3

Wastewater Characterization

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3.1 THE ORIGIN OF WASTEWATER

The production of waste from human activities is unavoidable. A significant part of this waste will end up as wastewater. The quantity and quality of wastewater is determined by many factors. Not all humans or industries produce the same amount of waste. The amount and type of waste produced in households is influenced by the behaviour, lifestyle and standard of living of the inhabitants as well as the technical and juridical framework by which people are surrounded. In households most waste will end up as solid and liquid waste, and there are significant possibilities for changing the amounts and composition of the two waste streams generated. For industry similar considerations apply.

The design of the sewer system affects the wastewater composition significantly. In most developing countries separate sewer systems are used. In these the storm water is transported in trenches, canals or pipes. Old urban areas might have combined sewer systems where different types of wastewater are mixed (Table 3.1). In combined systems a part (small or big) of the total wastewater is discharged to local water bodies, often without any treatment.

3.2 WASTEWATER CONSTITUENTS

The constituents in wastewater can be divided into main categories according to Table 3.2. The contribution of constituents can vary strongly.

Table 3.1 Wastewater types

Wastewater from society	Wastewater generated internally in treatment plants
Domestic wastewater	Thickener supernatant
Wastewater from institutions	Digester supernatant
Industrial wastewater	Reject water from sludge dewatering
Infiltration into sewers	Drainage water from sludge drying beds
Stormwater	Filter wash water
Leachate	Equipment cleaning water
Septic tank wastewater	

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Table 3.2 Constituents present in domestic wastewater (based on Henze *et al.*, 2001)

Wastewater constituents		
Microorganisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish
Biodegradable organic materials	Oxygen depletion in rivers, lakes and fjords	Fish death, odours
Other organic materials	Detergents, pesticides, fat, oil and grease, colouring, solvents, phenols, cyanide	Toxic effect, aesthetic inconveniences, bio accumulation in the food chain
Nutrients	Nitrogen, phosphorus, ammonium	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect, bioaccumulation
Other inorganic materials	Acids, for example hydrogen sulphide, bases	Corrosion, toxic effect
Thermal effects	Hot water	Changing living conditions for flora and fauna
Odour (and taste)	Hydrogen sulphide	Aesthetic inconveniences, toxic effect
Radioactivity		Toxic effect, accumulation

3.3 BOD AND COD

Organic matter is the major pollutant in wastewater. Traditionally organic matter has been measured as BOD and COD. The COD analysis is ‘quick and dirty’ (if mercury is used). BOD is slow and cumbersome due to the need for dilution series.

The COD analysis measures through chemical oxidation by dichromate the majority of the organic matter present in the sample. COD measurements are needed for mass balances in wastewater treatment. The COD content can be subdivided in fractions useful for consideration in relation to the design of treatment processes. Suspended and soluble COD measurement is very useful. Beware of the false COD measurement with permanganate, since this method only measures part of the organic matter, and should only be used in relation to planning of the BOD analysis.

The theoretical COD of a given substance can be calculated from an oxidation equation. For example, theoretical COD of ethanol is calculated based on the following equation:

$$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O \tag{3.1}$$

or, 46 g of ethanol requires 96 g of oxygen for full oxidation to carbon dioxide and water. The theoretical COD of ethanol is thus 96/46 = 2.09.

The BOD analysis measures the oxygen used for oxidation of part of the organic matter. BOD analysis has its origin in effluent control, and this is what it is most useful for. The standard BOD analysis takes 5 days (BOD_5), but alternatives are sometime used, BOD_1, if speed is needed and BOD_7 if convenience is the main option, as in Sweden and Norway. If measurement of (almost) all biodegradable material is required, BOD_{25} is used. It is possible to estimate the BOD values from the single measured value (Table 3.3).

Table 3.3 Relationship between BOD and COD values in urban wastewater

BOD_1	BOD_5	BOD_7	BOD_{25}	COD
40	100	115	150	210
200	500	575	750	1,100

In this chapter, the term BOD refers to the standard carbonaceous BOD_5 analysis.

Figure 3.1 shows the dependency of time and temperature for the BOD analysis. It is important that the BOD test is carried out at standard conditions.

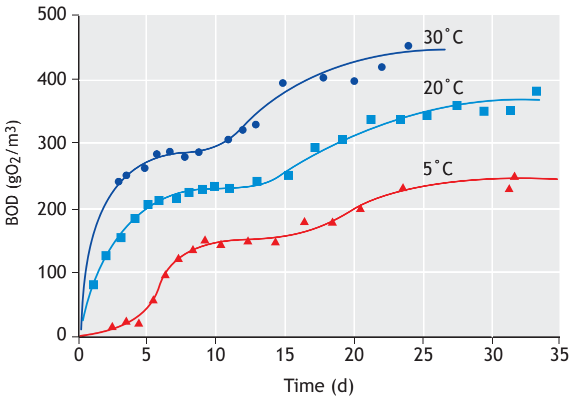


Figure 3.1 The BOD analysis result depends on both test length and temperature. Standard is 20°C and 5 days.

3.4 PERSON EQUIVALENTS AND PERSON LOAD

The wastewater from inhabitants is often expressed in the unit Population Equivalent (PE). PE can be expressed in water volume or BOD. The two definitions used worldwide are:

$$1\ \text{PE} = 0.2\ \text{m}^3/\text{d}$$
$$1\ \text{PE} = 60\ \text{g BOD/d}$$

These two definitions are based on fixed non-changeable values. The actual contribution from a person living in a sewer catchment, so-called the Person Load (PL), can vary considerably (Table 3.4). The reasons for the variation can be working place outside the catchment, socio-economic factors, lifestyle, type of household installation etc.

Table 3.4 Variations in person load (Henze *et al.*, 2001)

Parameter	Unit	Range
COD	g/cap.d	25-200
BOD	g/cap.d	15-80
Nitrogen	g/cap.d	2-15
Phosphorus	g/cap.d	1-3
Wastewater	m^3/cap.d	0.05-0.40

Person Equivalent and Person Load are often mixed or misunderstood, so one should be careful when using them and be sure of defining clearly what they are based upon. PE and PL are both based on average contributions, and used to give an impression of the loading of wastewater treatment processes. They should not be calculated from data based on short time intervals (hours or days). The Person Load varies from country to country, as demonstrated by the yearly values given in Table 3.5.

3.5 IMPORTANT COMPONENTS

The concentrations found in wastewater are a combination of pollutant load and the amount of water with which the pollutant is mixed. The daily or yearly polluting load may thus form a good basis for an evaluation of the composition of wastewater. The composition of municipal wastewater varies significantly from one location to another. On a given location the composition will vary with time. This is partly due to variations in the discharged amounts of substances. However, the main reasons are variations in water consumption in households and infiltration and exfiltration during transport in the sewage system.

The composition of typical domestic/municipal wastewater is shown in Table 3.6 where concentrated wastewater (high) represents cases with low water consumption and/or infiltration. Diluted wastewater (low) represents high water consumption and/or infiltration. Stormwater will further dilute the wastewater as most stormwater components have lower concentrations compared to very diluted wastewater.

Table 3.6 Typical composition of raw municipal wastewater with minor contributions of industrial wastewater

Parameter	High	Medium	Low
COD total	1,200	750	500
COD soluble	480	300	200
COD suspended	720	450	300
BOD	560	350	230
VFA (as acetate)	80	30	10
N total	100	60	30
Ammonia-N	75	45	20
P total	25	15	6
Ortho-P	15	10	4
TSS	600	400	250
VSS	480	320	200

The fractionation of nitrogen and phosphorus in wastewater has influence on the treatment options for the wastewater. Since most of the nutrients are normally soluble, they cannot be removed by settling, filtration, flotation or other means of solid-liquid separation. Table 3.7 gives typical levels for these components.

In general, the distribution between soluble and suspended matter is important in relation to the characterization of wastewater (Table 3.8).

Table 3.5. Person load in various countries in kg/cap.yr (based on Henze *et al.*, 2002)

Parameter	Brazil	Egypt	India	Turkey	US	Denmark	Germany
BOD	20-25	10-15	10-15	10-15	30-35	20-25	20-25
TSS	20-25	15-25		15-25	30-35	30-35	30-35
N total	3-5	3-5		3-5	5-7	5-7	4-6
P total	0.5-1	0.4-0.6		0.4-06	0.8-1.2	0.8-1.2	0.7-1

Table 3.7 Typical content of nutrients in raw municipal wastewater with minor contributions of industrial wastewater (in g/m^3)

Parameter	High	Medium	Low
N total	100	60	30
Ammonia N	75	45	20
Nitrate + Nitrite N	0.5	0.2	0.1
Organic N	25	10	15
Total Kjeldahl N	100	60	30
P total	25	15	6
Ortho-P	15	10	4
Organic P	10	5	2

Table 3.8 Distribution of soluble and suspended material for medium concentrated municipal wastewater (in g/m^3)

Parameter	Soluble	Suspended	Total
COD	300	450	750
BOD	140	210	350
N total	50	10	60
P total	11	4	15

Since most wastewater treatment processes are based on biological degradation and conversion of the substances, the degradability of the components is important (Table 3.9).

Table 3.9. Degradability of medium concentrated municipal wastewater (in g/m^3)

Parameter	Biodegradable	Inert	Total
COD total	570	180	750
COD soluble	270	30	300
COD particulate	300	150	450
BOD	350	0	350
N total	43	2	45
Organic N	13	2	15
P total	14.7	0.3	15

3.6 SPECIAL COMPONENTS

Most components in wastewater are not the direct target for treatment, but they contribute to the toxicity of the wastewater, either in relation to the biological processes in the treatment plant or to the receiving waters. The substances which are found in the effluent might end up in a drinking water supply system in which case it is dependent on surface water extraction. The metals in wastewater can influence the possibilities for reuse of the wastewater treatment sludge to farmland. Typical values for metals in municipal wastewater are given in Table 3.10.

Table 3.10 Typical content of metals in municipal wastewater with minor contributions of industrial wastewater (in mg/m^3) (Henze 1982, 1992, Ødegaard 1992, from Henze *et al.*, 2001)

Metal	High	Medium	Low
Aluminium	1,000	600	350
Cadmium	4	2	1
Chromium	40	25	10
Copper	100	70	30
Lead	80	60	25
Mercury	3	2	1
Nickel	40	25	10
Silver	10	7	3
Zinc	300	200	100

Table 3.11 gives a range of hydro-chemical parameters for domestic/municipal wastewater.

Table 3.11 Different parameters in municipal wastewater (from Henze, 1982)

Parameter	High	Medium	Low	Unit
Absol. viscosity	0.001	0.001	0.001	kg/m.s
Surface tension	50	55	60	Dyn/cm^2
Conductivity	120	100	70	mS/m^1
pH	8.0	7.5	7.0	
Alkalinity	7	4	1	Eqv/m^3
Sulphide	10	0.5	0.1	gS/m^3
Cyanide	0.05	0.030	0.02	g/m^3
Chloride	600	400	200	gCl/m^3

Wastewater may also contain specific pollutants like xenobiotics (Table 3.12).

Table 3.12 Special parameters in wastewater, xenobiotics with toxic and other effects (in mg/l)

Parameter	High	Medium	Low
Phenol	0.1	0.05	0.02
Phthalates, DEHP	0.3	0.2	0.1
Nonylphenols, NPE	0.08	0.05	0.01
PAHs	2.5	1.5	0.5
Methylene chloride	0.05	0.03	0.01
LAS	10,000	6,000	3,000
Chloroform	0.01	0.05	0.01

Figure 3.2 Hydrogen sulphide is often present in the influent to treatment plants, especially in case of pressurized sewers. It is very toxic and can result in casualties of personnel which do not take the necessary precautions. The picture shows measurement in the pumping station with high hydrogen sulphide concentration in the air (photo: M. Henze).

Figure 3.3 Detergents in high concentrations create problems to a wastewater treatment plant operator (photo: M. Henze)

3.7 MICROORGANISMS

Wastewater is infectious. Most historic wastewater handling was driven by the wish to remove the infectious elements outside the reach of the population in the cities. In the 19th century microorganisms were identified as the cause of diseases. The microorganisms in wastewater come mainly from human's excreta, as well as from the food industry. Table 3.13 gives an idea of the concentration of microorganisms in domestic wastewater. For more information on pathogenic microorganisms and their removal from wastewater the reader is referred to Chapter 8.

Table 3.13 Concentrations of microorganisms in wastewater (number of microorganisms per 100 ml) (based on Henze *et al.*, 2001)

Micro organisms	High	Low
E. coli	$5\cdot10^8$	10^6
Coliforms	10^{13}	10^{11}
Cl. perfringens	$5\cdot10^4$	10^3
Fecal *Streptococcae*	10^8	10^6
Salmonella	300	50
Campylobacter	10^5	$5\cdot10^3$
Listeria	10^4	$5\cdot10^2$
Staphylococus aureus	10^5	5.10^3
Coliphages	$5\cdot10^5$	10^4
Giardia	10^3	10^2
Roundworms	20	5
Enterovirus	10^4	10^3
Rotavirus	100	20

The high concentration of microorganisms may create a severe health risk when raw wastewater is discharged to receiving waters.

Figure 3.4 Surface aeration in activated sludge treatment plants creates aerosols which contain high amount of microorganisms. This poses a health risk to treatment plant employees and in some cases to neighbors (photo: D. Brdjanovic)

3.8 SPECIAL WASTEWATERS AND INTERNAL PLANT RECYCLE STREAMS

It is not only the wastewater in the sewerage that a treatment plant has to handle. The bigger the plant, the more internal wastewater recycles and external inputs/flows have to be handled.

If the catchment has areas with decentralised wastewater handling, septic tank sludge will be loaded into the plant by trucks. Table 3.14 shows the typical composition of septic sludge.

Table 3.14 Composition of septic sludge, (in g/m^3) (from Henze *et al.*, 2001)

Compound	High	Low
BOD total	30,000	2,000
BOD soluble	1,000	100
COD total	90,000	6,000
COD soluble	2,000	200
N total	1,500	200
Ammonia N	150	50
P total	300	40
TSS	100,000	7,000
VSS	60,000	4,000
Chloride	300	50
H_2S	20	1
pH	8.5	7.0
Alkalinity[1]	40	10
Lead	0.03	0.01
Fe total	200	20
F. coliforms[2]	10^8	10^6

[1] in milliequivalent/l
[2] in No/100 ml

This is a typical situation in many developing countries. Septic tank sludge can often create problems in biological treatment plants due to the sudden load from a full truck. For treatment plants of over 100,000 person equivalents the unloading of a truck with septic sludge will not create direct problems in the plant. For small treatment plants the septic tank sludge must be unloaded into a storage tank (Figure 3.5), from which it can be pumped to the plant in periods of low loading (often during the night).

Another significant external load to a treatment plant can be landfill leachate (Figure 3.6).

Figure 3.6 Collection and storage of leachate at sanitary landfill of Sarajevo in Bosnia and Herzegovina (photo: F. Babić)

Figure 3.5 Truck discharges content of septic tanks from households to a storage tank at wastewater treatment plant Illidge Road at St. Maarten, N.A. (photo: D. Brdjanovic)

Leachate can be transported or pumped to the central treatment plant. However, it is sometimes simply dumped into the sewer near the landfill. Leachate can contain high concentrations of soluble inert COD which passes through the plant without any reduction or change. In some cases where regulations do not allow discharge of untreated leachate, separate pre-treatment of leachate is required on-site prior to its discharge to a public sewer.

Table 3.15 Leachate quality (in g/m^3)

Parameter	High	Low
COD total	16,000	1,200
COD soluble	15,800	1,150
BOD total	12,000	300
N total	500	100
Ammonia N	475	95
P total	10	1
TSS	500	20
VSS	300	15
Chloride	2,500	200
H_2S	10	1
pH	7.2	6.5

Internal loading at treatment plants is caused by thickening and digester supernatant, reject water from sludge dewatering and filter wash water. Digester supernatant is often a significant internal load, especially concerning ammonia. This can lead to overload of nitrogen in the case of biological nitrogen removal (see also Chapter 6).

Figure 3.7 Digesters produce digester supernatant which often gives rise to problems in wastewater treatment plants due to the high loads of nitrogen and other substances (photo: M. Henze)

Table 3.16 Digester supernatant (in g/m^3)

Compound	High	Low
COD total	9,000	700
COD soluble	2,000	200
BOD total	4,000	300
BOD soluble	1,000	100
N total	800	120
Ammonia N	500	100
P total	300	15
TSS	10,000	500
VSS	6,000	250
H_2S	20	2

Reject water from sludge dewatering can have rather high concentrations of soluble material, both organics and nitrogen (Figure 3.8).

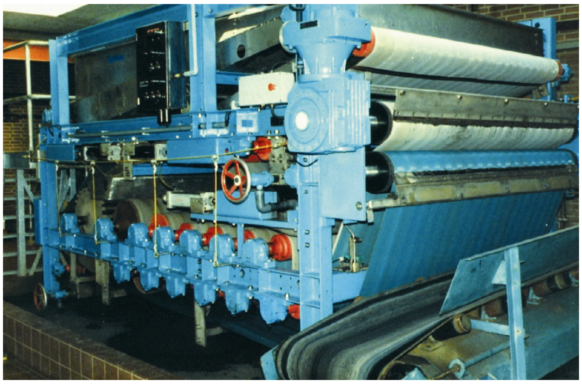


Figure 3.8 Belt filter for sludge dewatering: reject water collection takes place underneath the machinery (photo: D. Brdjanovic)

Table 3.17 Composition of reject water from sludge dewatering (in g/m^3)

Compound	High	Low
COD total	4,000	800
COD soluble	3,000	600
BOD total	1,500	300
BOD soluble	1,000	250
N total	500	100
Ammonia N	450	95
P total	20	5
TSS	1,000	100
VSS	600	60
H_2S	20	0.2

Filter wash water can create problems due to high hydraulic overload of the settling tanks in treatment plants. In some cases it can result in overload with suspended solids. Filter wash water in smaller treatment plants should be recycled slowly.

Table 3.18 Filter wash water (in g/m^3)

Compound	High	Low
COD total	1,500	300
COD soluble	200	40
BOD total	400	50
BOD soluble	30	10
N total	100	25
Ammonia N	10	1
P total	50	5
TSS	1,500	300
VSS	900	150
H_2S	0.1	0.01

3.9 RATIOS

The ratio between the various components in wastewater has significant influence on the selection and functioning of wastewater treatment processes. A wastewater with low carbon to nitrogen ratio may need external carbon source addition in order that biological denitrification functions fast and efficiently. Wastewater with high nitrate concentration or low concentration of volatile fatty acids (VFAs) will not be suitable for biological phosphorus removal. Wastewater with high COD to BOD ratio indicates that a substantial part of the organic matter will be difficult to degrade biologically. When the suspended solids in wastewater have a high volatile component (VSS to SS ratio) these can be successfully digested under anaerobic conditions.

While most of the pollution load in wastewater originates from households, institutions and industry, these contribute only partially to the total quantity of sewage. A significant amount of water in sewage may originate from rain water, (in some countries snow melting) or infiltration groundwater. Thus wastewater components are subject to dilution, which however will not change the ratios between the components. Table 3.19 shows typical component ratios in municipal wastewater.

The ratio between the components in a given wastewater analysis can also be used to investigate anomalies in the analysis which can be due to special discharges into the sewer system, often from industries, or due to analytical errors. The ratios between the concentrations of the components shown in Table 3.6 can be used as a rough guideline. If some of the analytical values fall out of the expected range provided in Table 3.6 this should be further investigated and the reason found. If industrial discharges cause the discrepancy, other, not (already) analysed components in the wastewater might also deviate from expected values. Since these discrepancies may affect the treatment process the reason for their appearance should be clarified.

Table 3.19 Typical ratios in municipal wastewater

Ratio	High	Medium	Low
COD/BOD	2.5-3.5	2.0-2.5	1.5-2.0
VFA/COD	0.12-0.08	0.08-0.04	0.04-0.02
COD/TN	12-16	8-12	6-8
COD/TP	45-60	35-45	20-35
BOD/TN	6-8	4-6	3-4
BOD/TP	20-30	15-20	10-15
COD/VSS	1.6-2.0	1.4-1.6	1.2-1.4
VSS/TSS	0.8-0.9	0.6-0.8	0.4-0.6
COD/TOC	3-3.5	2.5-3	2-2.5

3.10 VARIATIONS

The concentration of substances in wastewater varies with time. In many cases daily variations are observed, in some weekly and others are very likely a function of industrial production patterns. The variations are important for design, operation and control of the treatment plant. For example, ammonia-nitrogen, the main source of which is urine, does often show a diurnal pattern depicted by Figure 3.9.

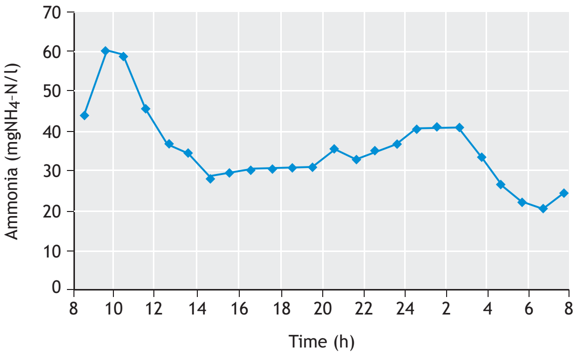


Figure 3.9 Daily variation of ammonia content in the influent of Galindo wastewater treatment plant in Spain

Variations in flow, COD and suspended solids can be significant as shown on Figure 3.10.

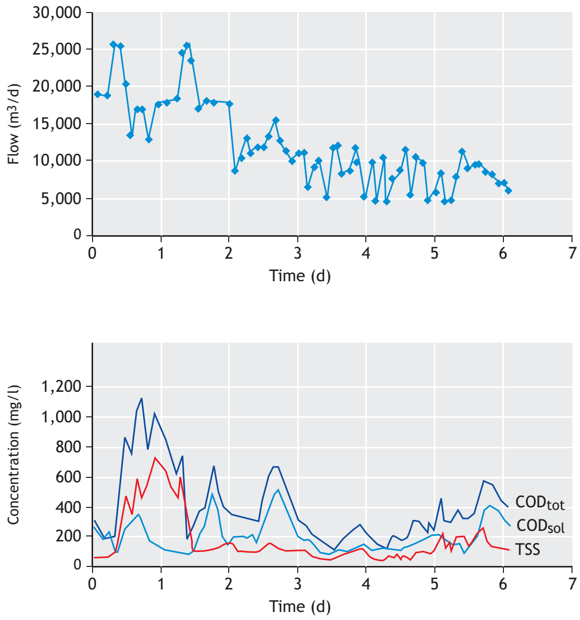


Figure 3.10 Variations in wastewater flow, COD and suspended solids (Henze *et al.*, 2002)

Sampling of wastewater is challenging due to the variations in flow and component contractions. It is important to be aware of the fact that the analytical results obtained will vary considerably with the chosen sampling procedure. Floatable materials such as oil and grease are difficult to sample and so are comparatively heavier components, such as sand and grit.

A number of sampling techniques are applied to wastewater:

- Grab samples (one sample collected in a bottle or a bucket at a specific time). This type of sampling gives highly variable results.
- Time proportional samples (this can be a number of samples, e.g. one sample per hour which is combined in one final sample). This type of sampling can be fine if the wastewater has only small variations in the concentration of its components.
- Flow proportional sampling (this can be a sample for each specified volume of wastewater flow, typically performed over 24 hours). This gives a reliable estimate of the wastewater quality – or lack of quality.
- 24 hour variations (e.g. one sample per hour kept separate in order to obtain an impression of the variations in wastewater concentrations). These are beneficial to modelling purposes.
- Weekly samples (time or flow proportional). Similarly, these are beneficial for design and modelling purposes.

3.11 WASTEWATER FLOWS

Wastewater flows vary with time and place. This makes them complicated to accurately measure. The basic unit for flow is volume of wastewater (m^3) per unit of time (day). The design flow for different units in a wastewater treatment plant varies. For units with short hydraulic retention time like screen and grit chamber, the design flow is represented by m^3/s, while for settling tanks the design flow is usually expressed by m^3/h. For domestic wastewater typical design calculations are shown in Figure 3.11.

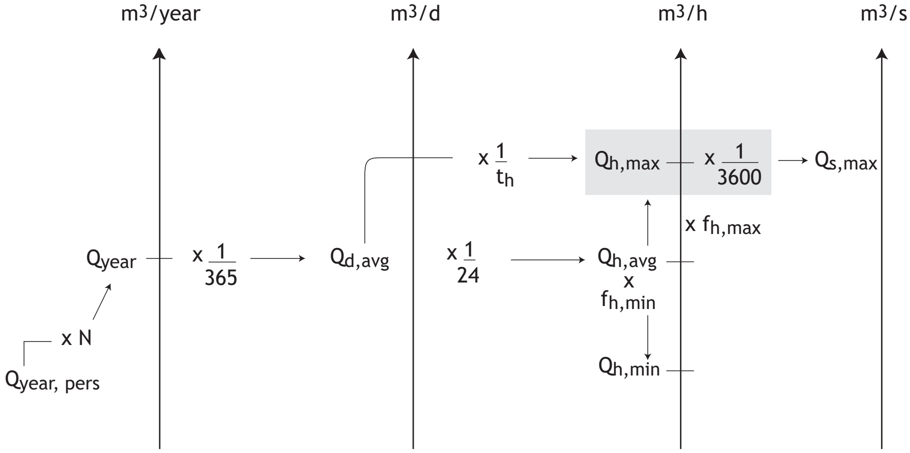


Figure 3.11 Calculation of design volumes for municipal wastewater with minor industrial wastewater contribution

Average daily flow, $Q_{d,avg}$, is calculated as wastewater flow per year divided by 365. Average hourly flow, $Q_{h,avg}$, is daily flow divided by 24.

The maximum flow per hour can be found by two calculations, either (*i*) from the average daily flow multiplied with the maximum hourly constant, $f_{h,max}$ (this constant varies with the size of the catchment: for large cities it will be 1.3-1.7, for small towns 1.7-2.4), or (*ii*) by dividing the average daily flow by the hourly factor, $t_{h,d}$ (this factor is 10-14 hours for small towns, and 14-18 hours for large cities).

3.12 TRADITIONAL WASTE FROM HOUSEHOLDS

The amount of wastewater and pollutants from households varies from country to country. These variations are influenced by the climate, socio-economic factors, household technology and other factors.

The amount of organic waste and nutrients produced in households is shown in Table 3.20. From this table one can realize the potential for changing the wastewater composition.

In the case of household waste, the composition of wastewater and solid waste from households is a result of contributions from various sources within the household. It is possible to change the amount and the composition of the waste streams. The amount of a given waste stream can be decreased or increased, depending on the optimal solution. For example, a reduction in the amount of waste(d) materials present in the wastewater can be achieved by two means: (*i*) overall reduction of waste generated in the household and, (*ii*) diversion of certain types of waste to the solid waste of the household.

Options for reducing the physiologically generated amount of waste are not obvious, although diet influences the amount of waste produced by the human organism. Thus one has to accept this waste generation as a natural result of human activity. Separating toilet waste (physiological waste or anthropogenic waste) from the waterborne route is reflected in a significant reduction in the nitrogen, phosphorus and organic load in the wastewater. Waste generated after the separation at source has taken place, however still has to be transported away from the household, and in many cases, the city.

There are several feasible technical options for handling waste separated at source, including:

- the night soil system, used worldwide
- compost toilets, mainly used in individual homes in agricultural areas (preferably with urine separation in order to optimise the composting process)
- septic tanks followed by infiltration or transport by a sewer system.

Urine is the main contributor to nutrients in household wastes, thus separating out the urine will reduce nutrient loads in wastewater significantly (Figure 3.12). Urine separation will reduce nitrogen content in domestic wastewater to a level where nitrogen removal is not needed.

Figure 3.12 Urine-separating toilet

Table 3.20 Sources for household wastewater components and their values for 'non-ecological' lifestyle (from Sundberg, 1995; Henze, 1997)

Parameter	Unit	Toilet		Kitchen	Bath/ laundry	Total
		Total[1]	Urine			
Wastewater	m^3/yr	19	11	18	18	55
COD	kg/yr	27.5	5.5	16	3.7	47.2
BOD	kg/yr	9.1	1.8	11	1.8	21.9
N	kg/yr	4.4	4.0	0.3	0.4	5.1
P	kg/yr	0.7	0.5	0.07	0.1	0.87
K	kg/yr	1.3	0.9	0.15	0.15	1.6

[1] Including urine

Kitchen waste contains a significant amount of organic matter which traditionally ends up in wastewater. It is relatively easy to divert some liquid kitchen wastes to solid waste by the application of so-called 'cleantech' cooking, thus obtaining a significant reduction in the overall organic load of the wastewater (Danish EPA 1993). Cleantech cooking means that food waste is discarded into the waste bin and not flushed into the sewer using water from the tap. The diverted part of the solid organic waste from the kitchen can be disposed together with the other solid wastes from the household. The grey wastewater from the kitchen could be used for irrigation or, after treatment, for toilet flushing. Liquid kitchen waste also contains household chemicals, the use of which can affect the composition and load of this type of waste.

Wastewater from laundry and bath carries a minor pollution load only, part of which comes from household chemicals, the use of which can affect the composition and the load of this waste fraction. Waste from laundry and baths could be used together with the traditional kitchen wastewater for irrigation. Alternatively, it can be reused for toilet flushing. In both cases considerable treatment is needed.

The compostable fraction of the solid waste from the kitchen can either be kept separate or combined with traditionally waterborne kitchen wastes, for later composting or anaerobic treatment at the wastewater treatment plant.

The use of kitchen disposal units (grinders) for handling the compostable fraction of the solid waste from households is used in many countries. Sometimes this option is discarded due to the increased waste load to the sewer. However, waste is generated in households, and it must be transported away from households and out of cities by some means. The discharge of solid waste to the sewer does not change the total waste load produced by the household, but it will change the transportation mean and the final destination of the waste.

3.13 WASTEWATER DESIGN FOR HOUSEHOLDS

The use of one or more of the waste handling technologies mentioned earlier in households in combination with water-saving mechanisms makes it possible to design wastewater with a specified composition, which will be optimal for its further handling. When the goal is to reduce the pollutant load to the wastewater, there are several actions to achieve this (Table 3.21).

Table 3.21 Reduced waste load to wastewater by toilet separation and cleantech cooking (in g/cap.d) (from Henze, 1997)

Technology	Traditional	Toilet separation[1]	Cleantech cooking[2]
COD	130	55	32
BOD	60	35	20
N	13	2	1.5
P	2.5	0.5	0.4

[1] Water closet → dry/compost toilet.
[2] Part of cooking waste diverted from the sink to solid waste bin

The coupling of water saving and load reduction is an additional argument for the wastewater design approach (example shown in Table 3.22).

Table 3.22 The concentration of pollutants in raw wastewater with toilet separation and cleantech cooking (in g/m^3) (from Henze 1997)

Wastewater production	250 l/cap.d	160 l/cap.d	80 l/cap.d
COD	130	200	400
BOD	80	125	250
N	6	9	19
P[1]	1.6	2.5	5

[1] Assuming phosphate-free detergents

The changes obtained in the wastewater composition also influence the detailed composition of the COD. This can result in changes between the soluble and the suspended fractions, or changes in degradability of the organic matter, for example, leading to more or less easily degradable organic matter in the given wastewater fraction. The composition of wastewater has a significant influence on the selection of treatment processes to be applied. By changing technology used in households and by diverting as much of the organic waste to the sewer system as possible, it is possible to obtain wastewater characteristics like those shown in Table 3.23.

Table 3.23 Concentration of pollutants in raw wastewater by maximum load of organic waste (in g/m^3) (Henze, 1997)

Wastewater production	250 l/cap.d	160 l/cap.d	80 l/cap.d
COD	880	1,375	2,750
BOD	360	565	1,125
N	59	92	184
P[1]	11	17	35

[1] Assuming phosphate-free detergents

Tendency for having rather detailed wastewater and biomass fractionation is the result of increasing application and requirements of mathematical models in wastewater treatment. In order to place COD, N, and P fractionation in the wider context of mathematical modelling, the list of state variables used by selected models is composed, as depicted in Table 3.25. Herewith, the authors made a proposal for an overarching list of common state variables (second column in Table 3.25). For the description of each component presented in this table, the reader is referred to a list of references listed in the footnote of the table.

The most common separation is the separation of toilet waste from the rest of the wastewater. This will result in grey and black wastewater generation, the characteristics of which can be seen in Table 3.24. For more details on grey wastewater, see Ledin *et al.,* 2000.

Table 3.24 Characteristics of grey and black wastewater. Low values can be due to high water consumption. Low water consumption or high pollution load from kitchen can cause high values (based on Henze, 1997; Sundberg, 1995; Almeida *et al*,. 2000)

Parameter	Grey wastewater		Black wastewater	
	High	Low	High	Low
COD	700	200	1,500	900
BOD	400	100	600	300
N	30	8	300	100
P	7	2	40	20
K[1]	6	2	90	40

[1] Exclusive of the content in the water supply

3.14 WASTEWATER AND BIOMASS FRACTIONATION

The relationship between various components of organic and inorganic matter, nitrogen and phosphorus components of either wastewater or sludge are illustrated in Figure 3.13. The definition of each term is given in Tables 3.25. For a more detailed description of each component presented here the reader is referred to the list of references attached.

Variables names vary between references depending on the authors' preferences. In this book, the notation used for variables was not standardized but a discussion on this topic was initiated with researchers interested in modelling (Comeau *et al.,* 2008) and the following indications were suggested as guidelines for the notation of variables.

First, a letter indicates the size of the component (capital letter in italics):

- S: soluble
- C: colloidal
- X: particulate
- T: total ($= S + C + X$).

The particle size of colloidal matter depends on the purpose of the model used and the method of its determination and may typically be in the range 0.01 to 1 micron. Modelling colloidal matter has risen in importance in recent years due to the need to reach very low effluent concentrations, a condition when the behaviour of colloidal matter becomes significant. Advanced treatment systems including membrane or adsorption processes are increasingly used for such purposes. In some cases, it may be useful to join the letters indicating the size of the matter (e.g. CX).

Subscripts are then used to describe the component or its nature (e.g. F: fermentable; OHO: ordinary heterotrophic organisms). Commas may be added to indicate that a component is part of another one (e.g. $X_{PAO,PHA}$ for the polyhydroxyalkanoate (PHA) storage component of phosphorus accumulating organisms; PAOs).

Organisms are proposed to be described with an acronym ending with the letter "O" (e.g. ANO: ammonia nitrifying organisms).

Each state variable is considered independent of each other (not true for combined variables). Thus, for example, the PHA storage of PAOs ($X_{PAO,PHA}$) is not considered to be part of the PAOs (X_{PAO}).

Total matter (T) is composed of inorganic (IG) and organic (ORG) components, the latter being divided in biodegradable (B) and unbiodegradable (U) matter. The word *unbiodegradable* was proposed instead of *inert,* notably to avoid using the letter "I" to minimize the risk of confusion with inorganic matter.

Variable names may be used for any location of a wastewater treatment system. It is proposed that a lower case superscript be used to indicate the location of the variable, when needed (e.g. X_{OHO}^{inf} for the OHOs concentration in the influent). Considering that some influent particulate unbiodegradable compounds accumulate in the activated sludge as a function of sludge age and hydraulic retention time, it is sometimes necessary to identify both their source and location (e.g. $X_{INF,U}^{OX}$ for the influent unbiodegradable component in the aerobic zone [OX] of the process).

The component is considered to be expressed in units of dry weight concentration (e.g. mg S_{VFA}/l). The various constituents of this component contribute to its concentration in other units of COD, BOD_U (ultimate BOD), BOD_5, residue (solids), nitrogen and phosphorus using appropriate conversion factors as needed to express them in these units. For example, expressing the VFA concentration in units of COD would require the state variable to be expressed as S_{VFA_COD} with the underscore used as a separator to specify the units of expression. However, since organic matter components in activated sludge models were expressed in COD units by default, the proposed symbol for a variable name in this table is shown without the underscore to indicate COD units (e.g. S_{VFA_COD} is shown as S_{VFA}). Similarly, components that contain essentially only nitrogen or phosphorus have no units specified in the variable name with units being indicated in the Units column. (e.g. S_{PO4} instead of $S_{PO4\_P)}$

When a component contributes to COD, BOD (if biodegradable), residue (solids), nitrogen and phosphorus, a star (*) is shown in the appropriate column of Figure 3.13. Note that for expressing variables in units of residues, since the components are considered to be expressed in dry weight units, no "_R" would strictly be required. Optionally, it may be used to specify that the compound is expressed in residue units, especially if the symbols were defined on a COD units basis, as often done in activated sludge models.

BOD components are carbonaceous BOD. BOD_U is about 10% less than the corresponding biodegradable COD components. The BOD_5/BOD_U ratio depends on the type of wastewater but is typically 0.67. Oxygen is considered to exert both a negative COD and a negative BOD.

3.15 SYMBOLS LIST OF VARIABLES FOR MODELS

A list of symbols for state variables used for various activated sludge models is shown in Table 3.25. Some state and combined variables that were not used in these models but are shown in Figure 3.13 are also described.

3.16 CHARACTERIZATION PROTOCOLS

Driven by requirements of mathematical modelling of activated sludge systems, several systematic protocols for activated sludge model calibration were developed and include different wastewater characterization protocols. Four major protocols were developed by as many research groups. The nature of these protocols range from simplified and rather practical, to those of increased complexity and more of academic and research interest.

- the STOWA protocol (Hulsbeek *et al.*, 2002)
- the BIOMATH protocol (Vanrolleghem *et al.*, 2003)
- the WERF protocol for model calibration (Melcer *et al.*, 2003)
- the Hochschulgruppe (HSG) guidelines (Langergraber *et al.,* 2004).

Which protocol to use depends on the purpose of the modelling. For more details on the activated sludge treatment modelling the reader is referred to Chapter 14.

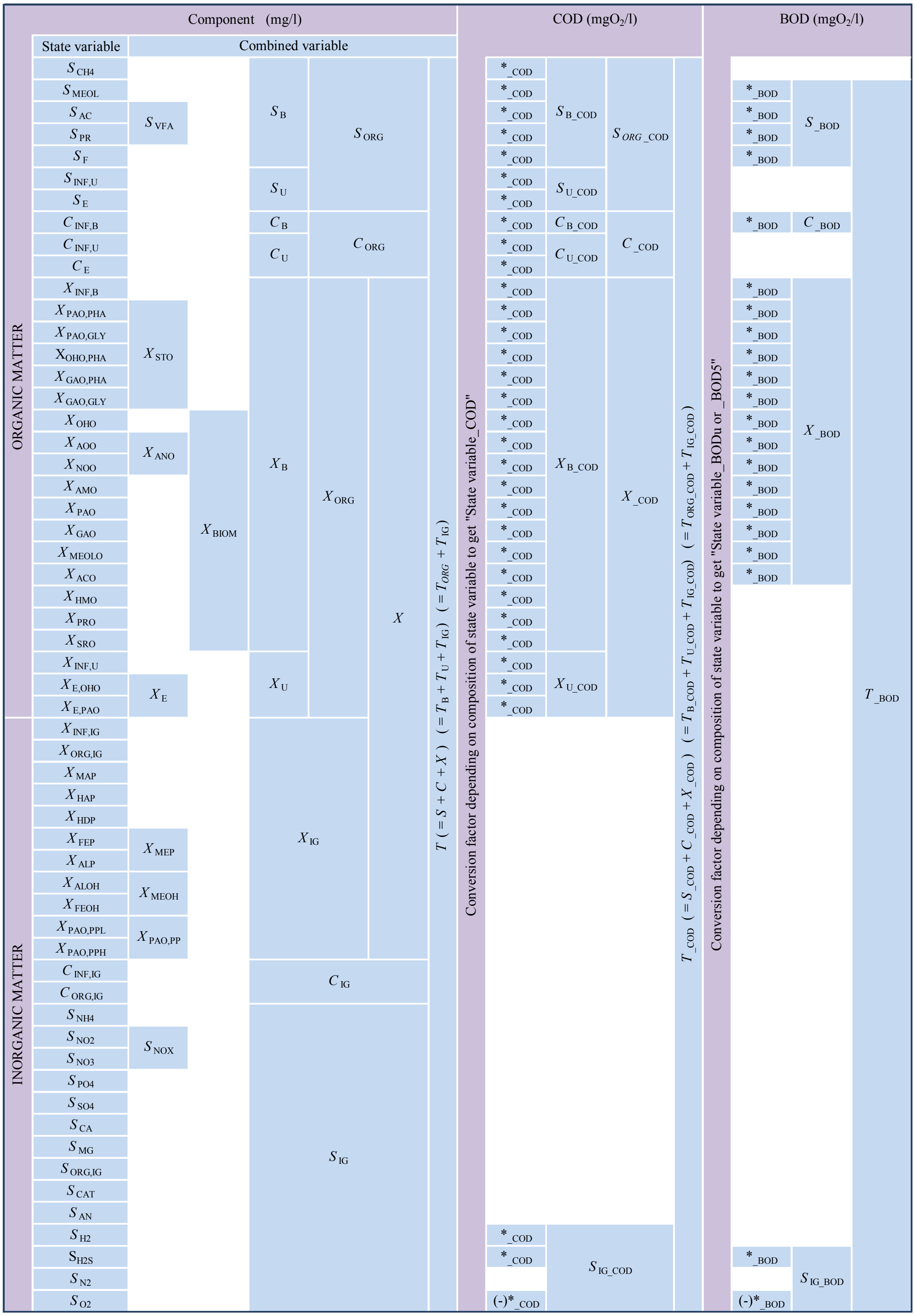
Typical fractions of the total influent COD for raw and primary effluent wastewaters are shown in Table 3.26 (adapted from EnviroSim, 2007).

3.17 EXAMPLE COMPOSITION OF INFLUENT, BIOREACTOR AND EFFLUENT

An example of concentration values for various state and combined variables for the influent, the aerated zone and the effluent of a Phoredox process is shown in Figure 3.14.

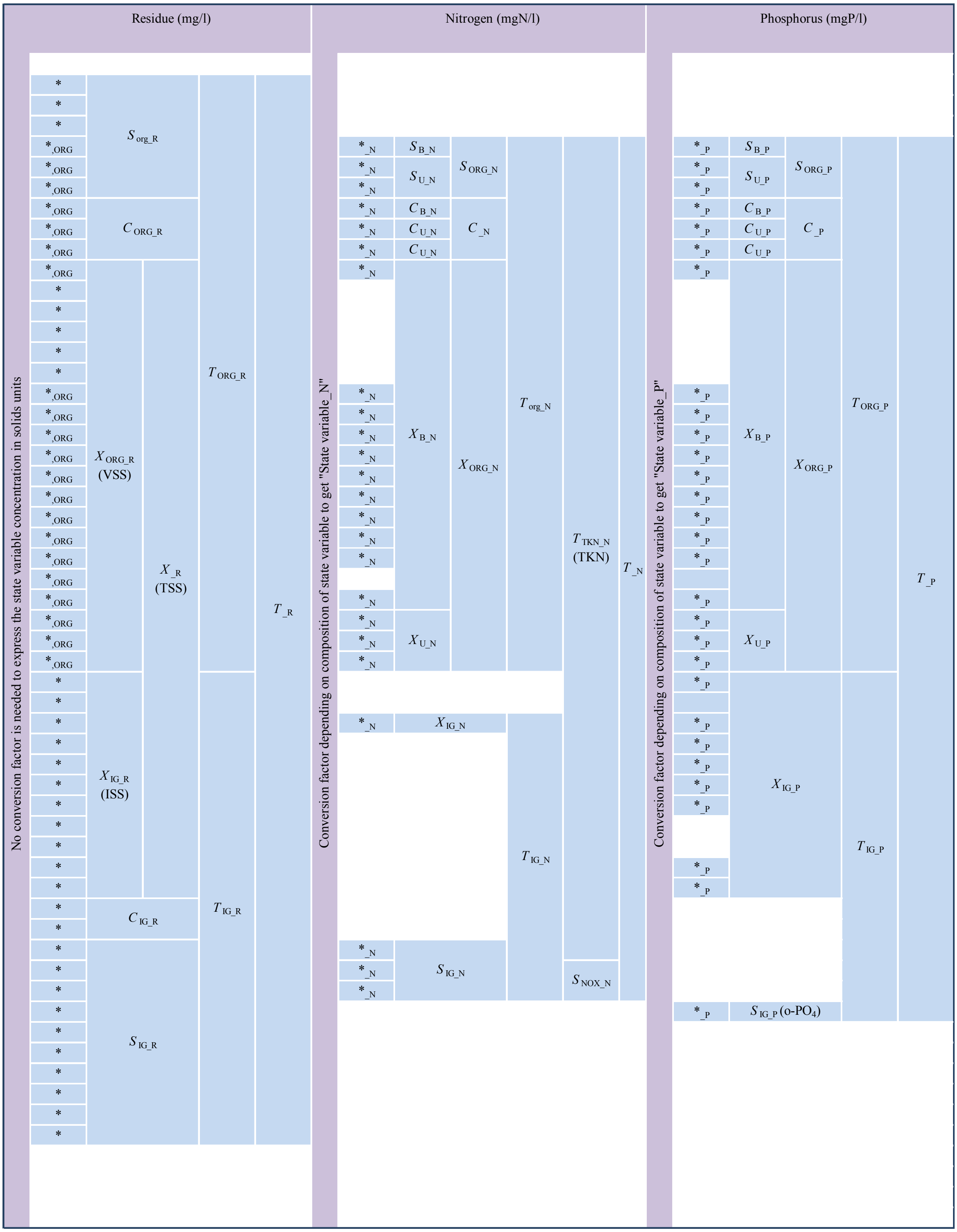
3.18 WASTEWATER FINGERPRINT

'Show me your wastewater and I will tell you who you are'. The wastewater from a particular person gives a very detailed picture of that person and its lifestyle. All human activities are registered and reflected in the wastewater, from the food we eat to the materials we use in our houses and the materials and production processes applied in industry. Through the wastewater one can get information on illness, sex, pregnancy, drugs use, personal hygiene, diet, environmental consciousness, alcoholism, etc. The 'fingerprint' we deliver with the wastewater, affects the environment. It is not the wastewater that spoils the environment; it is humans that pollute the water.



	Component (mg/l)							COD (mgO$_2$/l)				BOD (mgO$_2$/l)		
	State variable	Combined variable						Conversion factor depending on composition of state variable to get "State variable_COD"				Conversion factor depending on composition of state variable to get "State variable_BODu or _BOD5"		
ORGANIC MATTER	S_{CH4}			S_B	S_{ORG}		$T\ (= S + C + X)\ \ (= T_B + T_U + T_{IG})\ \ (= T_{ORG} + T_{IG})$	*_COD	S_{B_COD}	S_{ORG_COD}	$T_{\_COD}\ (= S_{\_COD} + C_{\_COD} + X_{\_COD})\ \ (= T_{B\_COD} + T_{U\_COD} + T_{IG\_COD})\ \ (= T_{ORG\_COD} + T_{IG\_COD})$			
	S_{MEOL}							*_COD				*_BOD	$S_{\_BOD}$	$T_{\_BOD}$
	S_{AC}	S_{VFA}						*_COD				*_BOD		
	S_{PR}							*_COD				*_BOD		
	S_F							*_COD				*_BOD		
	$S_{INF,U}$			S_U				*_COD	S_{U_COD}					
	S_E							*_COD						
	$C_{INF,B}$			C_B	C_{ORG}			*_COD	C_{B_COD}	$C_{\_COD}$		*_BOD	$C_{\_BOD}$	
	$C_{INF,U}$			C_U				*_COD	C_{U_COD}					
	C_E							*_COD						
	$X_{INF,B}$			X_B	X_{ORG}	X		*_COD	X_{B_COD}	$X_{\_COD}$		*_BOD	$X_{\_BOD}$	
	$X_{PAO,PHA}$	X_{STO}						*_COD				*_BOD		
	$X_{PAO,GLY}$							*_COD				*_BOD		
	$X_{OHO,PHA}$							*_COD				*_BOD		
	$X_{GAO,PHA}$							*_COD				*_BOD		
	$X_{GAO,GLY}$							*_COD				*_BOD		
	X_{OHO}		X_{BIOM}					*_COD				*_BOD		
	X_{AOO}	X_{ANO}						*_COD				*_BOD		
	X_{NOO}							*_COD				*_BOD		
	X_{AMO}							*_COD				*_BOD		
	X_{PAO}							*_COD				*_BOD		
	X_{GAO}							*_COD				*_BOD		
	X_{MEOLO}							*_COD				*_BOD		
	X_{ACO}							*_COD				*_BOD		
	X_{HMO}							*_COD						
	X_{PRO}							*_COD						
	X_{SRO}							*_COD						
	$X_{INF,U}$			X_U				*_COD	X_{U_COD}					
	$X_{E,OHO}$	X_E						*_COD						
	$X_{E,PAO}$							*_COD						
INORGANIC MATTER	$X_{INF,IG}$			X_{IG}										
	$X_{ORG,IG}$													
	X_{MAP}													
	X_{HAP}													
	X_{HDP}													
	X_{FEP}	X_{MEP}												
	X_{ALP}													
	X_{ALOH}	X_{MEOH}												
	X_{FEOH}													
	$X_{PAO,PPL}$	$X_{PAO,PP}$												
	$X_{PAO,PPH}$													
	$C_{INF,IG}$			C_{IG}										
	$C_{ORG,IG}$													
	S_{NH4}			S_{IG}										
	S_{NO2}	S_{NOX}												
	S_{NO3}													
	S_{PO4}													
	S_{SO4}													
	S_{CA}													
	S_{MG}													
	$S_{ORG,IG}$													
	S_{CAT}													
	S_{AN}													
	S_{H2}							*_COD	S_{IG_COD}					
	S_{H2S}							*_COD				*_BOD	S_{IG_BOD}	
	S_{N2}													
	S_{O2}							(-)*_COD				(-)*_BOD		

Figure 3.13 Fractionation of organic and inorganic matter components, and relationships between their content in dry weight, COD, BOD, residue (solids), nitrogen and phosphorus (continue…)


Residue (mg/l)
Nitrogen (mgN/l)
Phosphorus (mgP/l)
No conversion factor is needed to express the state variable concentration in solids units
Conversion factor depending on composition of state variable to get "State variable_N"
Conversion factor depending on composition of state variable to get "State variable_P"
S_{org_R}
C_{ORG_R}
X_{ORG_R} (VSS)
X_R (TSS)
X_{IG_R} (ISS)
C_{IG_R}
S_{IG_R}
T_{ORG_R}
T_{IG_R}
T_R
S_{B_N}
S_{U_N}
S_{ORG_N}
C_{B_N}
C_{U_N}
C_{U_N}
C_N
X_{B_N}
X_{U_N}
X_{ORG_N}
X_{IG_N}
S_{IG_N}
T_{org_N}
T_{IG_N}
T_{TKN_N} (TKN)
S_{NOX_N}
T_N
S_{B_P}
S_{U_P}
S_{ORG_P}
C_{B_P}
C_{U_P}
C_{U_P}
C_P
X_{B_P}
X_{U_P}
X_{ORG_P}
X_{IG_P}
S_{IG_P} (o-PO$_4$)
T_{ORG_P}
T_{IG_P}
T_P
*
*$_{ORG}$
*$_N$
*$_P$

… continued

Table 3.25 Symbol list of variables for various models

Group	Proposed symbol	Units	Description	ASM1 [1]	ASM2D [2]	ASM3P [3]	GenASDM [4]	UCTPHO+ [5]	TUDP [6]
S_{COD}									
	S_{CH4}	mgCOD/l	Methane				S_{CH4}		
	S_{MEOL}	mgCOD/l	Methanol				S_{BMETH}		
	S_{AC}	mgCOD/l	Acetate				S_{BSA}		
	S_{PR}	mgCOD/l	Propionate				S_{BSP}		
	S_{VFA}	mgCOD/l	Volatile fatty acids		S_{LF}			S_A	S_{AC}
	S_F	mgCOD/l	Fermentable organic matter		S_F		S_{BSC}	S_F	
	S_B	mgCOD/l	Soluble biodegradable matter	S_S		S_S			
	$S_{INF,U}$	mgCOD/l	Influent soluble unbiodegradable organics	S_I	S_I	S_I	S_{US}	S_I	
	S_E	mgCOD/l	Soluble unbiodegradable endogenous products						
	S_U	mgCOD/l	Soluble unbiodegradable organic matter						
	S_{ORG}	mgCOD/l	Soluble organic matter						
	S_{H2}	mgCOD/l	Dissolved hydrogen				S_{BH2}		
	S_{H2S}	mgCOD/l	Dissolved hydrogen sulfide						
O_2									
	S_{O2}	mgO_2/l	Dissolved oxygen	S_O	S_O	S_O	DO	S_{O2}	S_{O2}
C_{COD} and X_{COD}									
	$C_{INF,B}$	mgCOD/l	Influent slowly biodegradable colloidal matter				X_{SC}		
	C_B	mgCOD/l	Slowly biodegradable colloidal matter						
	$C_{INF,U}$	mgCOD/l	Influent unbiodegradable colloidal matter						
	C_E	mgCOD/l	Colloidal unbiodegradable matter						
	C_U	mgCOD/l	Unbiodegradable colloidal matter						
	C_{ORG}	mgCOD/l	Colloidal organic matter						
	$X_{INF,B}$	mgCOD/l	Influent slowly biodegradable particulate organics (non colloidal)				X_{SP}		
	$CX_{INF,B}$	mgCOD/l	Influent slowly biodegradable organics (colloidal and particulate)	X_S	X_S	X_S			
	$X_{INF,B,ENM}$	mgCOD/l	Influent $CX_{INF,B}$ instantaneously enmeshed onto the biomass					X_{ENM}	
	$X_{ADS,B}$	mgCOD/l	$X_{INF,B,ENM}$ adsorbed or produced from biomass decay					X_{ADS}	
	$X_{PAO,PHA}$	mgCOD/l	Stored polyhydroxyalkanoates (PHAs) in phosphorus accumulating organisms (PAOs)			X_{PHA}	S_{PHB}	X_{PHA}	X_{PHB}
	$X_{PAO,GLY}$	mgCOD/l	Stored glycogen in PAOs						X_{GLY}
	$X_{OHO,PHA}$	mgCOD/l	Stored PHAs in OHOs						
	$X_{GAO,PHA}$	mgCOD/l	Stored PHAs in GAOs						
	$X_{GAO,GLY}$	mgCOD/l	Stored glycogen in GAOs						
	X_{STO}	mgCOD/l	Stored PHAs and glycogen		X_{BT}	X_{STO}			
	X_B	mgCOD/l	Particulate biodegradable organics						
	$X_{INF,U}$	mgCOD/l	Particulate unbiodegradable organics from the influent						
	$X_{E,OHO}$	mgCOD/l	Particulate unbiodegradable endogen. products from OHOs						
	$X_{E,PAO}$	mgCOD/l	Particulate unbiodegradable endogen. products from PAOs						
	X_E	mgCOD/l	Particulate unbiodegradable endogenous products	X_U			Z_E	X_E	
	X_U	mgCOD/l	Particulate unbiodegradable organics	X_I	X_I	X_I	X_I	X_I	X_I
	X_{ORG}	mgCOD/l	Particulate organic matter						

Table 3.25 Continued

Group	Proposed symbol	Units	Description	ASM1[1]	ASM2D[2]	ASM3P[3]	GenASDM[4]	UCTPHO+[5]	TUDP[6]
Organisms									
	X_{OHO}	mgCOD/l	Ordinary heterotrophic organisms (OHOs)	$X_{B,H}$	X_{BH}	X_{H}	Z_{BH}	X_{H}	
	X_{AOO}	mgCOD/l	Ammonia oxidizing organisms				Z_{BA}		X_{NH}
	X_{NOO}	mgCOD/l	Nitrite oxidizing organisms				Z_{BN}		X_{NO}
	X_{ANO}	mgCOD/l	Autotrophic nitrifying organisms (NH_4^+ to NO_3^-)	$X_{B,A}$	X_{BA}	X_{A}		X_{AUT}	
	X_{AMO}	mgCOD/l	Anaerobic ammonia oxidizing (Annamox) organisms				Z_{BAMO}		
	X_{PAO}	mgCOD/l	Phosphorus accumulating organisms (PAOs)		X_{BP}	X_{PAO}	Z_{BP}	X_{PAO}	X_{PAO}
	X_{GAO}	mgCOD/l	Glycogen accumulating organisms (GAOs)						
	X_{MEOLO}	mgCOD/l	Anoxic methanol utilizing methylotrophic organisms				Z_{BMETH}		
	X_{ACO}	mgCOD/l	Acetoclastic methanogenic organisms				Z_{BAM}		
	X_{HMO}	mgCOD/l	Hydrogenotrophic methanogenic organisms				Z_{BHM}		
	X_{PRO}	mgCOD/l	Propionic acetogenic organisms				Z_{BPA}		
	X_{SRO}	mgCOD/l	Sulfate reducing organisms						
	X_{BIOM}	mgCOD/l	Organisms (biomass)						
Inorganics									
	$X_{INF,IG}$	mgISS/l	Influent particulate inorganics (excluding other state variables)						
	$X_{ORG,IG}$	mgISS/l	Inorganics that associated to organic matter (including organisms)						
	X_{MAP}	mgISS/l	Struvite (magnesium ammonium phosphate)				X_{STRU}		
	X_{HAP}	mgISS/l	Hydroxyapatite				X_{HAP}		
	X_{HDP}	mgISS/l	Hydroxydicalcium-phosphate				X_{HDP}		
	X_{FEP}	mgISS/l	Iron phosphate precipitates						
	X_{ALP}	mgISS/l	Aluminum phosphate precipitates						
	X_{MEP}	mgISS/l	Metal phosphate precipitates		X_{MEP}				
	X_{ALOH}	mgISS/l	Aluminum hydroxide precipitates						
	X_{FEOH}	mgISS/l	Iron hydroxide precipitates						
	X_{MEOH}	mgISS/l	Metal hydroxide precipitates		X_{MEOH}				
	T_{ME}	mgME/l	Metals (Al - Fe)				C_{ME}		
	$X_{PAO,PPL}$	mgP/l	Releasable stored phosphates in PAOs				PP_{LO}		
	$X_{PAO,PPH}$	mgP/l	Non releasable stored phosphates in PAOs				PP_{HI}		
	$X_{PAO,PP}$	mgP/l	Stored polyphosphates in PAOs		X_{PP}	X_{PP}		X_{PP}	X_{PP}
	X_{IG}	mgISS/l	Particulate inorganic matter						
	X_{B_P}	mgP/l	P content of particulate biodegradable organic matter				X_{OP}		
	X_{U_P}	mgP/l	P content of particulate unbiodegradable organic matter				X_{IP}		
	$C_{INF,IG}$	mgISS/l	Influent colloidal inorganics (excluding other state variables)						
	$C_{ORG,IG}$	mgISS/l	Inorganics associated to colloidal organic matter						
	C_{IG}	mgISS/l	Inorganics present in colloidal matter						
	S_{NH4}	mgN/l	Ammonia ($NH_4^+ + NH_3$)	S_{NH}	S_{NH}	S_{NH}	S_{NH3}	S_{NH4}	S_{NH4}
	S_{NO2}	mgN/l	Nitrite ($HNO_2 + NO_2^-$)				S_{NO2}		S_{NO2}
	S_{NO3}	mgN/l	Nitrate ($HNO_3 + NO_3^-$)				S_{NO3}		S_{NO3}
	S_{NOX}	mgN/l	Nitrite + nitrate	S_{NO}	S_{NO}	S_{NO}		S_{NO3}	
	S_{PO4}	mgP/l	Inorganic soluble phosphorus (o-PO_4 test)		S_{P}	S_{PO4}		S_{PO4}	S_{PO4}
	$S_{PO4} + X_{MEP}$	mgP/l	Total phosphate (soluble P + metal-P)				cPO_4		

Table 3.25 Continued

Group	Proposed symbol	Units	Description	ASM1[1]	ASM2D[2]	ASM3P[3]	GenASDM[4]	UCTPHO+[5]	TUDP[6]
	S_{SO4}	mgISS/l	Sulfate						
	S_{CA}	mgCa/l	Calcium				S_{CA}		
	S_{MG}	mgMg/l	Magnesium				Mg		
	$S_{ORG,IG}$	mgISS/l	Inorganics associated to soluble organic matter						
	$X_{PAO,PP,CAT}$	mgISS/l	Polyphosphate bound cations				X_{PPCat}		
	S_{CAT}	meq/l	Other cations (strong bases)				S_{CAT}		
	S_{AN}	meq/l	Other anions (strong acids)				S_{AN}		
	S_{N2}	mg/l	Soluble nitrogen		S_{NN}	S_{N2}	S_{N2}		S_{N2}
	S_{ALK}	mgCaCO$_3$/l	Alkalinity	S_{ALK}	S_{ALK}				
	S_{TIC}	mmolC/l	Total inorganic carbon			S_{HCO}	S_{CO2t}		
Water									
	S_{H2O}	mgH$_2$O/l	Water				S_{H2O}		
SS									
	X_{ORG_R}	mgVSS/l	Volatile (organic) suspended solids (residue)						
	X_{IG_R}	mgISS/l	Inorganic suspended solids (residue)						
	X_{T_R}	mgTSS/l	Total suspended solids (residue)			X_{TSS}			

[1] ASM1: Henze *et al.* (1987)
[2] ASM2D: Henze *et al.* (1999)
[3] ASM3-P: Rieger *et al.* (2001)
[4] General ASDM: EnviroSim (2007)
[5] UCTPHO+: Hu *et al.* (2007)
[6] TUDP: de Kreuk *et al.* (2007)

Note: 1) Since organic matter components in activated sludge models were expressed in COD units by default, the proposed symbol for a variable name in this table is shown without the underscore to indicate COD units (e.g. S_{VFA_COD} is shown as S_{VFA}). Similarly, components that contain essentially only nitrogen or phosphorus have no units specified in the variable name with units being indicated in the Units column. 2) Some compounds that were not independent of variables shown in Figure 3.13 were not illustrated in this Figure (e.g. as $X_{INF,B,ENM}$ and $X_{ADS,B}$ that are related to $CX_{INF,B}$).

Execution of sampling and monitoring program requires expertise and financial resources, but often returns multiple benefits including optimization of plant design, improved operation of wastewater facilities and overall savings (photo: K-water)

	State variables	Units	Influent	Aerobic	Effluent
ORGANIC MATTER	S_{CH4}	mgCOD/l	0	0.03	0.03
	S_{MEOL}	mgCOD/l	0	0	0
	S_{AC}	mgCOD/l	15	0	0
	S_{PR}	mgCOD/l	5	0.01	0.01
	S_{F}	mgCOD/l	30	1.7	1,7
	$S_{INF,U}$	mgCOD/l	25	25	25
	$C_{INF,B}$	mgCOD/l	15	0	0
	$X_{INF,B}$	mgCOD/l	110	93	0,3
	$X_{PAO,PHA}$	mgCOD/l	1	12	0.04
	X_{OHO}	mgCOD/l	30	1318	4.8
	X_{AOO}	mg COD/l	1	40.0	0.15
	X_{NOO}	mgCOD/l	1	29.8	0.11
	X_{AMO}	mgCOD/l	1	18.5	0.07
	X_{PAO}	mgCOD/l	1	153.6	0.56
	X_{MEOLO}	mgCOD/l	1	17.1	0.06
	X_{ACO}	mgCOD/l	1	7.3	0.03
	X_{HMO}	mgCOD/l	1	8.6	0.03
	X_{PRO}	mgCOD/l	1	8.3	0.03
	$X_{INF,U}$	mgCOD/l	35	681	2.5
	$X_{E,OHO}$	mgCOD/l	0	221	0.8
INORGANIC MATTER	X_{MAP}	mgISS/l	0	0	0
	X_{HAP}	mgISS/l	0.1	1.9	0.01
	X_{HDP}	mgISS/l	0.1	0.0	0.0
	$X_{PAO,PPL}$	mgP/l	0	31	0.11
	$X_{PAO,PPH}$	mgP/l	0	10	0.04
	S_{NH4}	mgN/l	16	1.8	1.8
	S_{NO2}	mgN/l	0.1	0.2	0.2
	S_{NO3}	mgN/l	1.0	4.1	4.1
	S_{PO4}	mgP/l	2.2	0.55	0.55
	S_{CA}	mgCa/l	66	66	66
	S_{MG}	mgMg/l	12	11	11
	S_{CAT}	meq/l	2.5	2.4	2.4
	S_{AN}	meq/l	3.0	3.0	3.0
	S_{H2}	mgCOD/l	0	0.3	0.3
	S_{N2}	mgN/l	15	19	19
	S_{O2}	mgO$_2$/l	0.0	2.0	2.0

Combined variables		Units	Influent	Aerobic	Effluent
COD	$SC_{\_COD}$	mgCOD/l	90	27	27.5
	$X_{\_COD}$	mgCOD/l	184	2608	9.6
	$T_{\_COD}$	mgCOD/l	274	2636	37.0
BOD$_5$	$S_{\_BOD5}$	mgO$_2$/l	46	1	1.2
	$X_{\_BOD5}$	mgO$_2$/l	80	973	3.6
	$T_{\_BOD5}$	mgO$_2$/l	126	975	4.8
Residue	X_{ORG_R}	mgVSS/l	118	1775	6.5
	X_{IG_R}	mgISS/l	17	524	1.9
	$X_{\_R}$	mgTSS/l	135	2299	8.4
Nitrogen	S_{TKN_N}	mgN/l	17.3	3.3	3.3
	X_{TKN_N}	mgN/l	9.7	191	0.7
	T_{TKN_N}	mgN/l	27.0	194	4.0
	$T_{\_N}$	mgN/l	28.1	198	8.3
Phosphorus	X_{B_P}	mgP/l	1.8	1.7	0.01
	X_{U_P}	mgP/l	0.3	10.7	0.04
	$T_{\_P}$	mgP/l	6.6	118	0.98

Figure 3.15 Concentration of various components for a Phoredox process with 5 d SRT operated at 12°C

Table 3.26 Typical fractions of total COD for raw and primary effluent wastewaters

State variable	Fraction of TCOD	
	Raw wastewater	1^{ry} effluent
S_U	0.03 - 0.08	0.05 - 0.10
S_{VFA}	0.0 - 0.08	0.0 - 0.11
S_F	0.05 - 0.18	0.06 - 0.23
$C_{INF,B}$	0.47 - 0.53	0.29 - 0.36
$X_{INF,B}$	0.16 - 0.19	0.29 - 0.36
X_{OHO}	0.1	0.1
X_U	0.13	0.08

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