].

Part 2 deals with the qualitative requirements for indirect discharges from the point of view of the operator of the public wastewater system [7, 13].

Part 3 [ATV-DVWK 2004] deals with the implementation of indirect discharger monitoring. It describes the procedures for creating and updating a register of indirect dischargers, for the initial registration of plants, for determining the hazard potential of indirect discharges and the resulting monitoring cycle, as well as possible monitoring strategies [7, 14].

The indirect discharge of wastewater into the public sewage system has always been regulated in two different and completely independent areas of law: water law and municipal statute law [7].

All requirements for the discharge of the non-domestic wastewater are based solely on the requirements for the orderly operation of the public wastewater system and the legal requirements of Appendix 1 of the Wastewater Ordinance or the discharge permit under water law. All prohibitions and restrictions for the non-domestic wastewater, when discharged into the public wastewater system, are justified exclusively with regards to ensuring the protection goals of the operator:

- protection of the public from damage, danger, and nuisance.
- protection of the existing infrastructure and optimal operation of the public wastewater system.
- protection of compliance with water law requirements for direct discharge into water bodies.
- protection of sludge treatment and disposal.
- protection of the personnel working in the public wastewater system from damage and hazards [7].

The limitations listed in M 115 Part 2 are not directly legally binding [13].

The enforcement of the indirect discharge requirements in accordance with the Wastewater Ordinance is the responsibility of the water authority. Generally, this is the public wastewater system operator, who thus acts in a sovereign capacity. If the indirect discharger cannot comply with the discharge limitations, they must pre-treat their wastewater or take suitable prevention/reduction/other measures. Dilution of the wastewater to comply with the concentration limits is not permitted [7].

Certain substances may not be introduced into the public wastewater system as a matter of principle because they can impair the protection objectives. This refers to substances that:

- impede the flow of wastewater,
- reduce the purification efficiency of the wastewater treatment plant,
- form toxic, malodorous, or explosive gases and vapours,
- attack the building structure [7].

Examples include mineral oil, (shredded) solid waste (debris, kitchen waste, etc.), animal faeces, biocides, hardening substances (cement, synthetic resin, etc.), gasoline, paints, grease, lubricating oils, and substances releasing harmful vapours and gases. This exclusion regulation is also intended to counteract the disposal of waste via the public sewer system [7].

M 115 Part 2 considers those characteristics and constituents that are known in practice to lead to hazards, damage, and malfunctions in the operation of the public wastewater system or for which there are requirements under water law for the wastewater treatment plant effluent. Non-compliance with the requirements of water law can lead to increased wastewater charges and even criminal consequences for the operator of the public wastewater system, depending on the extent of the violation [7, 13].

The derivation of the guideline values is also based on the assumption that the industrial wastewater flow containing these substances accounts for a maximum of 10% of the wastewater treatment plant influent. The procedure for deriving the guide values implies that they apply to all indirect discharges, regardless of the sector or origin of the commercial and industrial wastewater, and at all times [7].

Therefore, the guideline value catalogue of M 115 Part 2 is considered to be clearer than that of the Wastewater Ordinance. The guideline values of M 115 Part 2 are generally less stringent in terms of numbers for most parameters, since the specification of requirements according to the state-of-the-art technology is reserved for the Wastewater Ordinance. Furthermore, they apply at the point of transfer to the public sewer system, whereas the Wastewater Ordinance already imposes requirements upstream of mixing or at the point of occurrence. This applies particularly to hazardous substances; for priority hazardous substances, the phasing-out requirement also applies. An exemplary comparison of the requirements for selected parameters of Annex 40 of the Wastewater Ordinance with the guide values of M 115 Part 2 is illustrated in Table 2.2.1.1 [7, 13].

Table 2.2.1.1: Exemplary comparison of the requirements of selected parameters of Annex 40 AbwV with those of DWA M 115 Part 2 (adapted from [7])

Parameter	Unit	Annex 40 AbwV	DWA-M 115 Part 2
AOX	mg/l	1	1
Chromium VI	mg/l	0.1	0.2
Lead	mg/l	0.5	1
Sulphide, readily releasable	mg/l	1	2

The M 115 Part 2 recommends that in the case of an indirect discharge permit under the WHG, the requirements therein replace the guideline values of the M 115 Part 2. The guide values of M 115 Part 2 only become binding limit values in the local drainage statutes. Since the limit values are linked to the analytical methods these must also be stated in the bylaws [7, 13].

The verification of the requirements according to M 115 Part 2 is carried out in the qualified random sample. The DIN analysis methods to be used in monitoring are also specified [7, 13].

M 115 Part 2 also indicates the possibility of relaxing or tightening the discharge limits. This can be useful, for e.g., to avert danger in the case of undue hardship for the indirect discharger, or in the case of low loads that do not affect the protection objectives. The information sheet recommends that such exceptions be regulated, for e.g., within the framework of special permits or contracts under public law [7].

If an indirect discharger is responsible for a high load in the wastewater treatment plant influent that impairs the protection goals, M 115 Part 2 recommends that the operator set a load limit on a case-by-case basis [7].

M 115 Part 2 offers assistance by listing further parameters that may be relevant for the operator of the public wastewater treatment plant but does not provide them with guide values. For e.g., the parameter thallium, the concentration of which can become relevant for the protection goal of sludge disposal, or the parameter aluminium, as long as no difficulties occur during wastewater discharge and treatment and it can, if necessary, be sufficiently limited via the parameter "settleable substances". In addition, M 115 Part 2 provides for the possibility of limitation for the parameters "Aerobic biodegradability" and "Nitrification inhibition" if there are relevant operational problems at the wastewater treatment plant or as an accompanying measure to the heavy polluter surcharge [7].

Limitations of the so-called anthropogenic trace substances are currently not provided for in M 115 Part 2. Also, there are currently no requirements for the discharge of these substances in Annex 1 of the Wastewater Ordinance. Only if the operator is subject to requirements - be it in the discharge permit under water law or in the Wastewater Ordinance - can they pass these on to their indirect dischargers, as far as they are relevant in the non-domestic wastewater [7, 15].

2.2.2 Fees and heavy polluter surcharges

The user charge must correspond to the service received (principle of equivalence). This can only be fully met by a scale that precisely records the type and extent of use and accordingly distributes the fees to the individual users [7].

For wastewater treatment, this would mean that the quantities and variations of wastewater, the degree of pollution and the degradability would have to be recorded in each individual case, which would be neither technically possible nor financially viable. Hence, the legislation also allows the application of probability standards. Thus, the Federal Administrative Court in Germany has repeatedly stated that the principle of equivalence and the principle of equality do not require that drainage charges be levied according to the measure of the costs caused by the use in each individual case - the principle of equivalence under federal law essentially only requires that the charges must not be disproportionate to the service provided. It is generally recognised in case law that in the interest of practicable charging, it is not the fairness of the service in the individual case that is required, but only the fairness of the type. As a rule, the levying of wastewater charges according to the freshwater scale satisfies these requirements. If, however, the advantages of typification are no longer in proportion to the necessary inequality of the burden associated with typification, the choice of a separate scale or the levying of a surcharge/deduction according to the degree of use of the municipal facility makes sense and is legally required. Recognised cases of application in the calculation of fees for this are the "split fee scale", i.e., the co-treatment and discharge of less heavily polluted rainwater that accumulates in quantities independent of freshwater consumption, as well as the "heavy polluter surcharge", which considers the additional costs incurred by the co-treatment of more heavily polluted wastewater at the municipal sewage treatment plant [7].

Formulation of pollution-based charges

The purpose of pollution-related surcharges is to pass on additional costs to the polluter caused by an increased pollutant load discharge compared to municipal wastewater. In contrast to the largely established guidelines for the calculation of rainwater charges, there is no agreed procedure for the calculation of pollution-related charges for wastewater treatment. Neither the scale of charges, i.e., the definition of the relevant cost units, nor the distribution key for allocating the costs is uniformly specified. If, when calculating the charges, partial flows that deviate from the municipal wastewater in terms of flows are taken into account in the calculation of the charge, only such parameters may be used as cost units for the calculation of charges, for which elimination facilities are also provided and operated, i.e., all wastewater factors determining the technical concept. The additional charges are usually levied by means of:

- pollution surcharges or deductions,
- fluctuation surcharges or
- volume discounts [7].

The models used to calculate heavy polluter surcharges can basically be differentiated according to two surcharge types:

- the continuous surcharge calculation by means of a formula and
- the stepwise calculation of surcharges according to pollution categories [7].

In addition, the individual heavy-polluter surcharges applied differ according to:

1. the cost units taken into account, i.e., according to the parameters included in the calculation,
2. the level of the selected threshold values above which a surcharge is levied, and
3. the determination of the distribution key for the allocation of the cost centre costs to the cost units, represented by the factors for the pollution-related costs or the percentage surcharges on the wastewater charge [7].

The surcharge calculation models currently in use do not provide a sufficient basis for allocating pollution-related costs to the polluter. The compilation of different calculation models for heavy polluter surcharges shows that up to now almost exclusively the parameters COD and BOD_5 are used as cost units for the surcharge calculation. Furthermore, the pollutant concentrations are usually used in the surcharge calculation and not the pollutant loads. A comparison of the specific surcharges (€/kg BOD_5) makes it clear that this cannot achieve sufficient fairness in the charges. Only the load-based models enable a uniform surcharge calculation for the parameter [7].

In addition to the pollutant concentration approach, the decisive weakness of all models for fair cost distribution are the distribution factors, which are necessarily fixed over the long term and not very transparent with regards to the manageability of the models. If pollution-dependent charges are to be levied, the introduction of a process-cost-oriented charge model, which can determine plant- and situation-dependent factors by linking the charge calculation with a cost database created based on the continuous cost breakdown in an up-to-date and updatable manner, is therefore preferable to a fixed heavy polluter surcharge in any case [7].

2.2.3 Direct discharge

Direct dischargers must comply with the minimum requirements laid down for their sector before discharging, and stricter requirements may have to be met in the case of poorly performing water bodies. Industrial wastewater is essentially wastewater from production processes, domestic wastewater from sanitary facilities and canteens, as well as cooling water and precipitation water. In the case of cooling water, a distinction is made between polluted and unpolluted water, depending on the process. Wastewater occurs at several points within an industrial plant and can vary greatly in its quantity and composition depending on the point of occurrence. In many cases, it is useful to treat the wastewater sub-streams separately and in a targeted manner before final treatment, depending on the constituents and the specific requirements [7].

BREFs and BAT

With the adoption of the IED in 2010, the legally binding nature of the BREFs (best available technique reference document) was strengthened throughout Europe. The BREFs set a Europe-wide standard for environmentally friendly and resource-saving operation of industrial plants from a wide range of sectors. The inferences contained in the BREFs are an essential tool for implementing the Directive. They contain the emission levels associated with best available techniques (BAT AEL: Best available technique associated emission level) and form the basis for sub-legislative regulations (for e.g., annexes to the AbwV). The inferences thus serve as a reference document for the determination of permit conditions for installations falling within the scope of the IED. The emission limit values stipulated are decisive in this context; the use of certain techniques is not prescribed for compliance with these values [7].

The development of a BAT document is carried out through an exchange of information between the member states, relevant industries, environmental NGOs and the Commission. To take into account the continuous progress in research and development and the associated technological innovations, the IED stipulates that BAT reference documents should be updated as far as possible eight years after their publication [7].

BAT inferences relevant to wastewater exist so far for the following sectors (as per European Integrated Pollution Prevention and Control Bureau, 2018):

- tanning of hides and skins,
- glass manufacturing,
- intensive rearing of poultry and pigs,
- non-ferrous metal industry,
- iron and steel production,
- large combustion plants,
- production of cement, lime and magnesium oxide,
- chlor-alkali industry,
- waste treatment plants,
- wastewater and waste gas treatment/management in the chemical industry,
- manufacture of basic organic chemicals,
- manufacture of wood panels,
- pulp, paper and board production,
- refineries [7].
- for the following industries, BREFs exist without inferences:
- textile industry,
- waste gas treatment in the chemical industry,
- steel processing,
- food industry,
- surface treatment of metals and plastics (electroplating),
- energy efficiency,
- industrial cooling systems,
- manufacture of basic inorganic chemicals - solids and others,
- surface treatment using organic solvents,
- production of basic inorganic chemicals - ammonia, acids and fertilisers, etc.,

- manufacture of organic fine chemicals,
- waste incineration plants,
- manufacture of polymers,
- animal slaughterhouses and animal by-products processing plants by-products,
- manufacture of speciality inorganic chemicals,
- storage of hazardous substances and dusty goods,
- foundries,
- ceramic industry [7].

In addition, the following reference documents are applied across all sectors [7]:

- general monitoring principles,
- economic and cross-media effects.

The most recent version of each document can be found at http://eippcb.jrc.ec.europa.eu/reference/.

2.2.4 Special requirements and annexes of the AbwV

In Germany, the requirements for the discharge of wastewater are defined in the AbwV. All annexes can be accessed at http://www.gesetze-im-internet.de/abwv/.

Table 2.2.4.1 summarises the requirements for wastewater at the discharge point as an example for selected branches of the food industry. It should be noted that further requirements may arise depending on the area of origin within an industry. In any case, the specific ancillary provisions must be observed. All values refer to a qualified random sample or a 2-hour composite sample. Where limit values for nitrogen and/or ammonium nitrogen are defined, these generally apply to an effluent temperature of 12°C and above in the effluent of the biological reactor. In some cases, higher nitrogen concentrations are permissible as soon as corresponding efficiencies can be achieved in relation to the eliminated nitrogen load. For the oilseed processing, edible fat, and edible oil refining sector, it should be noted that limit values are partly defined as loads [7].

Table 2.2.4.1: Requirements for the discharge of wastewater from selected branches of the food industry (adapted from [7] and [10])

<table>
<tr><th></th><th>BOD_5</th><th>COD</th><th>NH_4-N</th><th>P_{total}</th><th>N_{total}, as the sum of ammonium, nitrite, and nitrate nitrogen.</th><th>Specific wastewater quantity</th></tr>
<tr><th></th><th>mg/l</th><th>mg/l</th><th>mg/l</th><th>mg/l</th><th>mg/l</th><th></th></tr>
<tr><td>Annex 3
Dairy processing</td><td rowspan="5">25</td><td rowspan="5">110</td><td rowspan="5">10</td><td rowspan="5">2</td><td rowspan="5">18</td><td rowspan="8">-</td></tr>
<tr><td>Annex 5 Production of fruit and vegetable products</td></tr>
<tr><td>Annex 11 Breweries</td></tr>
<tr><td>Annex 12 Production of alcohol and alcoholic beverages</td></tr>
<tr><td>Annex 10
Meat industry</td></tr>
<tr><td>Annex 7
Fish processing</td><td>25</td><td>110</td><td>10</td><td>2</td><td>25</td></tr>
<tr><td>Annex 8
Potato processing</td><td>25</td><td>150</td><td>10</td><td>2</td><td>18</td></tr>
<tr><td>Annex 18
Sugar production</td><td>25</td><td>200</td><td>10</td><td>2</td><td>30</td></tr>
</table>

Annex 6 Production of soft drinks and beverage bottling	25	110	-	2	-	
Annex 21 Malt-houses	25	110	-	-	-	
	g/t	**g/t**		**g/t**	**mg/l**	**m^3/t**
Annex 4 Oilseed processing, edible fat and edible oil re-fining						
Seed processing	5	20	-	0,4	30	0,2
Refining	38	200	-	4.5	30	1.5

Requirements for the discharge point for wastewater from petroleum refining are compiled in Table 2.2.4.2. Here, pollutant loads are to be defined within the framework of the water law approval, for which a specific wastewater volume of 0.5 m^3 per tonne of input product is to be taken as a basis. In the case of lubricating oil production, a value of 1.3 m^3 per tonne of input product is to be applied. Furthermore, the additional requirements for wastewater prior to mixing must be considered [7].

Table 2.2.4.2: Requirements for the discharge of wastewater from petroleum refining (adapted from [7] and [10])

	TOC mg/l	COD mg/l	BOD_5 mg/l	P_{total} mg/l	N_{total}, as the sum of ammonium, nitrite, and nitrate nitrogen. mg/l	Hydrocar-bons, total mg/l
Annex 45 Petro-leum refin-ing	25	80	15	1.3	20	1.5

Table 2.2.4.3 shows the wastewater requirements for the discharge point for the production of paper, paperboard or cardboard according to Annex 28. For certain areas, additional conditions apply with regard to the annual mean value if a daily production capacity of 20 tonnes or more is exceeded [7].

Table 2.2.4.3: Requirements for the discharge of wastewater from the production of paper, cardboard or paperboard (Adapted from [7] and [10])

	BOD_5 mg/l	P_{total} mg/l	Filterable sub-stances mg/l	Total bound ni-trogen TN_b mg/l	N_{total}, as the sum of ammonium, ni-trite, and nitrate nitrogen. mg/l	TOC kg/t	COD kg/t
Annex 28 Manufac-ture of pa-per, card-board, or paper-board*.	25	2	50	20	10	0.9	3
*darüber hinaus gelten spezifische Anforderungen für die Herstellung unterschiedlicher Pro-dukte							

The limit values defined in Annex 40 of the AbwV for the metalworking sector refer to twelve areas and are summarised as ranges in Table 2.2.4.4. The limit values for hydrocarbons are to be related to the sample. For the twelve source sectors, there are in part further requirements in the event of mixing of the wastewater [7].

Table 2.2.4.4: Requirements for the discharge of wastewater from metal processing (Adapted from [7] and [10])

	Alu-min-ium	NH_4-N	COD	Iron	Fluoride, dis-solved	NO_2-N	P_{total}	Toxicity to fish eggs (G_{Ei})	Hydro-carbons, total
	mg/l	mg/l	mg/l	mg/l	mg/l	kg/t	mg/l		mg/l
Annex 40 metal pro-cessing	2–3	20–100	100–400	3	20–50	5	2	2–6	10

For the chemical industry sector, the requirements of Annex 22 of the AbwV apply. The scope of application includes those industrial plants with a wastewater discharge of 10 m^3 per day or more. The specific requirements for the individual pollutant parameters generally depend on the product manufactured or the load at the point of origin [7].

In the case of nitrogen, a higher concentration of up to 75 mg/l can also be specified in the approval under water law if a reduction of the nitrogen load by 75 per cent is guaranteed. Furthermore, limit values for AOX as well as for an extract of other substances are included for the requirements prior to mixing [7].

The requirements for the discharge of wastewater from the production of inorganic pigments for e.g., colourants or fillers result from Annex 37. Table 2.2.4.5 lists the discharge limits for lead, cadmium, and total chromium as examples. For the production of cadmium pigments, the production-specific load values refer to the quantity of cadmium used. The pollutant load is determined from the concentration values of the qualified random sample or the 2-hour composite sample and from the wastewater volume flow corresponding to the sampling [7].

Table 2.2.4.5: Requirements for the discharge of wastewater from the production of inorganic pigments before mixing (Adapted from [7] and [10])

		Lead and zinc pig-ments	Cad-mium pig-ments	Lithopones, zinc sulphide pigments and precipitated barium sul-phate	Iron oxide pig-ments	Chro-mium ox-ide pig-ments	Mixed phase pigments, pig-ment and col-our body mix-tures and frits
		Qualified sample or 2-hour composite sample					
Lead	kg/t	0.04	-	-	-	-	-
Cad-mium	mg/l	-	-	0.01	-	-	-
	kg/t	-	0.15	-	-	-	
Chro-mium, total	mg/l	-	-	-	-	-	0.5
	kg/t	0.03	-	-	-	0.02	-

Wastewater resulting from the use of certain hazardous substances is regulated in Annex 48. These apply to wastewater facilities whose pollutant load essentially results from the use of the substances listed in the Annex. Table 2.2.4.6 lists the requirements for wastewater from the production of titanium dioxide pigments before mixing as an example. For the parameter total chromium, a concentration of 0.5 mg/l can also be permitted in the water-legislation approval when using the sulphate process [7].

Table 2.2.4.6: Requirements for the discharge of wastewater from the production of titanium dioxide pigments before mixing (Adapted from [7] and [10])

		Chloride process	Sulphate process
		Qualified sample or 2-hour composite sample	
Lead	kg/t	0.005	0.03
Cadmium	g/t	0.2	2
Chromium, total	kg/t	0.01	0.05

		Chloride process	Sulphate process
		Qualified sample or 2-hour composite sample	
Copper	kg/t	0.01	0.02
Nickel	kg/t	0.005	0.015
Mercury	g/t	0.1	1.5

2.3 Municipal Wastewater

2.3.1 Requirements and monitoring in Germany

In Germany, the discharge requirements for municipal wastewater listed in Table 2.3.1.1, which are graded according to size (SC 1 to SC 5), apply in accordance with Annex 1 of the Wastewater Ordinance (AbwV 2016). It should be noted that in other countries, the definition of the expansion size of wastewater treatment plants via load-specific population equivalents and size classes, which is common in Germany, is usually not used [1].

Table 2.3.1.1: Requirements for municipal wastewater according to the German Wastewater Ordinance (adapted from [1] and Annex 1 of [10])

Size Category	Equivalent to $ELV_{BOD,60}$	COD	BOD_5	NH_4-N*)	N_{inorg}*)	P
	l	mg/l	mg/l	mg/l	mg/l	mg/l
1: < 60 kg/d BOD_5	< 1,000	150	40	-	-	-
2: 60 – 300 kg/d BOD_5	1,000 – 5,000	110	25	-	-	-
3: > 300 – 600 kg/d BOD_5	> 5,000 – 10,000	90	20	10	-	-
4: > 600 – 6.000 kg/d BOD_5	> 10,000 – 100,000	90	20	10	18**)	2
5: > 6.000 kg/d BOD_5	> 100,000	75	15	10	13**)	1

NOTES
*) Requirements for NH_4-N and N_{inorg} apply at wastewater temperatures of ≥ 12°C. Instead of 12°C, a time limit of 1 May to 31 October may also apply.
**) A higher concentration of up to 25 mg/l may be permitted for N_{inorg} (= NH_4-N + NO_3-N + NO_2-N) in the water-law approval if the reduction of the total nitrogen load is ≥ 70%.

Different annexes of the AbwV regulate the requirements for different industries individually. The DWA M 115-2 provides supplementary guideline values for the quality of non-domestic wastewater discharged into public wastewater systems.

In Germany, the effluent values of wastewater treatment plants are determined on the basis of 2-h composite samples or qualified random samples (composite sample consisting of at least 5 random samples taken and mixed in a period of no more than 2 h at intervals of no less than 2 minutes) [1].

For compliance with the requirements, the "4 out of 5 rule" applies in Germany (Section 6 (1) of the Wastewater Ordinance): The purification requirements are deemed to be met if the results of the five most recent state inspections do not exceed the relevant value in four cases, and no result exceeds the value by more than and no result exceeds the value by more than 100% [1].

For direct dischargers, the following applies:

- Sampling
  - Qualified sample: "a composite sample of at least five samples taken and mixed at intervals of not less than two minutes over a period of not more than two hours",
  - 2-h composite sample,
  - Daily, monthly, or annual mean values are not relevant here.

- Governmental monitoring
  - Unannounced sampling,
  - 4 of 5 Rule: 4 of the last 5 results must not exceed the limit value and no value must exceed the limit value by 100%,
  - Separate regulations exist for individual industrial sectors (e.g., kg COD/t product).
- Self-monitoring
  - An operational wastewater register, and operational diary must be kept for all,
  - For specific industrial source areas, an annual report must also be prepared,
  - Parameters, sampling frequency and evaluation of the results are explicitly regulated.

2.3.2 Requirements and monitoring in the European Union

According to the European Urban Wastewater Treatment Directive 91/271/EEC, urban wastewater treatment plants must comply with the requirements in Table 2.3.2.1.

Table 2.3.2.1: Requirements for discharges from urban wastewater systems according to European Directive 91/271/EEC (adapted from [1] and [16])

Parameter	Concentration	Minimum percentage reduction
BOD_5	25 mg/l	70% to 90%
COD	125 mg/l	75%
DM	35 mg/l*) in mountain regions higher than 1,500 m above sea level: 60 mg/l for 2,000 to 10,000 P.E., 35 mg/l for more than 10,000 P.E.	90%*) in mountain regions higher than 1,500 m above sea level: 70% at 2,000 to 10,000 P.E., 90% for more than 10,000 P.E.
NOTE *) The requirement for DM is optional		

Either the concentration value or the percentage reduction related to the load of the influent shall be applied. Discharges to sensitive areas where eutrophication occurs shall additionally comply with the requirements for the parameters in Table 2.3.2.2.

Table 2.3.2.2: Requirements for discharges from urban wastewater systems in sensitive areas according to European Directive 91/271/EEC (adapted from [1] and [16])

Parameter	Concentration	Minimum percentage reduction
N_{total}*) (= KN + NO_2-N + NO_3-N)	15 mg/l for 10,000 to 100,000 P.E., 10 mg/l for more than 100,000 P.E.	70% to 80% as the annual mean value of the samples or 20 mg/l as the daily mean value
P_{total}	2 mg/l for 10,000 to 100,000 P.E., 1 mg/l for more than 100,000 P.E.	80% as the annual mean value of the samples
NOTE *) The requirement for N_{total} applies at wastewater temperatures of ≥ 12°C. Instead of the temperature, a time limit can also be specified that takes regional climatic conditions into account.		

The discharge values are determined in accordance with the European Directive based on 24-hour samples proportional to discharge or time (daily composite samples). For the monitoring of discharges the competent authorities or bodies take a specified minimum number of annual samples, which is staggered according to the size of the installation as follows:

- 2,000 - 9,999 E: 12 samples in the 1st year, 4 samples in the following years, if the wastewater complies with the regulations in the 1st year; if one of the 4 samples exceeds the limit value, 12 samples must be taken in the following year,
- 10,000 - 49,999 E: 12 samples,
- ≥ 50,000 E: 24 samples [1].

According to the Directive, the purification requirements are deemed to be met if:

a) for the parameters listed in Table 2.3.2.2, no more than the permitted number of samples specified in Table 2.3.2.3 does not fail to comply with the set requirements,
b) for the parameters mentioned in Table 2.3.2.1 and expressed in concentration values, the deviations do not exceed 100% under normal operating conditions (suspended matter: 150%),
c) for the parameters referred to in Table 2.3.2.2, the annual mean value of the samples does not exceed the relevant value [1].

Table 2.3.2.3: Permissible number of samples with deviations according to European Directive 91/271/EEC (adapted from [1] and [16])

Number of samples taken within one year	Maximum number of samples for which deviations are allowed
4 – 7	1
8 – 16	2
17 – 28	3
29 – 40	4
41 – 53	5
54 – 67	6
… …	… …

2.4 Industrial Wastewater

2.4.1 Requirements for direct dischargers - example dairy industry

Annex 3 of the AbwV applies to wastewater, the pollutant load of which originates mainly from the delivery, transferring or processing of milk and dairy products and which occurs in dairy factories, dairies, cheese factories and other operations of this type. It does not apply to wastewater from milk processing plants with a pollutant load in the raw wastewater of less than 3 kg BOD_5 per day, from indirect cooling systems and from process water treatment [10].

The following requirements are placed on the wastewater for the discharge point into the water body:

Table 2.4.1.1: Requirements for direct discharge for the dairy industry (adapted from [10])

Parameter	Qualified random sample or 2-hour mixed sample (mg/l)
Biochemical oxygen demand in 5 days (BOD_5)	25th
COD	110
Ammonium nitrogen (NH_4-N)	10
Nitrogen, as the sum of ammonium, nitrite, and nitrate nitrogen (N_{total})	18th
Total phosphorus	2

The requirements for ammonium nitrogen and nitrogen, total, apply to a wastewater temperature of 12°C and higher in the outflow of the biological reactor of the wastewater treatment plant and provided that the total raw nitrogen load on which the water law approval is based, is more than 100 kg per day. In the approval under water law, a higher concentration of up to 25 mg/l can be approved for total nitrogen if the reduction in the total nitrogen load is at least 70%. The reduction relates to the ratio of the nitrogen load in the inlet to that in the outlet in a representative period of time which should not exceed 24 hours. The total bound nitrogen (TN_b) is to be used as a basis for the loads [10].

The requirement for total phosphorus applies if the total raw phosphorus load on which the water law approval is based is more than 20 kg per day [10].

If a sample is clearly coloured by algae in pond systems that are designed for a residence time of 24 hours and more and for which the daily wastewater volume on which the water law approval is based does not exceed 500 m^3, the COD and the BOD_5 are to be determined from the algae-free sample. In this case, the values specified in paragraph 1 of the AbwV for COD are reduced by 15 mg/l and for BOD_5 by 5 mg/l [10].

No additional requirements are placed on the wastewater before it is mixed with other wastewater, i.e., indirectly discharged [10].

3 Wastewater treatment methods

3.1 Municipal Wastewater

In municipal wastewater treatment plants, carbon and nitrogen elimination is essentially carried out by the biological treatment stage. Different treatment objectives can be achieved with the relevant treatment processes, like activated sludge tanks, trickling filter, anaerobic and wastewater pond systems.

Table 2.4.1.1: Fulfilment of purification targets through selected wastewater treatment processes (adapted from [1])

Process	C Elimination	N Elimination	
		Nitrification	Denitrification
Activated Sludge	X	X	X
Trickling Filter	X	X	(X)
Anaerobic processes (e.g., UASB)	(X)		
Wastewater Pond Systems	X	(X)	

In addition to the required purification goals, the choice of process technology for wastewater treatment plants and their design in industrialised countries is mainly based on the criteria of operational safety, low personnel deployment, compact size, etc., and thus inevitably leads to technologically high-quality plants with extensive use of automation and remote-control technology [1].

If the biological stage must meet purification requirements that cannot be fulfilled by a single process, a combination of processes becomes necessary. In the case of foreseeable increasing requirements for the degree of purification, this must be taken into account in advance, e.g., in the case of a plant initially designed for C elimination only, which is to be expanded for N elimination with increasing requirements. A corresponding conceptual and planning consideration of this approach is then already mandatory for the first expansion stage. The dimensioning of the individual stages of a process chain requires the calculation of the effluent values of the previous stages as input values for the subsequent process [1].

3.2 Industrial wastewater

Water is characterized by a variety of remarkable chemical and physical properties which industries use in different production processes. Industrial wastewater is correspondingly contaminated with several different pollutants.

To eliminate these contaminants from industrial wastewater, process combinations must almost always be used. Chemical-physical methods occupy a special position as soon as biologically inaccessible substances are used in the process and enter the wastewater.

3.2.1 Chemical-physical and thermal processes

Table 3.2.1.1 provides an overview of various treatment processes for inorganically contaminated wastewater and their intended applications. The individual processes, their advantages and disadvantages are outlined below.

Table 3.2.1.1: Overview of suitable processes for the removal of wastewater constituents (adapted from [7])

Process \ Contamination	Solids	Heavy metals	Sulphates, Phosphates	CN, Cr6+, NOx, As	Ions	Gases	Dyes	Oils / Fats	Refractory Organics	AOX
Ion exchange (Chemical)		Suitable	Limited	Limited	Suitable				Limited	
Oxidation (e.g., AOP) (Chemical)				Limited			Suitable	Side-effect	Suitable	Limited
Detoxification (Chemical)				Suitable						
Precipitation, floccu-lation (Chemical)	Suitable	Suitable	Suitable		Limited		Side-effect	Limited	Side-effect	Side-effect
Electrolysis (Chemical)		Suitable	Limited		Suitable					
Adsorption (acti-vated carbon) (Physical)							Side-effect	Side-effect	Suitable	Suitable
Sedimentation (Physical)	Suitable	Side-effect	Side-effect					Limited		
Flotation (Physical)	Suitable	Limited				Limited		Suitable		
Centrifugal separa-tion (hydrocyclone) (Physical)	Suitable	Limited						Suitable		
Depth filtration (Physical)	Suitable	Limited					Side-effect	Side-effect		
Microfiltration (Physical)	Suitable							Side-effect		
Ultrafiltration (Physical)	Suitable						Suitable	Suitable	Side-effect	Side-effect
Nanofiltration (Physical)	Limited	Limited	Suitable	Suitable	Limited	Limited	Suitable		Limited	Limited
Reverse osmosis (Physical)	Side-effect	Suitable	Suitable	Suitable	Suitable	Limited			Suitable	Suitable
Electrodialysis (Physical)	Side-effect	Suitable	Suitable		Suitable					
Extraction (Physical)	Side-effect						Suitable	Suitable		
Distillation / Rectifi-cation (Thermal)	Side-effect	Side-effect	Side-effect		Side-effect		Suitable	Suitable	Side-effect	Side-effect
Thermolysis / Hy-drolysis (Thermal)	Side-effect						Limited	Limited	Suitable	Suitable
Evaporation (Thermal)	Side-effect	Suitable	Suitable		Suitable		Side-effect		Side-effect	Side-effect
Stripping (Thermal)						Suitable				

Contamination: Solids; Inorganic; Organic
Type of process: Chemical; Physical; Thermal
Applicability: Suitable; Limited suitability; Possible side-effect; Unsuitable

Precipitation, flocculation

The oft combined processes of precipitation and flocculation are widely used in industrial wastewater treatment and are predominantly used to remove (heavy) metals and fine suspended substances [7].

Precipitation is used to convert the ions dissolved in the water into an insoluble form. Anions are selectively added to the positively charged metal ions to produce salts with the lowest possible solubility product. Hydrolytic precipitation is carried out in alkaline conditions using lime or caustic soda [7].

Since the sinking velocity increases or decreases exponentially with the radius, the precipitates must be aggregated into flocs to effectively separate them from the water in most cases [7].

Ion exchange

In industrial wastewater treatment, ion exchange can be used to remove ionic compounds from the wastewater like inorganic metal catalysts or as a second step of heavy metal removal after precipitation. The removal of the salts of organic acids is also possible by adjustment of the corresponding pH value. The choice of regenerant as well as the process control (counter- or co-current, fixed or floating bed, single or multistage) are further parameters of the ion exchange process. If no recovery of the respective separated substance takes place, the ion exchange process is merely a separation process with which the wastewater is concentrated, as in the membrane processes [7].

The decisive factor for the ion exchange process is thus not only the practically usable capacity, but also the efficiency of the regeneration in terms of the quantity and type of regenerant used [7].

Detoxification of toxic inorganic compounds

Some inorganic ions are highly toxic in certain valencies or cannot be precipitated or can only be precipitated with difficulty, which is why they must be reduced or oxidized with suitable reducing or oxidizing agents [7].

Oxidation of organic compounds

Oxidation processes are an essential part of wastewater pre-treatment in industry to reduce the toxicity of wastewater or to increase its biodegradability. Practically relevant oxidants are oxygen (requiring higher temperature and/or catalysis), hydrogen peroxide (also catalytic/activated) and ozone, possibly combined as so-called AOP (advanced oxidation processes), as well as electric current. For all of them, the effectiveness depends crucially on the structure of the organic substances. Aromatic compounds are generally easy to oxidize, while low-molecular-weight acids and alcohols are difficult to oxidize. In the case of aromatic compounds, the substituent also influences oxidizability [7].

Electrolysis

The driving force in electrolysis is the applied electric field. The advantage is the avoidance of a salination. The disadvantages are the high energy demand and the sensitivity to interfering substances, especially solids. By means of electrolysis, mainly dissolved metal cations are separated from highly concentrated solutions at the cathode and thus recovered. Due to the high process requirements and their costs, this process is mainly used for the recovery of non-ferrous and precious metals from highly concentrated solutions [7].

Flotation

In the case of impurities that sediment poorly or not at all, that form gas bubbles or even float, it is advisable to separate the substances by means of flotation. In this process, fine gas bubbles are introduced into the wastewater, which attach themselves to the impurities and reduce their density to such an extent that they collect on the surface and can be skimmed off there [7].

Centrifugal separation with a hydrocyclone

Hydrocyclones are static separators for solids and free oil droplets. The driving force is the density difference to water. A rotating flow is generated by the tangential introduction of the inlet, causing the heavy fraction to be thrown against the cyclone wall due to centrifugal acceleration and to leave the tapering outlet hopper as underflow, while the lighter fraction exits the system at the cyclone head as overflow. Solids with a diameter of 5 µm to 0.5 mm can be separated particularly energy-efficiently by means of hydrocyclones [7].

Adsorption with activated carbon

Activated carbon treatment is one of the most widely used wastewater (pre)treatment processes for the removal of organic compounds, especially those with aromatic structure. In this process, the removal is based on adsorption on activated carbon, which is characterized by a very high internal surface area (often up to 1,000 m^2/g) distributed in a widely branched pore structure of different diameters [7].

For simple wastewater treatment in industry, the type of activated carbon is often less decisive; here, economic optimization occupies a decisive place. For special substances or when using activated carbon in circuits, the type of carbon can determine the feasibility. Not only the adsorption, but also the elution of possible interfering substances like iron from the activated carbon is relevant. In particular, the adsorption can also be influenced by the pH value [7].

Depth filtration

To separate solids which cannot be separated economically by sedimentation or flotation due to their small diameter or difference in density from the water, spatial filters are often used. The wastewater flows through a packing - usually sand or gravel placed on a support layer - in the filtration apparatus. The solids penetrate deep into the filter bed and are removed from the water flow by adhesion [7].

In this process, the flow channels slowly become smaller, but do not disappear. The pressure-drop increases. Since the effective filter area can be very large due to the inner surface, spatial filters can hold large quantities of solids. In order to realize effective depth filtration, the selection of the appropriate particle size is particularly important [7].

Sedimentation

Sedimentation is by far the most cost-effective method of separating solids from wastewater. Therefore, in wastewater treatment, considerable efforts are made to convert contaminants into solids and then remove them from the water using gravity. Many different designs exist, adapted to the separation task and space conditions. The prerequisite is a sufficiently high density and size of the solids [7].

Membrane filtration

The sufficiently well-known membrane filtration processes refer to physical, pressure-driven processes that exploit the selectivity of a thin, fine-pored, or semi-permeable membrane to divide the feed stream into a concentrate enriched with retained components and a permeate or filtrate depleted of these components. During the passage through the membrane, the components are not changed [7].

Membrane processes are mostly used in combination with other process stages. Above all, processes for solids separation are regularly found as a pre-treatment to prevent the membranes from becoming clogged [7].

Microfiltration and ultrafiltration

These two processes, characterized by the use of pore membranes, are used to separate solids, colloids or organic macromolecules. They differ only in the pore size of the membranes. Typically, microfiltration membranes have pores > 0.1 µm while ultrafiltration membranes have smaller ones or separation limits between 1,000 and 100,000 Dalton [7].

Nanofiltration

Nanofiltration is used to separate dissolved molecules with a molar mass > 200 g/mol and divalent or higher ions and to separate them as a concentrate while the water permeates through the closed membrane together with monovalent ions. For this reason, nanofiltration requires a lower pressure than reverse osmosis and is therefore preferably used when the valuable substances remain in the concentrate [7].

Reverse osmosis

Reverse osmosis retains almost all water content, undissolved and dissolved. Only the water passes through the membrane. The permeate is therefore characterized by high purity, which is why reverse osmosis is recommended when water is to be recovered from wastewater streams that are largely free of solids. Here, reverse osmosis is the standard process, usually at the end of a process chain that often includes a biological stage and micro- or ultrafiltration [7].

Extraction

In extraction, a substance or mixture of substances is removed from the water by its higher solubility in an extraction agent. In this process, the distribution coefficient of some substances can be influenced by a suitable pH value (e.g., in the case of phenols and amines) or by a chemical reaction (reactive extraction). The separation of the substance from the extractant is carried out by phase separation and distillation [7].

Electrodialysis

In electrodialysis, the ions are separated from each other according to their charge by cation or anion exchange membranes by means of an electric field. The membranes are thus penetrated by the charged particles and not by the water. The design here is based on stacks of anion and cation exchange membranes, with the crude solution introduced into each interstitial space between the membranes. The cation exchange membranes allow the cations to pass through and retain the anions. Accordingly, anions can pass through the anion exchange membranes, but not the cations. This results in an alternating flow of salt-enriched concentrate and desalinated water [7].

Thermolysis/Hydrolysis

Various organic compounds decompose at higher temperatures and suitable pH values (mostly alkaline) and can thus lose their toxicity or gain biodegradability. Typical operating conditions are residence times of one to three hours and temperatures of 150-320°C, with corresponding pressures of 5 to 120 bar. The temperature is maintained by heat recuperation, inlet/outlet and compensation of the temperature difference by means of steam (indirect or direct steam injection) or thermal oil as well as outlet cooling [7].

Distillation/Rectification

This thermal separation process is often used to separate solvents and water. An attempt should be made to run the process in such a way that enables the reuse of the separated light boiling agent [7].

Stripping

Substances with favourable gas/water distribution coefficients can be removed from water using a stripping gas, which is often air or steam. In the case of air stripping, the waste gas stream must then be treated, and the residual substance usually disposed of. In steam stripping, on the other hand, which can also be regarded as a simplified distillation process, it is often possible to recover the condensate. Stripping is used particularly for chlorinated low-molecular solvents such as dichloromethane, tetrachloromethane, dichloroethane or perchloroethene [7].

Evaporation

In cases where reverse osmosis is no longer suitable due to excessive salt concentration or cannot be used due to highly acidic or alkaline pH values, evaporation is used for further concentration. In this process, the water is usually evaporated at negative pressure on heat exchanger surfaces and recovered as condensate on the other side of the heat exchanger. Multi-stage operation and corresponding heat recuperation reduce the specific energy requirement. Alternatively, mechanical vapor recompression can be used for this purpose [7].

3.2.2 Biological processes

Organically polluted industrial wastewater is usually treated biologically, where depending on concentration, temperature, and requirements, both anaerobic and aerobic processes and combinations of both processes are used - also in combination with chemical-physical treatment [7].

The main advantage of anaerobic processes is that no aeration is required, significantly less excess sludge is produced, and biogas can be produced from the carbon content of the wastewater. In this respect, instead of consuming energy for aeration of an aerobic biology, anaerobic treatment produces energy-rich biogas. The main disadvantage of the anaerobic processes is that, as a rule, no purification to direct discharge quality can take place and the nitrogen in the effluent remains as ammonium nitrogen. In the following, different aerobic and anaerobic processes will be presented [7].

Aerobic biological processes

Aerobic activated sludge process

The term activated sludge process refers to biological wastewater treatment using suspended microorganisms (activated sludge), which are capable of forming flocs, settling, and can be enriched in the system by recirculation. The continuously operated activated sludge process consists of the aeration tank, the secondary sedimentation tank, the sludge recirculation, and the excess sludge removal. If nitrogen is also to be eliminated in the plant, a denitrification zone or time is required and, in the case of upstream denitrification, an internal return flow is required [7].

Sequencing Batch Reactor (SBR)

The SBR process is a discontinuously operated process that uses suspended activated sludge. In this process, one or more basins are filled, aerated, agitated, sedimented and decanted in cycles. A separate secondary clarifier and a return sludge line are not required. This system can have advantages in terms of investment and operation especially for small industrial plants [7].

Membrane Bioreactor Process

Membrane bioreactors (MBRs) have been in use since the 1990s in various areas of municipal and industrial wastewater treatment. However, a distinction must be made between submerged and dry installed modules [7].

The membranes are often installed as micro- or ultrafiltration membranes in plate or hollow fibre modules. The materials used today are mainly synthetic polymer membranes such as polysulfone (PSU), polyethersulfone (PES), polyamide (PA), polypropylene (PP), polyvinylidene fluoride (PVDF) and polyacrylonitrile (PAN), as well as inorganic membranes [7].

Membrane processes are linked to permanently good filtration performance due to the hydraulically sensitive situation of peak load design. This can be disturbed by fouling and scaling processes. Fouling is the accumulation of organic substances from the activated sludge on the membrane. This then leads to a long-term decrease in the permeability of the membrane. The substances causing fouling can accumulate on or in the membrane pores and can lead to complete or partial blocking of the pores, or they can accumulate on the membrane's surface and form a gel layer (biofilm) there. The problem of fouling is mitigated by controlling membrane operation [7].

Biofilm

Biofilm processes are used in both aerobic and anaerobic industrial wastewater treatment. Depending on the process, the materials used to support the biofilm are plastics (PVC, PE), gravel, sintered glass, anthracite, shale, coke, basalt, and quartz sand with grain sizes of 0.5-4 mm (exception: trickling filters up to 80 mm). The specific surface areas are approx. 70 to 200 m^2/m^3 for fixed beds and up to 6,000 m^2 for fluidized beds (exception: sintered glass up to 30,000 m^2/m^3) [7].

Nitrogen elimination by nitritation/denitritation or deammonification

In the nitrogen elimination processes, wastewaters or partial streams with high nitrogen contents and low carbon contents (poor C/N ratios) are of particular interest. An alternative to the classical nitrification/denitrification is offered by nitritation/denitritation, which does not completely oxidize the nitrogen to nitrate, but only oxidizes it to nitrite and reduces it again [7]. Also processes of Deammonification (partial Nitritation and Anammox) are available.

Aerobic granular

For aerobic treatment, the process is one of the newer processes. The advantage of using aerobic granular is on the one hand the increase of the biomass density and consequently a reduction of the required volume compared to the activated sludge process. The biomass can settle very well, enabling retention to take place in the reaction tank such that no separate secondary sedimentation is required [7].

Anaerobic biological processes

Because of the clear advantages in energy balance and sludge production, anaerobic processes are used today for many organically polluted industrial wastewaters. Anaerobic reactors have been used to treat organically polluted wastewater in Germany since the early 1980s. The application of anaerobic wastewater treatment processes was initially limited to wastewater with a COD between 1,500 and 40,000 mg/l from the food and beverage industry (sugar, starch, yeast, fruit and vegetable factories, breweries, distilleries, dairies, cereal processing) as well as wastewater from the paper and pulp industry or from rendering plants. Since then, anaerobic processes are also increasingly used in other branches of industry - e.g., the chemical and pharmaceutical industries as well as for inorganic wastewater [7].

The essential criterion for the classification of anaerobic process technology is the type of biomass enrichment. If the biomass is enriched in the form of flocs, biomass concentrations of 5-12 kg oDM/m^3 volume can be achieved in the reactor. If the biomass is enriched on carrier material, biomass concentrations of up to 20 kg oDM/m^3 can be achieved. The highest biomass concentration of 50-80 kg oDM/m^3 can be achieved in the sludge bed of reactors with granular sludge [7].

In addition to the above-mentioned reactors, there are modified systems and hybrid reactors. Here, UASB and EGSB reactors are the most frequently used reactor types. They account for more than 50% of the processes used in industrial wastewater treatment in Germany [7].

Areas of application

The anaerobic activated sludge process can be used in almost all industrial sectors, although only very low space loads of 2-6 kg COD/(m^3*d) are achieved in relation to the other reactor types. Due to its insensitivity to solids and its general robustness, the anaerobic activated sludge process is the most frequently used reactor type in German sugar factories (high calcium contents) [7].

Fixed-bed reactors are used in many industrial sectors and in wide load ranges. UASB and EGSB reactors, together with fluidised bed reactors, have the highest space loads. The anaerobic membrane process is far less established than the aerobic one [7].

One and two-stage processes

Methanogens, in combination with acetogenic bacteria, can essentially only use organic acids (formic acid and acetic acid) as well as CO_2, H_2 and methanol as substrates. Recent studies by have shown the so-called third pathway, whereby methane is produced from the betaines of sugar beet via trimethylamine by methylotrophic anaerobic bacteria. In most cases, the hydrolysis and acidification of the wastewater constituents is the essential prerequisite for good performance of anaerobic treatment. This applies regardless of whether the hydrolysis and acidification are spatially separated from the methane stage (2-stage process) or whether there is only one reactor (1-stage process) [7].

Biogas composition and properties

The biogas produced by the decomposition of organically highly polluted wastewater is a mixture of the main components methane (CH_4), carbon dioxide (CO_2) and minute amounts of nitrogen (N_2), oxygen (O_2), hydrogen sulphide (H_2S) and traces of other substances. In principle, the biogas composition depends on the composition of the degraded substrate - in particular the ratio of fat, carbohydrates and protein. The theoretical methane yield per kg of degraded COD is approx. 0.32 m^3/kg after deduction of the COD incorporated in biomass yield; the total biogas quantity per kg of degraded COD is then calculated from the methane content in the biogas. Empirical values of the specific biogas yield of various industries are summarised in Table 3.2.1.1 [7].

Table 3.2.2.1: Operating results of industrial biogas plants (adapted from [7])

Wastewater origin (industry)	Specific pollutant load	COD reduction	Gas yield	CH_4 concentration in gas
	kg COD/Mg Prod.	%	m^3 CH_4/kg COD_{in}	Vol.-%
Sugar industry	6 – 8	70 – 90	0.24 – 0.32	65 – 85
Starch industry				
Potato starch	30 – 40	75 – 85	0.26 – 0.30	75 – 85
Molasses processing industry (incl. molasses distilleries)	180 – 250	60 – 75	0.21 – 0.26	60 – 70
Wheat starch	100 – 120	80 – 95	0.28 – 0.33	55 – 65
Maize starch	8 – 17	80 – 90	0.28 – 0.32	65 – 75

Wastewater origin (industry)	Specific pollutant load	COD reduction	Gas yield	CH_4 concentration in gas
	kg COD/Mg Prod.	%	m^3 CH_4/kg COD_{in}	Vol.-%
Pectin extraction	–	75 – 80	0.26 – 0.28	50 – 60
Potato distilleries	50 – 70	55 – 65	0.19 – 0.23	65 – 70
Potato processing	15 – 25	70 – 90	0.24 – 0.32	70 – 80
Corn distilleries	180 – 200	55 – 65	0.19 – 0.23	65 – 70

Special attention must be paid to the hydrogen sulphide content during recycling; this depends on the COD/SO_4 ratio and can lead to problems occurring during anaerobic treatment. In any case, it must be checked whether desulphurisation of the biogas is necessary prior to utilisation [7].

3.2.3 Water Cycle Management (Re-use/Recycling)

In Germany, industry uses the majority of fresh water. Almost 19 billion cubic metres of fresh water are used annually, of which more than 91% is still subject to single use. Cooling plants accounted for almost 89% of the total water used, while 8-9% was used for production tasks and about 2% for irrigation and workforce purposes. With a share of over 62%, energy supply has the highest water demand, while manufacturing accounted for almost 28%. Large individual consumers in Germany are, for example, the chemical industry, steel production and the manufacture of paper and cardboard [7].

Due to the high demand for water and the increasing scarcity of natural water resources, concepts for water cycle management in industrial production are being developed and implemented worldwide. The actual availability of water and its quality varies greatly from place to place. Although there is sufficient supply security throughout the country, there are also water stress areas with limited groundwater resources or saltwater intrusion in Germany. Therefore, a water cycle management can be motivated differently:

- securing sites with limited water resources or abstraction rights,
- obtaining permits for plant expansions or new plant construction subject to water conservation requirements,
- commitment to sustainability goals based on the UN Sustainable Development goals,
- prevention or reduction of costs for freshwater procurement, treatment, and wastewater treatment,
- resource protection and recovery of products from watery effluents from production plants [7].

Water uses can be established integrated into production, within a company, between different production companies or even between different sectors of the water infrastructure (industrial, municipal, agricultural) [7].

In inter-company or cross-sectoral cycles, organisational and legal aspects between legally independent units are essential for the success of water saving measures, in addition to appropriate treatment technologies [7].

Water reuse and recycling

In the case of multiple water use, a distinction is made between recycle and reuse, which can take place directly or with intermediate treatment [7].

The recycling of water that has already been used is based on the renewed use of the water in the same process or for the same purpose. Reuse, on the other hand, pursues the goal of being able to use the water again for a different purpose or in a different production step [7].

The possible applications in industrial closed-loop or multiple use are wide-ranging:

- cooling systems with open or closed circuit,
- cleaning water,
- sealing water,
- boiler feed water,
- process water (up to ultrapure or Demin water),
- infrastructure applications, like firefighting, street cleaning, grey water use and irrigation [7].

The requirements and application areas of industrial water use depend on the industry, the specific industrial processes as well as their efficiency targets. For this reason, it is not possible to generalise the quality requirements for recycled water used as process water. A case-specific consideration of potential consumers and required water qualities is often based on a water audit or a risk assessment programme for water reuse, which is complemented by practical trials [7].

In process-integrated rinsing processes, for example, the widespread establishment of rinsing cascades means that no intermediate treatment steps are necessary. In production-related cooling circuits, multiple recirculation is generally carried out with dosing of different auxiliary agents, such as stabilisers and biocides. When process-integrated and production-related measures have been exhausted, the multi-stage, additive purification of industrial wastewater can enable both further use and reuse. For this purpose, depending on the intended use, graduated technology chains are also used to produce water "fit-for-purpose". For such use scenarios, the additional water infrastructure must also be adapted to enable the targeted distribution of the produced water qualities to the consumers. The costs associated with this are not negligible [7].

Zero Liquid Discharge (ZLD)

In some industrial sectors and in countries with limited water availability, regulatory requirements regulatory requirements in particular lead to the implementation of measures for further cycle closure and wastewater-free production (Zero Liquid Discharge - ZLD, e.g., in dry painting, textile or paper industry). ZLD concepts also avoid the risk of environmental pollution through wastewater discharges and maximise the efficiency of industrial efficiency of industrial water use, thereby achieving a balance between the use of freshwater resources and the preservation of the aquatic environment. With competition for use from other water consumers (agriculture, municipalities), low municipal wastewater infrastructure and treatment capacity, high demands on the quality of treated wastewater or the lack of receiving waters, ZLD or MLD (Minimum Liquid Discharge) can be necessary options for further economic development for further economic development. As a rule, however, this entails energy consumption and technically demanding processes with high treatment costs, which have to be evaluated economically [7].

The main areas of use for ZLD applications are in China, India and the USA. In India, ZLD plants are required in the textile industry with a daily wastewater volume flow Q_d>25 m^3. Standard applications consist of pre-treatment, biological treatment, reverse osmosis and multi-stage evaporation. For coal chemistry/refining in China, ZLD plants have already been installed or are in the planning and construction phase. These applications cover a wide range of salt concentrations in the feed 2,000-16,000 mg/l with simultaneous high-volume flows of 110-2,300 m^3/h. Concepts have also been developed for other regions with water stress concepts have been implemented, e.g., in the production of solar cells or the fertiliser implemented [7].

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