The EU funded SWIM-SM: developing capacity for Sustainable and Integrated Wastewater Treatment and Reuse

Online Course on Natural Treatment Systems: Wastewater and Sludge Characterisation

Wastewater (and sludge) characterisation

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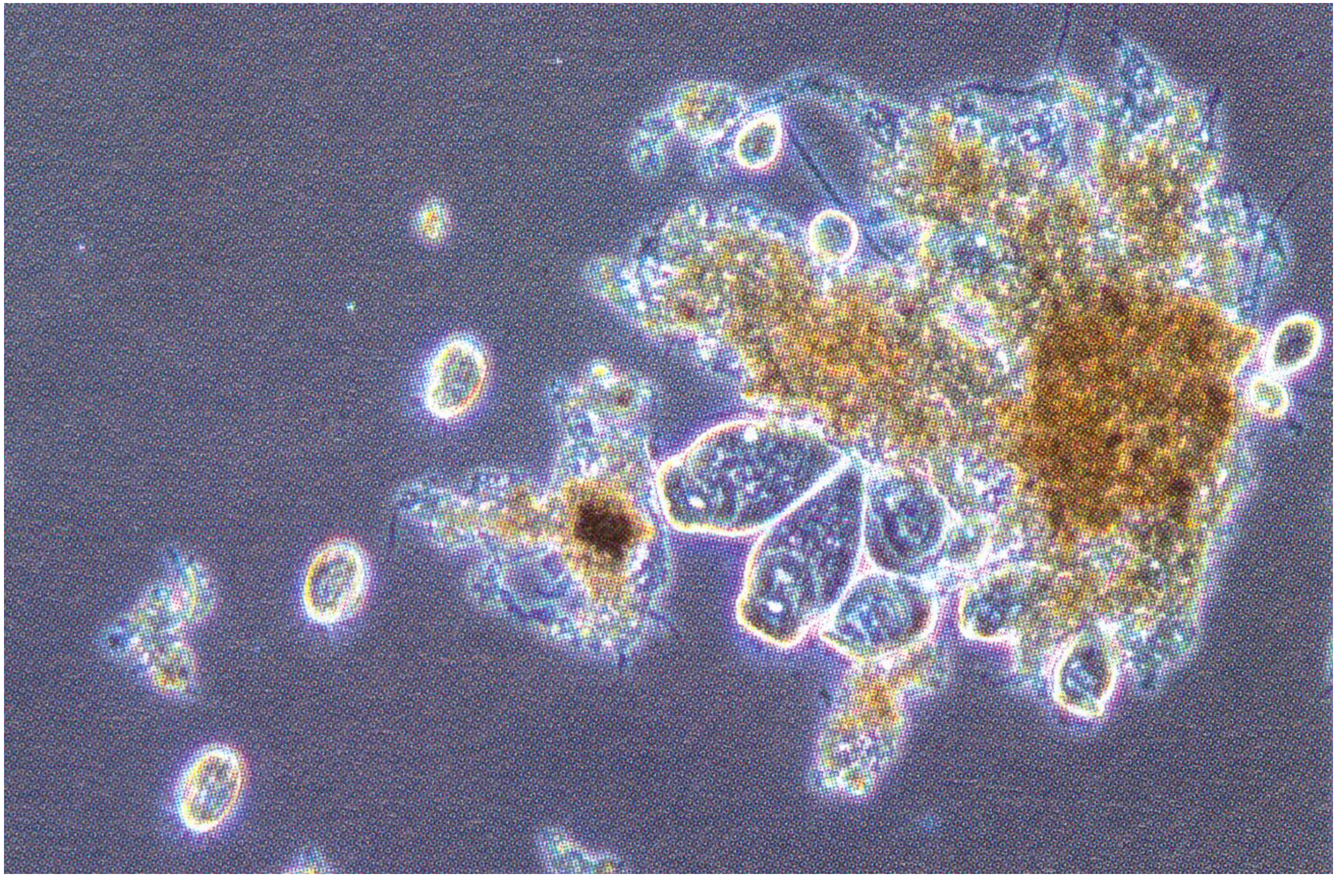


Table 3.2 Constituents present in domestic wastewater (based on Henze *et al.*, 2001)

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

Organic matter in WW

- composed of:

    carbon (C),

    hydrogen (H),

    oxygen (O)

    sometimes (N)

$C_{18}H_{19}O_9N$

- consists of:

    proteins (40-60%),

    carbohydrates (25-50%)

    oils and fats (8-12%)

    urea

    many synthetic org. molecules

Source: Wastewater Engineering, Metcalf & Eddy, 2002

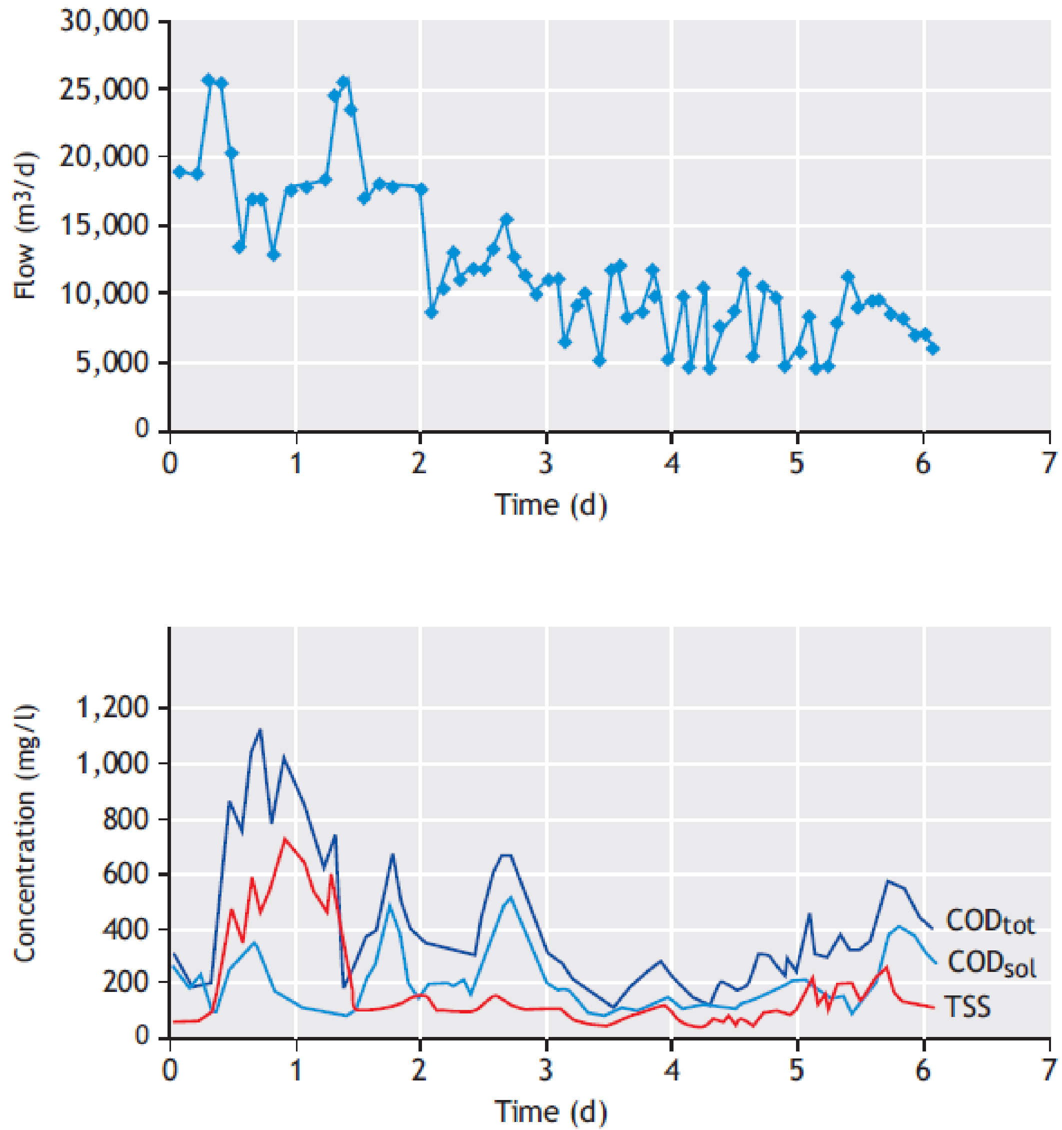


Figure 3.10 Variations in wastewater flow, COD and suspended solids (Henze *et al.*, 2002)

Analyses for organics in wastewater and their inter-relationship

Element	Name	Typical conc. ($g\ O_2/m^3$)	
		Raw wastewater	Biol. treated wastewater without nitrification
C_{CODp}	Chemical oxygen demand (with potassium permanganate in alkaline solution)	180	30
C_{BOD}	5-day biochemical oxygen demand	280	25
C_{BOD7}	7-day biochemical oxygen demand	320	30
$C_{BOD\infty}$	Total biochemical oxygen demand	400	35
C_{COD}	Chemical oxygen demand (with potassium dichromate)	600	100
$S_{S,COD}$	Easily biodegradable matter, measured as COD	60	5
$X_{S,COD}$	Slowly biodegradable matter	200	10
C_{TOD}	Total oxygen demand (at 900 °C, platinum catalyst)	800	230
C_{TOD} (theoretical)	Theoretical total oxygen demand*	850	270
C_{TOC}	Total organic carbon (at 800° C)	200**	35**
C_{TOC}(theoretical)	Theoretical TOC*	200**	35**

* Calculated stoichiometrically, if the content of organic matter is assumed to be known
** Unit: $g\ C/m^3$

UNESCO-IHE Institute for Water Education

Source: Wastewater Treatment, Henze et al., 1996

COD

Expressed as amount of oxygen required for chemical oxidation of organic matter by a strong oxidant (permanganate or dichromate) in acid solution.

Unit mg O_2/L

(consumption of permanganate or dichromate is converted into

An equivalent oxygen demand (amount of oxygen which will be consumed if the oxidation would have taken place by using oxygen)

Measuring organics: COD

- Bi-chromate as oxidizing agent
- High T
- Sulphuric acid
- All C oxidized to CO_2
- Actually: organics expressed as g oxygen, or g COD, which is required for oxidation
- COD of a compound can also be calculated (thOD)

BOD

Expressed as amount of oxygen required by the micro-organisms for oxidation of organic matter and ammonia

Unit mg O_2/L

Used to determine:

- the appr. amount of O_2 to biologically stabilize the organics in wastewater
- the size of wastewater facilities
- efficiency of some treatment processes
- compliance with wastewater discharge permits

CBOD

Principles of BOD test

Portion of the organics is oxidized to end products to obtain energy for cell maintenance and the synthesis of the new cell tissue

Some of the organics are converted into new cells using part of the energy released during oxidation

When organics become exhausted, the new cells begin to consume their own cell tissue to obtain energy for cell maintenance.

Oxidation: catabolism

CHONPS + O_2 + bacteria -> CO_2 + H_2O + NH_3 + end products + energy

Synthesis: anabolism

CHONPS + O_2 + bacteria + energy -> new cell tissue

Endogenous respiration

new cell tissue + $5O_2$ -> $5CO_2$ + $2H_2O$ + NH_3

Carbonaceous BOD: The oxygen needed for oxidation of only carbon present in the wastewater is called

NBOD

Conversion of ammonia to nitrite (by Nitrosomonas)

$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$ + energy

Conversion of nitrite to nitrate (by Nitrobacter)

$2NO_2^- + O_2 \rightarrow 2NO_3^-$ + energy

Overall conversion of ammonia to nitrate

$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$ + energy

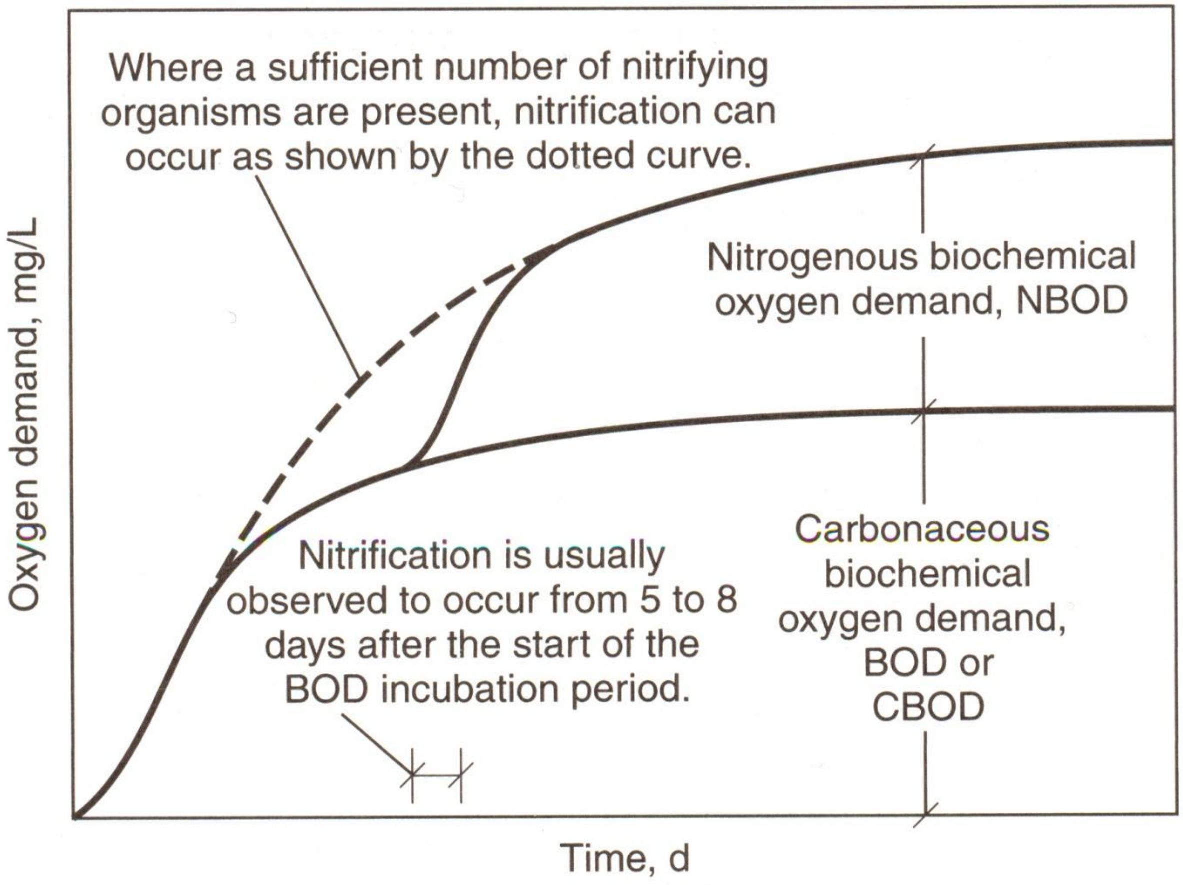
- 2 moles of O_2 for nitrification of 1 mole of N
- NCOD = 4.57 gO_2 per 1gN
- 2 moles of H+ produced: reduced sewage pH

Nitrogenous BOD:

The oxygen needed for oxidation of ammonia present in the wastewater to nitrate.

Source: Wastewater Engineering, Metcalf & Eddy, 2002

Typical CBOD and NBOD curve



$$BOD_t = BOD_5\ (1-e^{-k \cdot t})$$

$$k = k_{20°C} \cdot e^{t-20°C}$$

$k = 0{,}12 - 0{,}46\ d^{-1}$

(typical $0{,}23\ d^{-1}$)

Standard BOD test at 20°C and 5 days

$$BOD_5 = BOD_t\ (1-e^{-0{,}23 \cdot 5}) = 0.68\ BOD_t$$

Source: Wastewater Engineering, Metcalf & Eddy, 2002

Measuring organics: BOD

- No oxidizing agent, conversion by bacteria
- Need inoculum
- 5 days or 20 days test
- Add ATU (Allyl-thio-ureum)
- EU: BOD/COD ratio WW is 0.5

TOD

Amount of oxygen needed for oxidation of organics at a high temperature and use of suitable catalyst

Unit mg O_2/L

TOD > COD for the same sample

TOC

The difference between the carbon dioxide concentration obtained before and after oxidation of organics by heating.

Unit mg C/L

- TOC does provide the amount of carbon atoms
- TOC does not give information on the state of oxidation of C atoms
- TOC does not give information on how much oxygen should be used for oxidation

Two wastewater analyses both have a TOC-value of 12 g/m^3. One test contains methane and the other acetic acid.

Calculate the COD-values of the two samples (if everything is oxidized by the COD-analysis)

1. Methane CH_4.

1 mole of CH_4 contains 1 mole of carbon = 12 g, signifying that the wastewater contains 1 mole of CH_4.

Oxidation of methane:

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O \qquad (2.6)$$

Oxygen demand = $2\,O_2 = 2 \cdot (16 \cdot 2) = 64$ g oxygen.

COD = 64 g/m^3.

2. Acetic acid CH_3COOH

½ mole contains 1 mole of carbon = 12 g, signifying that the wastewater contains ½ mole of acetic acid.

Oxidation of ½ mole of acetic acid:

$$\frac{1}{2}\,CH_3\,COOH + O_2 \rightarrow CO_2 + H_2O \qquad (2.7)$$

Oxygen demand = $O_2 = 16 \cdot 2 = 32$ g

COD = 32 g/m^3

It appears that in spite of the same TOC-value, the two water types have very different COD-contents.

Alkalinity

Conductivity

Pathogens

Temperature

Odor and color

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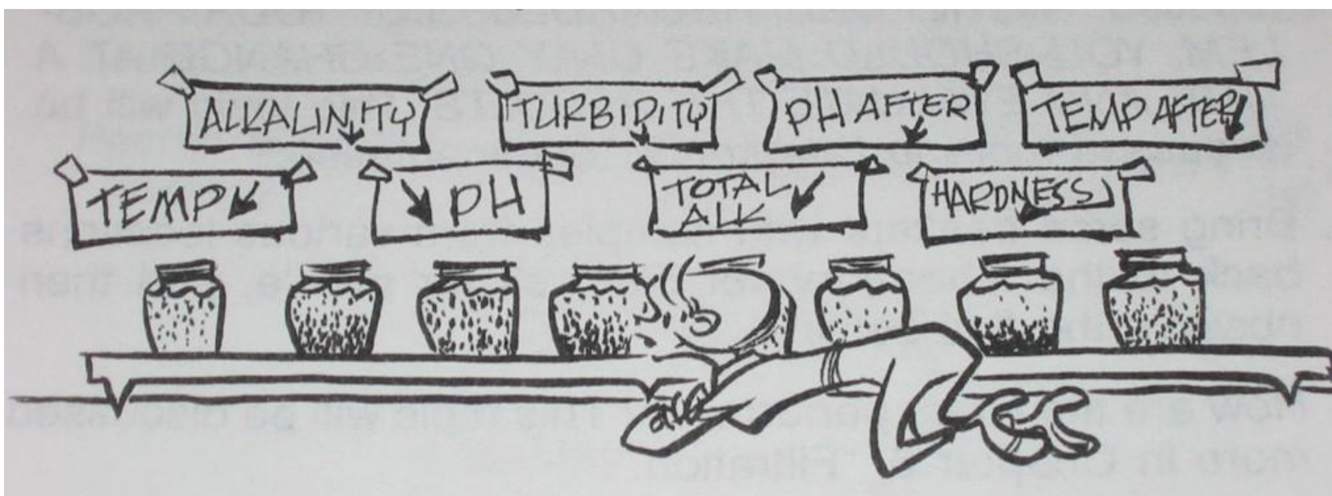
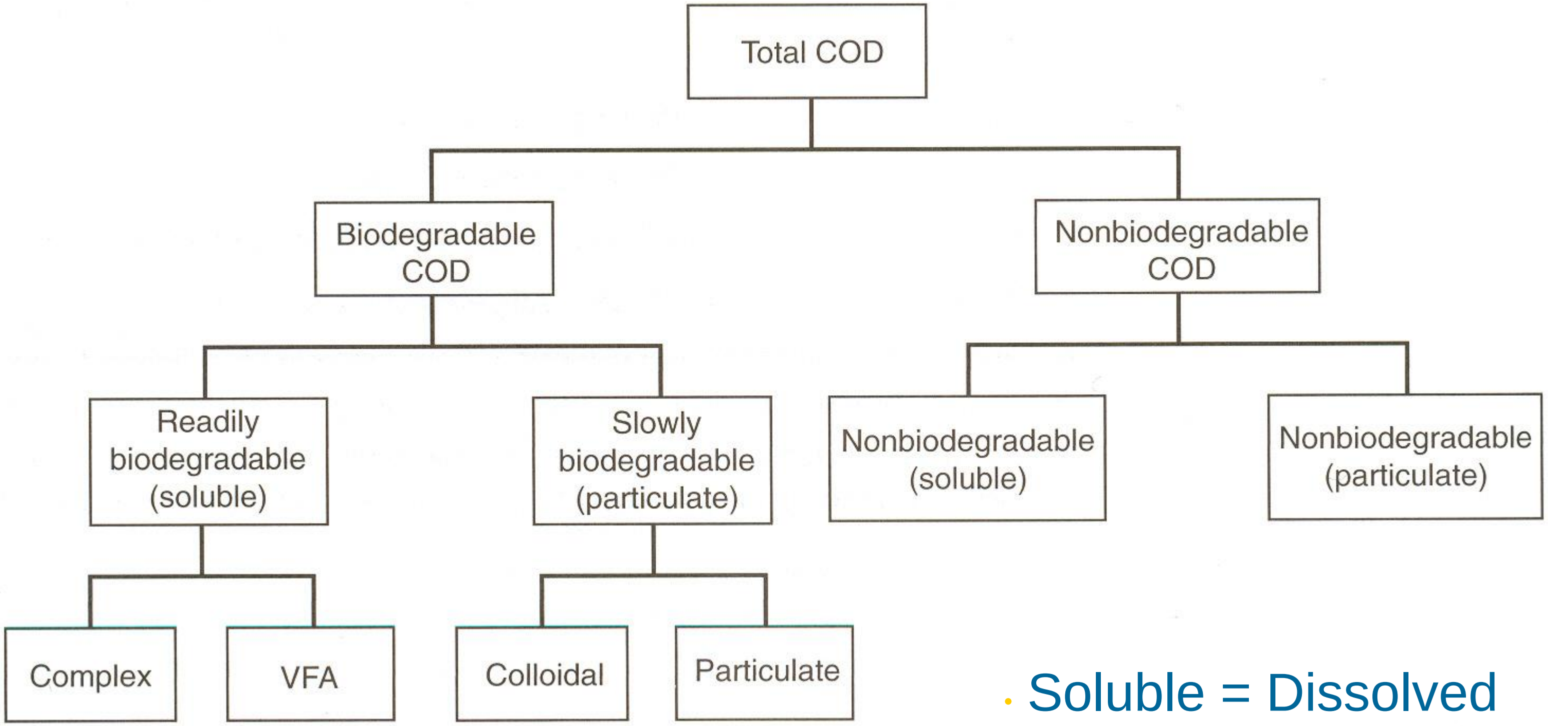


COD fractionation

- Not used for the day-to-day management control and operation of WWTPs
- Used for : design, operational tests, optimization, modeling



- Soluble = Dissolved
- Particulate = Suspended

COD, N and P fractionation

COD

$$C_{COD} = S_S + S_I + X_S + X_I$$

where
- S_S is (dissolved) easily biodegradable organic matter,
- S_I is dissolved biological inert organic matter,
- X_S is (suspended) slowly biodegradable organic matter,
- X_I is suspended biological inert organic matter.

N

$$C_{TN} = S_{NOX} + S_{NH4} + S_{I,N} + X_{S,N} + X_{I,N}$$

where
- C_{TN} is total nitrogen,
- S_{NOX} is nitrite + nitrate nitrogen,
- S_{NH4} is ammonium- + ammonia nitrogen,
- $S_{I,N}$ is dissolved inert organic nitrogen,
- $X_{S,N}$ is suspended easily degradable organic nitrogen,
- $X_{I,N}$ is suspended inert (organic) nitrogen.

P

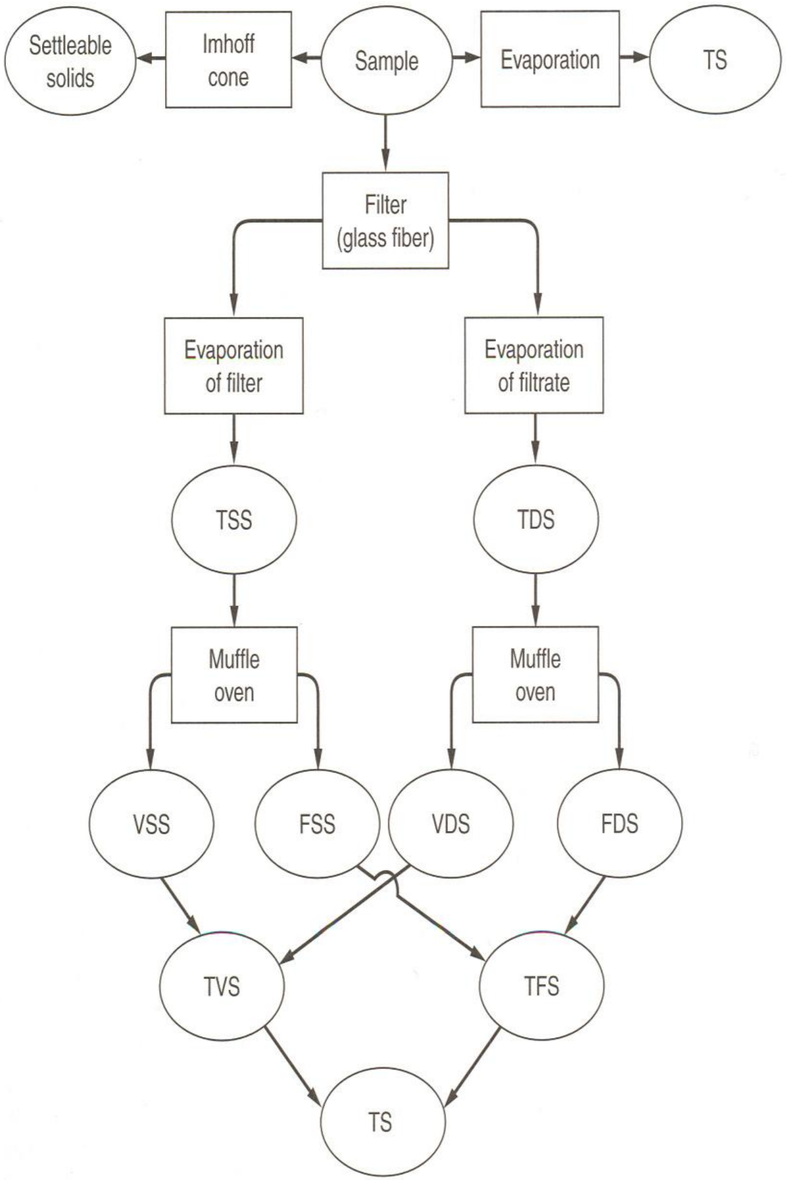
$$C_{TP} = S_{PO4} + S_{p\text{-}P} + S_{org.P} + X_{org.P}$$

where
- C_{TP} is total phosphorus,
- S_{PO4} is dissolved inorganic orthophosphate,
- $S_{p\text{-}P}$ dissolved inorganic polyphosphate,
- $S_{org.P}$ is dissolved organic phosphorus,
- $X_{org.P}$ is suspended organic phosphorus.

Fraction of N and P in municipal ww (g/gCOD)

Symbol	Component	Typical range	
		N	P
S_S	Readily (fermentable) biodegradable substrate	2-4	1-1.5
S_A	Volatile acids (acetate)	0	0
S_I	Inert, non-biodegradeable organics	1-2	0.2-0.8
X_I	Inert, non-biodegradeable organics	0.5-1	0.5-1
X_S	Slowly biodegradeable substrate	2-4	1-1.5
X_H	Heterotrophic biomass	5-7	1-2
X_{PAO}	Phosphorus-accumulating organisms	5-7	1-2
X_{PHA}	Stored poly-hydroxy-alkanoate	0	0
X_A	Autotrophic, nitrifying biomass	5-7	1-2

Classification of solids found in wastewater



Test[b]	Description
Total solids (TS)	The residue remaining after a wastewater sample has been evaporated and dried at a specified temperature (103 to 105°C)
Total volatile solids (TVS)	Those solids that can be volatilized and burned off when the TS are ignited (500 ± 50°C)
Total fixed solids (TFS)	The residue that remains after TS are ignited (500 ± 50°C)
Total suspended solids (TSS)	Portion of the TS retained on a filter (see Fig. 2–4) with a specified pore size, measured after being dried at a specified temperature (105°C). The filter used most commonly for the determination of TSS is the Whatman glass fiber filter, which has a nominal pore size of about 1.58 μm
Volatile suspended solids (VSS)	Those solids that can be volatilized and burned off when the TSS are ignited (500 ± 50°C)
Fixed suspended solids (FSS)	The residue that remains after TSS are ignited (500 ± 50°C)
Total dissolved solids (TDS) (TS − TSS)	Those solids that pass through the filter, and are then evaporated and dried at specified temperature. It should be noted that what is measured as TDS is comprised of colloidal and dissolved solids. Colloids are typically in the size range from 0.001 to 1 μm
Total volatile dissolved solids (VDS)	Those solids that can be volatilized and burned off when the TDS are ignited (500 ± 50°C)
Fixed dissolved solids (FDS)	The residue that remains after TDS are ignited (500 ± 50°C)
Settleable solids	Suspended solids, expressed as milliliters per liter, that will settle out of suspension within a specified period of time

[a] Adapted from Standard Methods (1998).

[b] With the exception of settleable solids, all solids values are expressed in mg/L.

Source: Wastewater Engineering, Metcalf & Eddy, 2002

SVI

SVI represents the volume occupied millimeters by 1 g of settled sludge

- SVI provides some information on flocculation and settling characteristics of the activated sludge
- The lower the SVI is, the better flocculation and settling of sludge
- SVI of 100 mL/g usually satisfactory indicator of good performance of activated sludge system
- Sludge density index (SDI) is the sludge concentration in the sludge phase after settling of 30 min (= $X_{0,5}$)

OUR

The oxygen consumption (in g O_2) by the microorganisms (in kg VSS) per hour

Unit $gO_2/kgVSS.h$

- Provides information on sludge condition

OUR of 20-40 $gO_2/kgVSS.h$:

sludge is activated (many living organisms)

sufficient substrate (organic matter) is presen

OUR of 5-10 $gO_2/kgVSS.h$:

the sludge is poisoned

no easily degradable organic matter is present

the sludge has been stabilized

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