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LAB SCALE SEQUENCING BATCH REACTOR CONSTRUCTION AND CHARACTERIZATION FOR DYNAMIC MODELLING WITH ACTIVATED SLUDGE MODEL

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ABSTRACT. Activated sludge wastewater treatment is one of the most commonly used domestic wastewater treatment methods. Modelling and simulation of the treatment process allow for a deeper insight into, and a better understanding of the system, enabling a better control of the treatment facility and high quality effluent production. The characterization of the system is crucial for getting accurate simulation results that correctly represent the studied system. In this paper we present the construction details of a laboratory-scale activated sludge sequencing batch reactor (SBR), and we provide a step-by-step description of the methodology used for wastewater and system characterization with the aim of process modelling and simulation. As the Activated Sludge Model No. 3 (ASM3) has been chosen for later modelling and simulation work, the fractionation of the wastewater was done such way to finally obtain the ASM3 state variables.

Keywords: *SBR, wastewater treatment, ASM3 modelling, wastewater fractionation*

INTRODUCTION

The modern activated sludge processes are reliable, produce high quality effluent and are considered to be the most cost-effective way for the removal of organic materials from wastewater [1]. Today's activated sludge wastewater treatment plants (WWTPs), besides the oxidation of organic matter, provide biological nutrient removal, meet the newest emission limits and are able to deal with the increasing magnitude and complexity of wastewater loads. Among other activated sludge systems, the SBR activated-sludge systems represent a re-emerging, highly efficient wastewater treatment technology, with several advantages over the continuous activated-sludge plants: they combine all of the

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treatment steps and processes into a single basin, or tank, whereas conventional facilities rely on multiple basins [2]; they can easily be controlled on a time-schedule; they are much less affected by the variation of hydraulic loads than the continuous plants, meaning that they can provide a constantly high pollutant removal efficiency.

Simulation models of activated sludge WWTPs have been successfully used for a number of tasks, such as WWTP design and retrofitting, process control and optimization. Simulation can also help the understanding of the underlying phenomena [3, 4]. While it is now widely accepted, that a mathematical model of a WWTP, able to predict how the plant will react under various operating conditions, is an excellent tool for the design, analysis, control, forecasting and optimization of WWTPs [5], modelling studies mainly focused on the more widespread, continuous activated sludge processes, SBR modelling being a bit neglected.

A number of activated sludge models (ASMs) exist, describing the biochemical processes involved in the technical purification of wastewater. Through these biochemical processes the organic matter and nutrient content of the wastewater is eventually converted into carbon-dioxide, nitrogen and a particulate fraction (cell material) [5].

The modelling of the biochemical processes is based on several basic kinetic equations, describing bacterial growth, substrate utilization and the endogenous metabolism (decay) of bacteria, as well as the hydrolysis of entrapped organics. In the last 40 years several activated sludge models have been developed, describing the biochemical processes in a various manner ([6]; [7]; [8]). The "state-of-the-art models" for activated sludge processes are considered to be the ASM1 – ASM3 models developed by the IWA Task Group [9]. These models incorporate carbon oxidation, nitrification, denitrification, and ASM2d also describes the biological and chemical phosphorus removal. The ASM models have been "updated" several times since the first coming out of the ASM1 and most of the problems identified in the earlier versions have been corrected. The models are based on COD units (use chemical oxygen demand to define carbonaceous material); ASM3 has a total organic carbon (*TOC*) based version as well.

The main difference between ASM1 and ASM3 is the recognition of the importance of storage polymers in the heterotrophic conversions in the activated sludge processes in ASM3 [4]. The aerobic storage process in ASM3 describes the storage of the readily biodegradable substrate (S_S) into a cell internal component (X_{STO}). This approach requires that the biomass is modelled with cell internal structure, similar to ASM2 which will be described later in this work. The energy required for this process is obtained via aerobic respiration. This internal component is then subsequently used for growth. In ASM3 it is assumed that all S_S is first taken up and stored prior to growth. A division of the storage and growth process, allowing growth to take place on external substrate directly, is not considered. The death regeneration concept is replaced by endogenous respiration, which is closer to the phenomena observed in reality. Also, ASM3 allows differentiating between aerobic and anoxic decay. Figure 1 illustrates the difference in COD flows between ASM1 and ASM3. The first thing to notice is that the conversion processes of both groups of organisms (autotrophs and heterotrophs) are clearly separated in ASM3, whereas the decay - regeneration cycles of the autotrophs and heterotrophs are strongly interrelated in ASM1. This change of decay concept (and introduction of the storage step) means that there exist more “entry” points for oxygen utilization resulting in, at some points, easier separation and characterization of the processes. Second, there is a shift of emphasis from hydrolysis to storage of organic matters. This gives a change in how wastewater characterization should be defined since the separation between S_S and X_S now should be based on the storage process rather than on the growth process. Still, the separation remains somewhat based on biodegradation rates. In ASM3 hydrolysis represents a less dominating importance on the rates of oxygen consumption since only hydrolysis of X_S in the influent is considered.

The compounds present in the wastewater are divided in 13 categories; these constitute the state variables of ASM3:

S_{ALK} - alkalinity of the wastewater [mole HCO_3/m^3] Alkalinity is used to approximate the conservation of ionic charge in biological reactions. Alkalinity is introduced in order to obtain an early indication of possible low pH conditions, which might inhibit some biological processes. For all stoichiometric computations, S_{ALK} is assumed to be bicarbonate, HCO3, only.

S_I - inert soluble organic material [g COD/m^3] The prime characteristic of S_I is that these organics cannot be further degraded in the treatment this material is assumed to be part of the influent and may be produced in the context of hydrolysis of particulate substrates X_S.

S_S - readily biodegradable organic substrates [g COD/m^3] This fraction of the soluble COD is directly available for consumption by heterotrophic organisms. In ASM3, for simplification, it is assumed that all these substrates are first taken up by heterotrophic organisms and stored in the form of X_{STO}.

S_{N2} - nitrogen [g N/ m^3] is assumed to be the only product of denitrification. S_{N2} may be subject to gas exchange, parallel with oxygen, S_{O2}.

S_{NH4} - ammonium plus ammonia nitrogen [g N/ m^3] For the balance of the ionic charges, S_{NH4} is assumed to be all NH_4^+.

S_{NOX} - nitrate plus nitrite nitrogen [g N/ m^3] S_{NOX} is assumed to include nitrate as well as nitrite nitrogen.

S_{O2} - dissolved oxygen [g COD/m^3] Dissolved oxygen can directly be measured and is subject to gas exchange.

X_A - nitrifying organisms [g COD/m^3] Nitrifying organisms are responsible for nitrification; they are obligate aerobic, chemo-litho-autotrophic. It is assumed that nitrifiers oxidize ammonium, S_{NH4}, directly to nitrate, S_{NOX}.

X_H - heterotrophic organisms [g COD/m^3] These organisms are assumed to be the all type heterotrophic organisms, they can grow aerobically and many of them also anoxically (denitrification). These organisms are responsible for hydrolysis of particulate substrates XS and can metabolize all degradable organic substrates. They can form organic storage products in the form of poly-hydroxyalkanoates or glycogen. X_H are assumed to have no anaerobic activity except cell external hydrolysis, which is the only anaerobic process in ASM3.

X_I - inert particulate organic material [g COD/m^3] This material is not degraded in the activated sludge systems it is flocculated onto the activated sludge. X_I may be a fraction of the influent and is produced in the context of biomass decay.

X_S - slowly biodegradable substrates [g COD/m^3] Slowly biodegradable substrates are high molecular weight, soluble, colloidal and particulate organic substrates which must undergo cell external hydrolysis before they are available for degradation. It is assumed that the products of hydrolysis of X_S are either readily biodegradable (S_S) or inert (S_I) soluble organics.

X_{SS} - suspended solids [g/m^3] Suspended solids are introduced into the biokinetic models in order to compute their concentration via stoichiometry.

X_{STO} - organics stored by heterotrophic organisms [g COD/m^3] It includes poly-hydroxy-alkanoates (PHA), glycogen, etc. It occurs only associated with X_H; it is, however, not included in the mass of X_H.

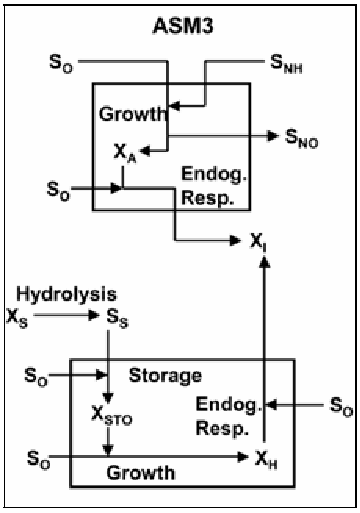

Figure 1. Substrate flows for autotrophic and heterotrophic biomass in the ASM1 and ASM3 models (modified from Gujer et al., 1999) [4]

There are a total of 12 biochemical processes modelled in ASM3. Figure 1 presents in a schematic way how the different compounds participate in the conversion processes. The kinetic expressions of the conversion processes are presented in detail elsewhere [9]; due to space limitations here only a list of them is provided:

- hydrolysis of organic matter in readily available soluble substrate
- anoxic and aerobic storage of soluble substrate
- growth of heterotrophic organisms under aerobic and anoxic conditions
- endogenous respiration of the heterotrophic organisms under aerobic and anoxic conditions
- aerobic growth of autotrophic organisms
- aerobic and anaerobic endogenous respiration of the autotrophic organisms
- aerobic and anaerobic respiration of the storage products

The ASM models however are all conceptual models, their state variables being conceptual wastewater fractions that are not commonly used in "real-world" wastewater characterisation and WWTP operation. Unlike the common wastewater indicators (such as pH, chemical oxygen demand (COD) or biochemical oxygen demand (BOD5)), the ASM fractions include readily and slowly biodegradable organic matter (S_S and X_S), heterotrophic and autotrophic organisms (X_H, X_A), biochemically inert soluble and particulate matter (S_I, X_I), etc. Fractionation in such conceptual groups of the wastewater components is called characterisation of wastewater for modelling purposes, and it is as important for successful modelling of the treatment process as the model itself. An adequate wastewater characterization is one of the dominating factors for the quality of model description.

It might be generally stated that the development of activated sludge models [9,10] led to a much better understanding of different treatment processes but it also required a more intensive wastewater characterization. In accordance with practical experiments, it was proposed that the biodegradable COD in the influent wastewater consisted of two fractions: readily and slowly biodegradable COD (S_s and X_s). The readily biodegradable COD was assumed to consist of simple molecules able to pass through the cell membrane and immediately used in biosynthetic processes by the organisms. Moreover, the active biomass was divided into two types of organisms: heterotrophic biomass (X_H) and autotrophic biomass (X_A) in accordance that which kind of substrate types they need for metabolism and process, autotrophic biomass produce nitrate (S_{NO}) from ammonium ions (S_{NH}) by nitrification process and heterotrophic biomass use oxygen (S_O) for the hydrolysis of substrate (S_S, X_S). The slowly biodegradable COD (X_S), which consists of larger complex molecules, was found to be enmeshed by the sludge mass, adsorbed and then required extracellular enzymatic breakdown before being transferred through the cell wall and used for metabolism.

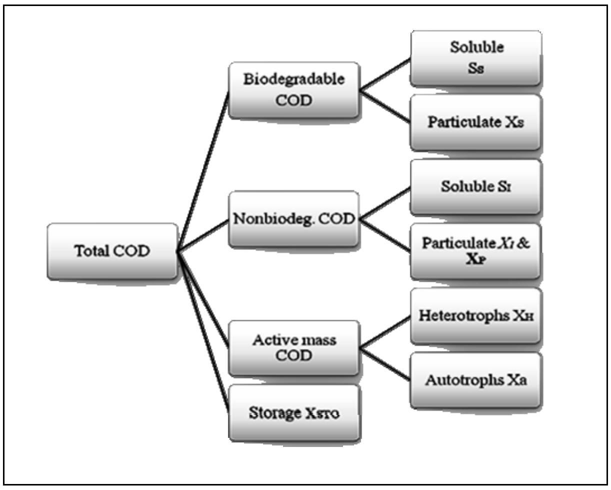

Figure 2. COD components in ASM3 (redrawn after Jeppson, 1996 [11])

Fractionation of the wastewater components is measurement-intensive and should be done with great care (possibly according to standardized protocols) when reliable simulation results are desired. In this work the standardized guidelines for wastewater characterization advised by the Dutch Foundation for Applied Water Research (STOWA) have been used. STOWA made an inventory of different methods and evaluated them on reproducibility and ease of use in practice [12]. Their standardized guidelines for wastewater characterization are based on a physical-chemical method to characterize the sum of the soluble COD fractions S_I and S_S. This is combined with a BOD-analysis for determining the biodegradable fraction of the influent COD (S_S+X_S). The fraction X_I is found as the difference between the total COD and other COD fractions. One important assumption in the fractionation of the influent COD is the negligence of biomass fractions in the influent. These fractions are usually very small in the influent and can be neglected in comparison with total COD [10]. Neglecting biomass assumption is sustained by the theory that the bacterial diversity in activated sludge is a product of selection by the environment rather than inoculation by wastewater [12].

RESULTS AND DISCUSSION

A laboratory-scale activated sludge SBR system has successfully been constructed and put in operation using artificial wastewater. The operating parameters of the SBR have been determined in order to get high COD removal efficiency. A treatment cycle of 4 h has been found to be adequate for providing a treatment efficiency of at least 90%. According to our settings a treatment cycle consists of:

- 15 minutes of fill phase
- 3 hours of aeration and mixing
- 30 minutes of settling
- 15 minutes of drawn phase

With such settings and a reactor load of 0.3 kg BOD_5/m^3/day, the resulting average COD removal efficiency of the reactor turned out to be around 92% (Table 1), which is in good concordance with literature values [14]. The duration of the different operation phases found by us are also are close to real-scale activated-sludge SBR operation phases. These reactor settings led to a sludge concentration in the reactor of MLSS = 1300 mg/l and to a SVI of the settled sludge of 98 ml/g. The goodness of the established process parameters is reflected also by the good settling properties of the activated sludge, meaning that “healthy” activated sludge flocs are formed during the treatment process. When trying to use longer aeration in order to further improve organic matter removal, an increase of the final DO values and a simultaneous decrease of the MLSS has been observed. Such behaviour can be explained by the lack of biodegradable substrate, leading to the intensification of the endogenous respiration of the microorganism.

Table 1. Effluent COD variation and COD removal efficiency of the SBR for 6 consecutive treatment cycles

Influent COD [mg/L]	Effluent COD [mg/L]	COD removal Efficiency %
575	40.81	92.9
575	37.77	93.43
575	26.21	95.44
575	55.71	90.31
575	49.45	91.4
575	53.62	90.67
Average: 575	**43.92**	**92.36**

The artificial wastewater used proved to be adequate for the activated sludge experimentation. The wastewater has been characterized according to the STOWA guidelines for wastewater characterization, in order to get input variables for later modelling work. The wastewater characterisation procedure proved to be very labour-intensive, but the results of the fractionation (presented in Table 2) give valuable information about the possibilities of the treatment process and the expectable removal rates. For example, the total biodegradable COD shows the potential of the treatment plant, and the particulate COD provides information about the expected sludge production.

Table 2. Results of the wastewater fractionation

Analysed parameters [mg/L]	Calculated components [mg/L]
$BCOD = 483 \pm 10.3$	$S_I = 17.35 \pm 0.35$
$COD_{\mathrm{inf},tot} = 575 \pm 12.5$	$S_S = 191.14 \pm 4.18$
$COD_{\mathrm{inf},sol} = 208.5 \pm 3.68$	$X_S = 292.38 \pm 10.11$
$COD_{eff} = 44.5 \pm 9.11$	$X_I = 74.61 \pm 5.52$

As can be seen in Table 2, the COD of the wastewater is around 575 mg/L, with a biodegradable part of 483 mg/L, which corresponds to 84%. Apparently this is contradictory to the measured COD removal of 92%. The explanation is, that not only the BCOD is removed during the treatment process, but also part of the biologically inert particulate COD (X_I) enmeshed into (and thus settled and removed together with) the activated sludge.

The ASM3 state variables obtained are summarized in Table 3. These variables can readily be used as inputs for ASM3-based WWTP models, enabling thus the simulation of the constructed reactor.

Table 3. The ASM3 fractions obtained from the wastewater characterization

No.	Variable name	Symbol	Value [mg/L]
1	Dissolved Oxygen	S_{O2}	0
2	Soluble inert organics	S_I	17.35988
3	Readly biodegradable substrate	S_S	191.1401
4	Ammonium	S_{NH4}	6.4
5	Dinitrogen	S_{N2}	0
6	Nitrite plus nitrate	S_{NOx}	0
7	Alkalinity, bicarbonate	S_{Alk}	5
8	Inert particulate organics	X_I	74.6103
9	Slowly biodeg. Substrate	X_S	292.3899
10	Heterotrophic biomass	X_H	0
11	Organics stored by heterotrophs	X_{STO}	0
12	Autotrophic biomass	X_A	0
13	Total suspended solids	X_{SS}	483.53

CONCLUSIONS

The constructed lab-scale activated-sludge SBR and the established process parameters provide satisfactory wastewater treatment, achieving very good pollutant removal efficiency. The characterization of the artificial wastewater following the STOWA guidelines proved to be labour-intensive, but it is pretty straightforward, and it can be performed using basic experimental equipment.

The wastewater fractionation done in this work opens the possibility of modelling and simulation of the treatment process, as the parameters calculated can directly be used as input variables for the ASM3. Future modelling will allow for the optimisation of the process, bettering also the nitrogen removal. Moreover, since this paper provides the detailed composition of the artificial wastewater, other modellers also can use the results of the fractionation as input for their models, saving precious time and work. The obtained wastewater fractions present high similarity with literature values for urban wastewater. The stringency of the analysis and the truthfulness of the calculated parameters can be further tested in the calibration process of the mathematical model of the treatment process.

EXPERIMENTAL SECTION

Reactor details and set-up

The laboratory scale reactor used in this study is of cylindrical shape, with a diameter of 190 mm and a height of 320 mm. The reactor was made of 5 mm thick Plexiglas (10 mm thick at the bottom) and has a total volume of 9 litre, of which 6 litres are effectively used (Figure 3). In each treatment cycle 1 l of raw wastewater was added to 5 l of mixed liquor present in the reactor (left from the previous cycle).

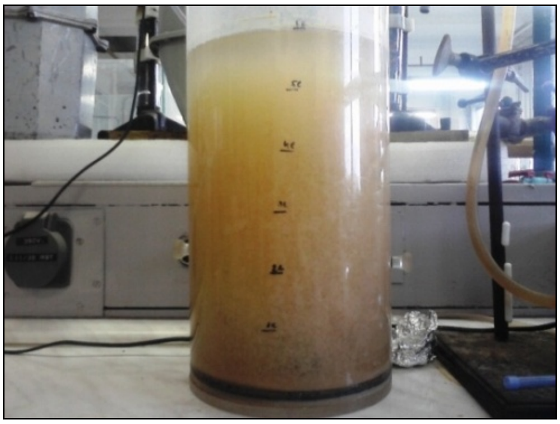

Figure 3. The constructed lab-scale SBR reactor

The aeration equipment consists of an air pump with a nominal 5 L/min air flow rate and two pieces of coarse aquarium aeration elements positioned at the bottom of the reactor (fine ceramic aeration elements were also tried but they proved to be unsuitable because of clogging with activated sludge). The concentration of the dissolved oxygen was kept during aeration at DO = 2.2±0.2 mg/l. DO levels were measured using a luminescent DO sensor. In addition to the pneumatic mixing induced by aeration, additional mixing was provided with a magnetic laboratory stirrer at 500-600 rpm. The reactor has been operated at room temperature; however, at the beginning of each treatment cycle a small temperature drop was observed, due to the low temperature influent (synthetic wastewater kept at 4ºC to avoid deterioration).

The seed sludge was taken from the activated sludge tank of the municipal wastewater treatment plant of Veszprém (Hungary). Excess sludge has been removed at the end of each complete cycle such way to keep the sludge retention times at 6 days. After the settling phase, a sludge volume index of SVI = 98 ml/g was obtained. Mixed liquor suspended solids concentration (MLSS) was approx. 1300 mg/l for each new treatment cycle.

In order to minimize odour problems in the laboratory, synthetic wastewater has been used for this work (for its exact composition see Table 4). The use of synthetic wastewater has also the advantage of having a known composition that makes fractionation easier. The COD/N/P ratio of the synthetic wastewater was around 100:17:5, its theoretical BOD_5 was 300 mg/l, assuming a COD to BOD conversion factor of 0.65. [15]

Table 4. Composition of the synthetic wastewater used in the experiments, modified from Nopens*et al.* 2001 [15]

	mg/l		**mg/l**
Chemical Compounds		***Trace Metals***	
Urea	91.74	**$Cr(NO_3)_3.9\ H_2O$**	0.770
NH_4Cl	12.75	**$CuCl_2.2\ H_2O$**	0.536
o Na-acetate . $3H_2O$	131.64	**$MnSO_4.\ H_2O$**	0.108
Peptone	17.41	**$NiSO_4.6\ H_2O$**	0.336
$MgHPO_4.3H_2O$	29.02	**$PbCl_2$**	0.100
KH_2PO_4	23.4	**$ZnCl_2$**	0.208
$FeSO_4.7H_2O$	5.80		
Food ingredients			
Starch	122.00		
Milk powder	116.19		
Yeast	52.24		
Soy oil	29.02		
Total	**631.21**		

The efficiency (E) of COD removal of the reactor was calculated as follows: $E\ (\%) = [(COD_{influent} – COD_{effluent}) / COD_{influent}] \times 100$. For the determination of the nominal efficiency, six sets of measurements have been performed for six complete treatment cycles, and the average efficiency was calculated (Table 1).

MLSS, COD and SVI measurements were performed according to *Standard Methods* [16].

Wastewater characterization

Determination of the organic and inorganic fractions

For the future modelling of our activated sludge SBR we have chosen the ASM3, the most recent activated sludge model developed by the International Water Association [3]. Thus wastewater characterization was done with the aim of obtaining the ASM3 state variables. Wastewater fractionation has been done according to the STOWA wastewater characterization guidelines [12]. This protocol seemed to be somewhat simpler than other methods and the artificial wastewater used for this work has no microorganisms at all, meaning that the simplifying assumptions of STOWA are completely correct in this case. More detailed (and also more measurement-intensive) wastewater characterisation methods can be found in the literature [11, 12 and 13].

The working sequence was composed of the following steps:

1. Determination of S_I based on the inert soluble COD in the effluent of the WWTP.
2. Determination of S_S by subtracting the fraction S_I from the soluble COD in the influent.
3. Determination of X_S by subtracting the fraction S_S from the biodegradable COD (BCOD, Figure 5.)
4. Determination of X_I with the equation presented in table 5.

For the determination of S_S and S_I filtration and chemical precipitation was used to differentiate the soluble components in the wastewater. After filtration on 1.2 µm pore size filter the particulate fractions of the wastewater are mainly held up by the filter but colloidal part of COD (S_{COL}) still making part of the particulate fraction can pass and chemical precipitation is needed prior to a 0.45 µ membrane filtration (Figure 4) to separate this fraction. Chemical precipitation/flocculation was made using $ZnSO_4$ and NaOH. Since both biodegradable and inert COD pass through the 0.45 µm pore size filter, the inert fraction S_I has to be determined independently and subtracted from the soluble COD to give the fraction S_S.

The biodegradable COD (BCOD) in the influent is the sum of the readily biodegradable soluble COD (S_S) and the slowly biodegradable particulate COD (X_S). According to the STOWA the BCOD fraction is determined from BOD analysis where BOD is measured as a function of time. BOD_5 is determined in general but does not represent the total biodegradable fraction of the COD. Depending on the wastewater, 50 - 95 % of the COD is oxidized after 5 days, and after 20 days 95 - 99 % of the COD is oxidized. The total biodegradable fraction of the COD can be calculated by following the BOD-course as a function of time, and calculating BOD_{tot} of the wastewater. Figure 5 shows the BOD curve of the synthetic wastewater, together with the equations used for BOD_{tot} and BCOD calculations. On days 1-10 two parallel BOD measurements were performed for increased accuracy.

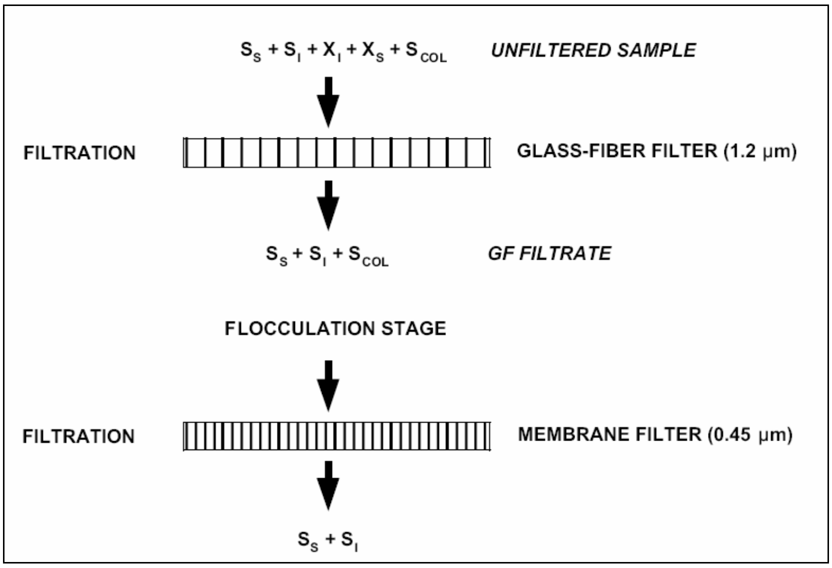

Figure 4. Retention/Passage of Influent Wastewater COD Components through Sequential1.2 μm Glass-Fiber Filtration, Flocculation and 0.45μm Membrane Filtration [13]

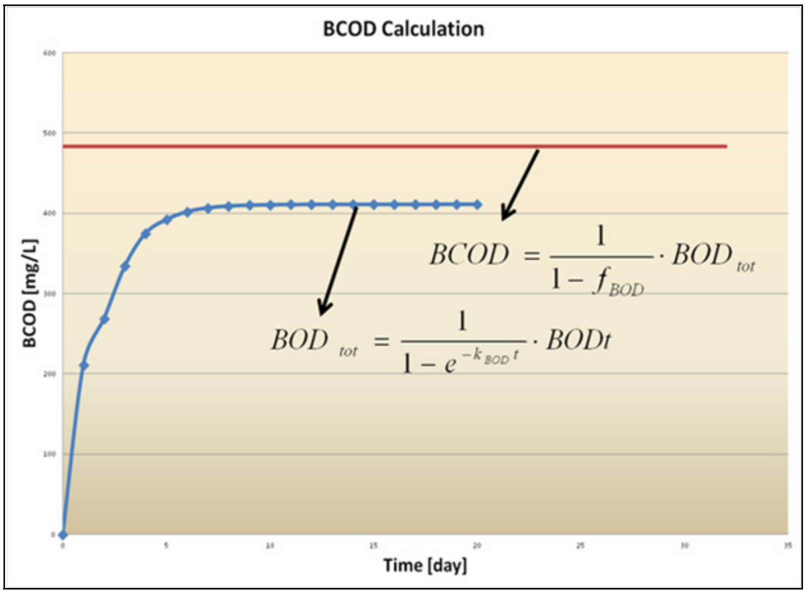

Figure 5. Fitted BOD curve for determination of k_{BOD}, BOD_{tot} and BCOD.k_{BOD} constant is the first order constant of the BOD vs. time measurements and can be determined by fitting the BOD-curve on the measured data with BOD_{tot} equation [12].

During the BOD-measurements there is an interaction of growth and decay of biomass, and for long-term BOD measurements this results in the partial conversion of the biodegradable COD into an inert fraction. Therefore, the initial concentration of BCOD will be higher than the determined BOD_{tot} and a correction factor (f_{BOD}) has to be used. For f_{BOD} a value of 0.15 (0.1-0.2) can be taken, which is in close accordance with the ASM literature value for inert COD [12].

Determination of the nitrogen fraction of the wastewater

The major part of the nitrogen in a wastewater treatment system is present as ammonium, which has no coupling to organic components and can be measured analytically. For this synthetic wastewater the ammonium concentration is 6.3 mg/L. For the calculus of the organic part of the nitrogen fixed nitrogen conversion factors can be used (i_N) for the various COD components [11, 12, 13]. These conversion factors represent the nitrogen part of different COD components playing role in the total nitrogen load of the system (Table 5.)

Table 5. Conversion factors for nitrogen

Conversion factors for nitrogen		Typical Ranges
i_{NSI}	0.01 g N/g COD	0.01-0.02 g N/g COD
i_{NSA}	0 g N/g COD	0 g N/g COD
i_{NSF}	0.03 g N/g COD	0.02-0.04 g N/g COD
i_{NXI}	0.03 g N/g COD	0.01-.06 g N/g COD
i_{NXS}	0.04 g N/g COD	0.02-0.06 g N/g COD

The equations required for the calculus of the different wastewater components are summarized in Table 6.

Table 6. Equations of calculating the different wastewater fractions as applied in activated sludge models

Equations for wastewater characterization	Calculation of wastewater characteristics
$COD_{\inf,tot} = S_I + S_S + X_I + X_S$ assumption $X_A, X_H = 0$	$S_I = 0.9 * COD_{eff}$ for low loaded WWTP [12]
$COD_{\inf,tot} = COD_{\inf,sol} + COD_{\inf,part}$	$S_S = COD_{\inf,sol} - S_I$
$COD_{\inf,sol} = S_I + S_S$	$X_S = BCOD - S_S$
$COD_{\inf,part} = X_I + X_S$	$X_I = COD_{\inf,tot} - S_I - S_S - X_S$
$BCOD = S_S + X_S$	$X_A, X_H = 0$
$N_{tot} = S_{NH} + S_{NO} + S_{N_2} + i_{NSI} \cdot S_I + i_{NSS} \cdot S_s + i_{NXS} \cdot X_S + i_{NBM} \cdot (X_H + X_A) + i_{NXI}$	
$COD_{tot} = S_I + S_S + X_I + X_S + X_H + X_A$	

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