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MEASUREMENT OF COMPOSITION OF ORGANIC CONSTITUENTS OF MUNICIPAL WASTEWATER FOR PLANT-WIDE MODELLING

By

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ABSTRACT

Historically wastewater treatment unit operation models have been developed in isolation. Attempts have been made at creating common platform models, which would allow modellers to speak a common language when researching wastewater treatment modelling. However, few attempts have been made at integrating different models into a plant-wide WWTP simulation model. Increasing pressure towards the optimisation of water treatment systems have prompted investigation into integrated WWTP modelling.

The use of different state variables in WWTP unit operation models has meant that modelling incompatibilities exist in the theoretical coupling of certain models. Attempts made towards the development of integrated WWTP models have experienced difficulties due to a number of factors. State variables required in one model may be non-existent in other models, the definition of state variables may be different between different unit process models and compounds that are considered constant in a unit process model may be a state-variable in another unit process model Thus the difficulties in coupling different unit process models are mainly due to differences in state variable meaning and occurrence in different unit process models.

Recent approaches towards the development of plant-wide WWTP simulation models have included the continuity based interfacing method (CBIM) of Vanrolleghem et al. (2005) and Volcke et al. (2006), the 'supermodel approach' of Jones &Tákacs (2004 cited in Grau et al 2007) and Seco et al. (2004 cited in Grau et al 2007) , the transformation based approach of Grau et al. (2007) and the mass balances based plant-wide WWTP model approach of Ekama et al. (2006 a,b), Sötemann et al. (2006) and Wentzel et al. (2006). The use of compounds in their elemental composition forms, viz. C, H, O, N, P and charge content, as part of a method to transform incompatible unit process state variables into compatible forms is a general theme in integrated modelling approaches. The elemental compositions of readily biodegradable (RB), slowly biodegradable (SB), unbiodegradable soluble (US) and unbiodegradable particulate (UP) organic compounds are often unknown. Little practical investigation into their determination for the purpose of integrated WWTP modelling has been performed.

This project was therefore focussed on the determination of wastewater compound elemental compositions, with the inclusion of carbon data, for integrated WWTP modelling purposes. The aims of this project were therefore two fold, viz. an investigation into current whole WWTP integration model approaches and the performance evaluation of a simple batch test method for the determination of organic compound elemental compositions over a standard WWTP incorporating primary settling, an AS reactor as well as primary sludge and WAS anaerobic digestion.

A simple anaerobic batch test approach towards determining wastewater organics total, biodegradable and unbiodegradable as well as soluble and particulate fraction elemental compound compositions was investigated. This approach was evaluated according to the fulfilment of three research objectives, viz. (1) the fractionation of raw wastewater, PS and WAS organics into biodegradable and unbiodegradable soluble and particulate components, (2) the fractionation of raw wastewater concentrations (C,N,COD,VS) into settlable and colloidal particulate organic material, (3) the determination of the organic compositions of the form $C_xH_yO_zN_a$ for the above wastewater and sludge fractions. Research performed by Wentzel et al. (2006) and Ekama et al (2006 b) have supported the notion that organic material termed unbiodegradable from an activated sludge

standpoint remain unbiodegradable under anaerobic digestion processes. Thus, the use of an anaerobic batch test method for determination of unbiodegradable organic compositions over a plant-wide WWTP was considered to be valid.

The first experimental research objective, viz. the fractionation of raw wastewater, PS and WAS into unbiodegradable and biodegradable fractions was considered to have been achieved. However, the accuracies of these fractionations were found to be inadequate to determine colloidal and settlable raw wastewater unbiodegradable and biodegradable fractions. Four different calculation methods with different requisite data sets were used to calculate particulate organic compound elemental compositions. The results were variable and this was ascribed to data inaccuracy. The calculation methods used for the determination of organics compositions was found to be highly sensitive to input variable error. This indicated that the indirect determination of particulate organics compositions requires measured data of very high accuracy. It was considered doubtful whether such accuracies may be achieved with the batch test method evaluated in this chapter. Therefore the second and third experimental research objectives, viz. the fractionation of raw wastewater concentrations into settlable and colloidal particulate organic material and the determination of unbiodegradable and biodegradable organics compositions for different wastewater streams could not be ascertained with the batch test method used. Therefore, the batch test method designed and evaluated in this project was considered to be invalid for the determination of readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate organic compound elemental compositions at links between unit operations over a WWTP.

SYNOPSIS

1. BACKGROUND

Historically wastewater treatment unit operation models such as activated sludge and anaerobic digestion have been developed in isolation. Attempts have been made at creating common platform models, which would allow modellers to speak a common language when researching wastewater treatment modelling. Thus, the activated sludge models ASM1, ASM2, ASM2d and ASM3 and the anaerobic digestion model ADM1 have been developed and widely accepted. These models have been commonly used as a basis for further model development (Vanrolleghem et al 2005). However, few attempts have been made at integrating different models into a plant-wide WWTP simulation model. WWTP emissions were traditionally considered to be the most important focus of WWTP modelling. This view is changing due to increasing pressure towards the optimisation of water treatment systems. WWTP treatment processes are physically integrated and have great impact on one another e.g. nitrogen removal during activated sludge processes are affected by the recycled sludge stream removed from the AS reactor. Thus, the integration of WWTP unit operation models is necessary for the optimisation of WWTP systems as a whole.

Unit operations in wastewater treatment have different functions and are thus inherently different in the physical, chemical and biological processes they retain. Process differences have resulted in the development of models that rely on different variables (state variables). The use of different state variables has meant that modelling incompatibilities exist in the theoretical coupling of certain models. Attempts have been made towards the development of integrated WWTP models; however, difficulties have been experienced due to a number of factors. One such factor is that state variables required in one model may be non-existent in other models e.g. carbon is usually not included in activated sludge models, but is of high importance in anaerobic digestion models. The definition of state variables may also be different between different unit process models e.g. biodegradable components in one model may not be biodegradable in another (Vanrolleghem et al 2005). Compounds that are considered constant in a unit process model may be a state-variable in another unit process model e.g. pH is considered to be constant in the ASM models but is a state variable in the SHARON model (Volcke et al 2006). Thus the difficulties in coupling different unit process models are mainly due to differences in state variable meaning and occurrence in different unit process models.

2. CURRENT INTEGRATED PLANT-WIDE WWTP MODELLING APPROACHES

Recent approaches towards the development of plant-wide WWTP simulation models have included the continuity based interfacing method (CBIM) of Vanrolleghem et al. (2005) and Volcke et al. (2006), the ‘supermodel approach’ of Jones &Tákacs (2004 cited in Grau et al 2007) and Seco et al. (2004 cited in Grau et al 2007) , the transformation based approach of Grau et al. (2007) and the mass balances based plant-wide WWTP model approach of Ekama et al. (2006 a,b), Sötemann et al. (2006) and Wentzel et al. (2006). All of these approaches have been aimed at circumventing the model interfacing difficulties caused by state variable incompatibilities. A general theme in the model approaches is the use of compounds in their elemental composition forms, viz. C, H, O, N, P and charge content, as part of a method to transform incompatible unit process state variables into compatible forms.

The CBIM approach and the mass balances based plant-wide WWTP model approaches have been designed to leave the existing unit process models unaffected. The CBIM approach requires the production of model interfaces in which state variables from the origin model are transformed to become compatible with state variables from the destination model. The mass balances based plant-wide WWTP model approach uses models that already retain compatible state variables, with the exception of biodegradable organics compositions requirement for the AD steady state model of Sötemann et al. (2005). This requirement is fulfilled through the inclusion of stoichiometry theory over the plant-wide WWTP. Thus, the above stated models impose new modelling techniques over and above the use of existing unit process models. In contrast to this, a requirement for the transformation-based approach is the re-writing of current unit operation models to contain a common set of compatible state variables. Though this eliminates the need for model interfaces, it may become a momentous task. Current unit process models are often excellent representations of reality and thus careful consideration must be given towards the need to change them in order to create a plant-wide WWTP simulation model.

The CBIM approach leaves a large degree of freedom to the user of the approach in the definition of the transformation matrices used in this method. It has been proposed that such definitions are performed based on process knowledge and insight by the user of the method. This may result in different solutions to specific WWTP simulation problems solved by different users. Thus, though the CBIM approach has initially been aimed at providing a basis for the development of plant-wide WWTP simulation models, it diverts from this notion by allowing a large degree of reasoning to be subjective to the user (Volcke et al 2006).

All of the simulation strategies discussed above requires the determination of biodegradable and unbiodegradable organics elemental compositions of the form $C_xH_yO_zN_a$ in relevant Waste Water Treatment Plant (WWTP) streams. The CBIM and transformation-based approaches requires the elemental compositions of all state variables in all WWTP models. The mass balances approach requires biodegradable organics compositions for the anaerobic digestion of sludge (primary of waste activated) as well as unbiodegradable organics compositions for carbon balances over unit operations and the plant-wide WWTP model. The elemental compositions of standard compounds, such as volatile fatty acids, proteins, lipids etc. are known. However, certain organic compounds consist of (possibly) variable and unknown compositions. These compounds comprise readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate components. Case studies performed with the above methods have relied on assumptions regarding the compositions of these compounds. Thus, no practical investigation into their determination was performed. An investigation towards the solution of this problem has been performed in this project

3. DESIGN AND EVALUATION OF AN AD BATCH TEST METHOD FOR ORGANICS COMPOSITIONS DETERMINATION: METHODOLOGY

3.1. Introduction

The aim of this investigation was to design and evaluate a simple batch test method for determination of organics compositions in wastewater streams over a WWTP. Therefore, an attempt was made to determine total, unbiodegradable and biodegradable soluble and particulate organics compositions of the form $C_xH_yO_zN_a$ in raw wastewater, settled wastewater, primary sludge (PS) and waste activated sludge (WAS).

3.2. Theoretical approach

Wastewater organic fractions for modelling purposes have in the past typically been divided into biodegradable and unbiodegradable fractions. Furthermore, biodegradable fractions have been divided into readily (RB) and slowly (SB) biodegradable components, while unbiodegradable fractions have been divided into soluble (US) and particulate (UP) components as was done in the IWA ASM models (Henze et al 2000). These terms and definitions have been adhered to in this investigation. The determination of biodegradable and unbiodegradable fractions of soluble and particulate organic constituents (C,H,O,N) and parameters (COD,VSS) that compose and define organics compositions (of the form $C_xH_yO_zN_a$) is necessary. A simple anaerobic batch test approach towards determining wastewater organics total, biodegradable and unbiodegradable as well as soluble and particulate fractions was investigated. Research performed by Wentzel et al. (2006) and Ekama et al (2006 b) have supported the notion that organic material termed unbiodegradable from an activated sludge standpoint remain unbiodegradable under anaerobic digestion processes. Thus, the use of an anaerobic batch test method for determination of unbiodegradable organic compositions over a plant-wide WWTP was considered to be valid.

Wastewater particulate or soluble organics compositions may theoretically be directly measured or derived via a number of methods. It was hypothesized in this project that the unbiodegradable fraction of particulate or soluble organics may be determined from the residual matter after biodegradation processes (aerobic or anaerobic) have degraded all biodegradable material. Once particulate and soluble organics compositions and molar concentrations have been obtained, total organics compositions may be calculated. There is, as yet, no method for the determination of the biodegradable organic fraction and it's relative constituents (C,H,O,N,COD,VS) directly in wastewater streams. The total organic fraction of a wastewater stream may be determined with direct constituent measurement. Therefore, the biodegradable fraction of a wastewater type (raw wastewater, settled wastewater, primary sludge, waste activated sludge) is the difference between it's total and unbiodegradable fraction. Wastewater organics compositions were considered to consist mainly of the elements carbon, hydrogen, oxygen and nitrogen. This approach has been followed by the authors of the integrated WWTP modelling approaches. The theory described in this paper for the determination of organics compositions from measured data may be easily extended to include Phosphorus. Phosphorus measurements were included in this project for batch test mass balances considerations and as an element in the particulate organics compositions calculation method 3 only. The content of the elements carbon, hydrogen, oxygen and nitrogen in specific wastewater fractions may be tested for and derived in a variety of ways.

Experimental methodology

An anaerobic digestion batch test method with long standing times was employed in an attempt to obtain the total (particulate and soluble) and unbiodegradable particulate organics fraction of raw wastewater, primary sludge and waste activated sludge. Successful determination of these fractions enables the determination of the biodegradable fraction of the above stated wastewater types as discussed above. The settled wastewater (colloidal) total, biodegradable and unbiodegradable particulate fractions were considered to be obtainable as the difference between raw wastewater and primary sludge total, biodegradable and unbiodegradable particulate fractions.

Waste activated sludge for the experiment was obtained from a Modified Ludzack-Ettinger (MLE) system at the University of Cape Town. This system was fed raw wastewater from the same source as used for the raw wastewater and primary sludge batch tests. The source was the Mitchell's Plain WWTP (Cape Town). The unbiodegradable soluble organics fraction of raw wastewater, settled wastewater, primary sludge and waste activated sludge was assumed equal over a wastewater treatment system. Therefore, it was obtainable from organics constituent measurements on the treatment system effluent.

The batch test experimental setup comprised 6 batch test groups (BTG's). Each batch test group contained 3 batch tests. The contents of the batch tests per BTG comprised flocculated raw wastewater sludge (FS), primary sludge (PS) and waste activated sludge (WAS). Total COD, TKN and TP measurements were made on raw wastewater (Fig.3.2 a below), settled wastewater and unconcentrated WAS (points 1, 3 and 4). Raw wastewater was flocculated to produce flocculated raw wastewater sludge; and settled to produce primary sludge. Unconcentrated WAS was settled to produce concentrated WAS sludge. Dissolved measurements (COD, TKN, FSA, TP, OP, DOC) were made on flocculated raw wastewater and WAS 0.45 µm membrane filtered supernatants (points 2 and 4). Wastewater sludge were inserted into 2L Erlenmeyer flasks and were buffered and inoculated with anaerobic seed. Samples were taken from the batch tests for solids (TSS, VSS and ISS) testing and elemental analysis (C,H,N,P) (points 6, 7 and 8). Batch tests were sealed and connected to gas impermeable collection bags. Batch tests were incubated for long standing times. Batch test contents were tested for total and dissolved (0.45 µm membrane filtered samples) COD, TKN, FSA, TP, OP, DOC, solids and elemental analyses were performed (C, H, N, P) (points 9, 10 and 11). At the end of the digestion periods, the gas bags were sealed, disconnected and connected to a Ritter Drum type gas measuring device. The gas bag nozzles were opened and the volume of gas in the bags (L) were measured by manually expelling all gas contained in a specific bag through the gas measuring device. All gas was analysed for Carbon Dioxide (CO_2) and methane (CH_4) content.

Calculations

Batch test COD, TKN, TP and carbon (C) mass balances were required to lend validity to the experimental results. Mass balances were calculated for each batch test with the philosophy that the mass of COD or any element entering the system at batch test set up must exit the system at batch test termination. TKN and TP entered and exited the system in particulate or dissolved form and mass calculations were thus simple (concentration x volume). COD and C entered the batch tests in particulate or dissolved form; but exited in particulate, dissolved and gaseous form. COD mass exiting the system included COD in methane gas (MSm). This quantity was calculated with the following formulae:

$$n = PV / RT$$

$$MSm\ (g) = n_{CH4} \times 64 (gCOD/gmethane)$$

where: n is the moles of gas produced
P is the atmospheric pressure in the laboratory (assumed 1 atm)
V is the volume of gas produced
R is the universal gas constant (0.0821 atm.L/mol.K)
T is the laboratory temperature (K)

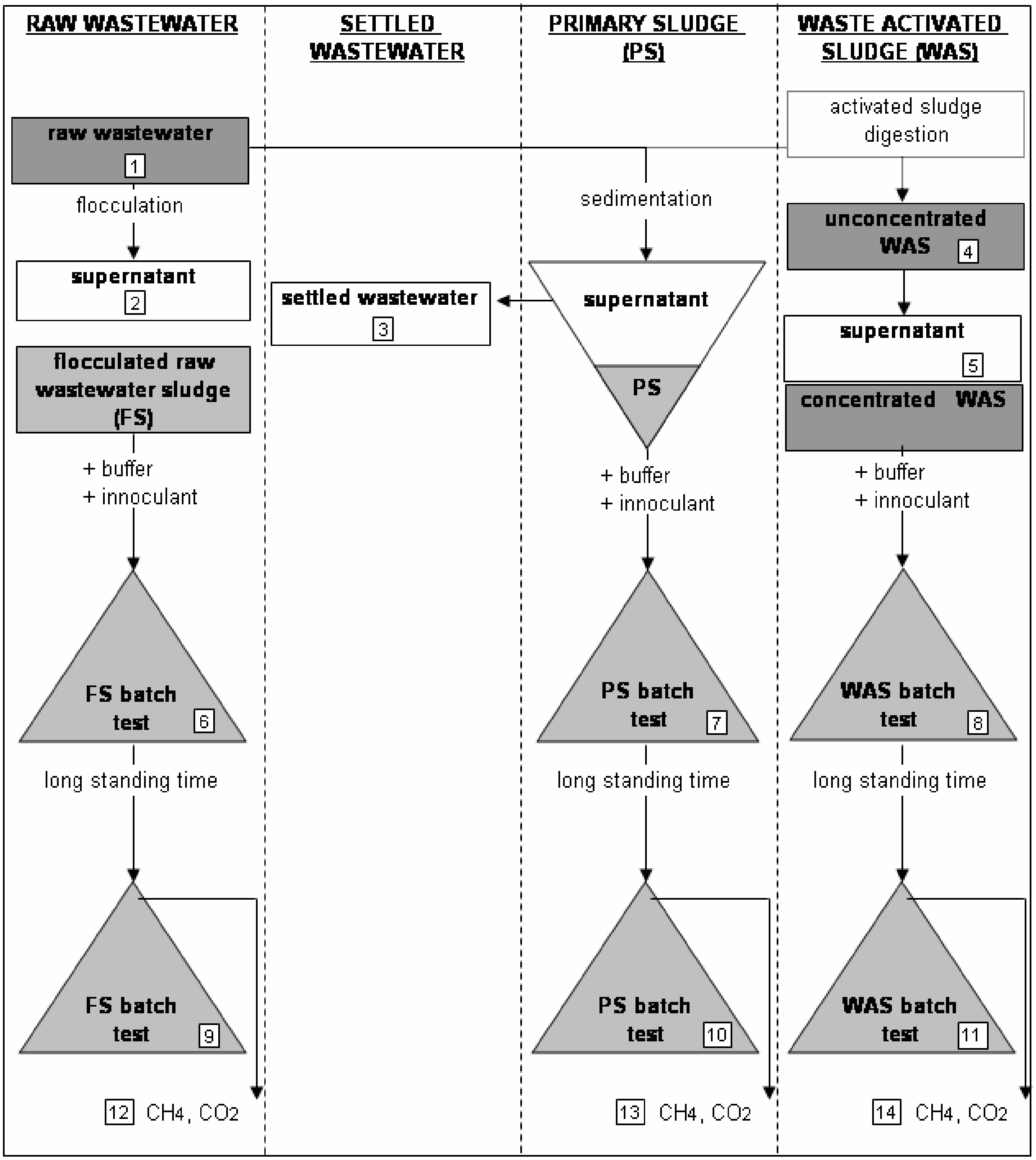
Carbon exiting the system included carbon in methane gas and carbon dioxide gas. The moles of carbon dioxide gas was calculated with the equation stated above. The mass of carbon exiting the system as gas was calculated with the following formulae:

$$MC_{CH4,CO2} = (n_{CH4} + n_{CO2}) \times 12.01\ (gC/mol)$$

where : $MC_{CH4,CO2}$ is the mass of carbon in CH_4 and CO_2

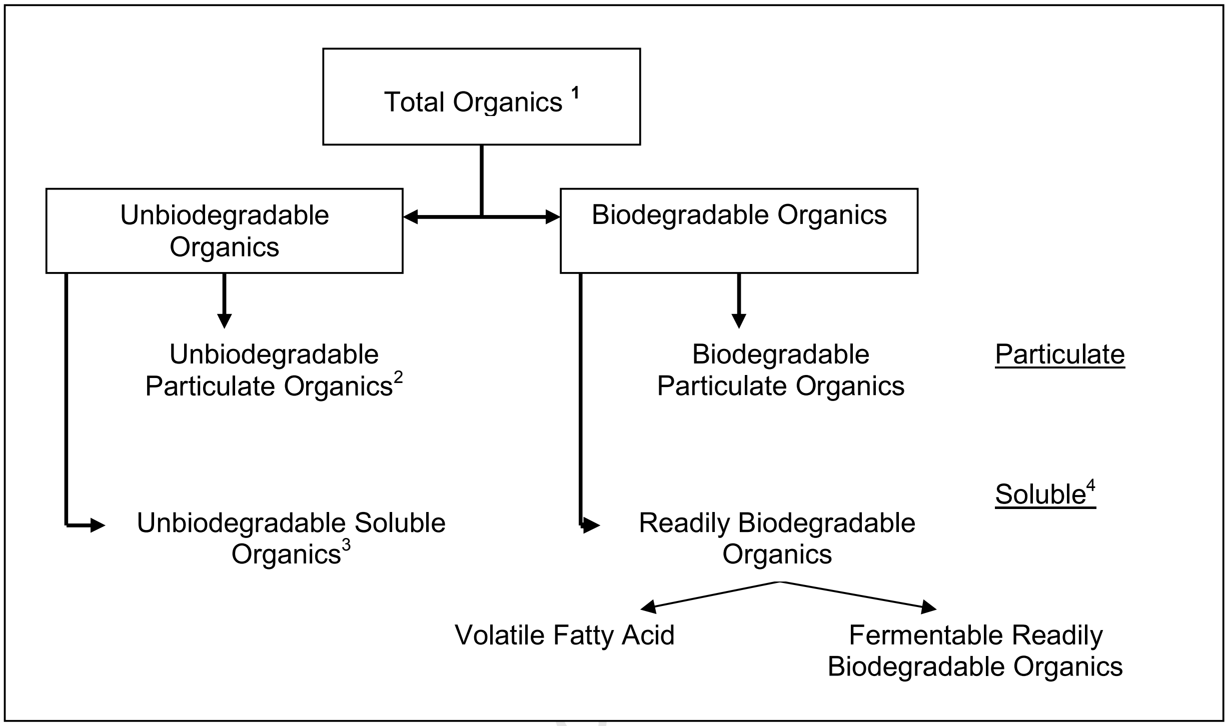
n_{CH4} is the moles of methane gas produced
n_{CO2} is the moles of carbon dioxide gas produced

COD, TKN, C and VSS data were characterised with block characterisation diagrams according to physical state (particulate or soluble) and biodegradability. Characterisation was performed for all wastewater streams (raw wastewater, settled wastewater, PS and WAS) and concentrations pertaining to organic compounds (COD, OrgN, C and VSS).



Diagrammatic representation of experimental methodology

Total and unbiodegradable particulate organics compositions were calculated from measured batch test data. Total compositions were calculated from particulate organics measurements at batch test setup and unbiodegradable compositions were calculated from particulate organics measurements at batch test termination. Biodegradable organics compositions were calculated from a difference between total and unbiodegradable compositions parameters.



Characterisation diagram ((1) Total COD, OrgN, C or VSS concentrations measured at batch test setup, (2) UP concentrations measured at batch test termination, (3) US concentrations measured in M.L.E. system effluent, (4) Soluble concentrations measured at batch test setup)

Four different calculation methods were used in the determination of particulate organics compositions from measured data. The choice of method depends on the data set available. All methods must yield the same result and discrepancies in results were used as an indication of data accuracy. The C,H,N and P content of dried samples of a particular compound were measured with elemental analysis. The results were displayed as a percentage composition by mass of the compound (%C, %H, %N, %P). In this project it was assumed that the majority of the mass of any organic compound in municipal wastewater is composed of carbon, hydrogen, nitrogen and oxygen. The compound compositions of all particulate compounds were calculated with the following equations and assumptions:

Method 1: Composition determination with COD (Stp), OrgN (Ntp), VSS (Xv), TSS (Xt) and %C (Brink et al 2007)*:*

$$x = fc\,(y + 16z) / [\,(12\,(1 - fc - fn)\,]$$
$$y = 7$$
$$z = [\,y\,(1 - fcv/8 - 8fc/12 - 17fn/14)\,] / [\,2\,(1 + fcv - 44fc/12 + 10fn/14)\,]$$
$$a = [\,fn\,(y + 16z)\,] / [\,(14\,(1 - fc - fn)\,]$$

where: $fcv = Stp / Xv$
$fn = Ntp / X$
$fc = Ctp / Xv$ and $Ctp = (\%C)(Xt)$

It must be noted that y is set equal to 7 in this method. This is due to a lack of adequate information in the derivation of four simultaneous equations. Only three data points are know, viz. fc, fcv and fn. The setting of y = 7 has no effect on the final outcome of elemental concentrations in treatment plant stoichiometry as the compound parameters (x,z,a and *M'*) adjust accordingly. However, it must be noted that these are preliminary subscripts and the *M'* calculated from this composition is not the true molar mass for this substance (which is unknown), although it will provide the correct elemental concentration results when used in conjunction with the preliminary subscripts calculated above**.**

Method 2: Composition determination with COD (Stp), TSS (Xt) and VSS (Xv) measurements and substance elemental analysis:

$$x = (\%C / 100) (Xt) / M_{\text{carbon}}$$
$$y = (\%H / 100) (Xt) / M_{\text{hydrogen}}$$
$$z = [x (32 – 12 fcv) + y (8 – fcv) – a (24 + 14 fcv)] / [16 fcv + 16]$$
$$a = (\%N / 100) (Xt) / M_{\text{nitrogen}}$$

Method 3: Composition determination with TSS (Xt) and VSS (Xv) measurements and substance elemental analysis:
The x, y and a subscripts were calculated as in method 2.

$$z = [Xv – Xt (\%C + \%H + \%N + \%P)] / (M_{\text{oxygen}} \times 100)$$

Method 4: Composition determination with COD (Stp) and TSS (Xt) measurements and substance elemental analysis:
The x, y and a subscripts were calculated as in method 2.

$$z = [(8 – 3 Stp / Ctp) x + 2 y – 6 a] / 4$$

The determination of soluble organics compositions was based on the assumption that y/z = 7/2. Evaluation of the results indicated that this assumption was not valid. Soluble organics compositions may also be determined with the formulae proposed by (Brink et al 2007) as used in method 1 for particulate organics compositions determination above. This method then requires the determination of volatile dissolved solids (VDS) concentrations in the relevant wastewater types. Such measurements were not performed in this project.

Raw wastewater, settled wastewater and PS soluble (total, biodegradable and unbiodegradable) soluble compositions were considered to be identical. This is based on the assumption that no biodegradation occurs during primary sludge settling. WAS total and unbiodegradable soluble organics compositions were considered to be identical. This was based on the assumption that the MLE aerobic reactor effluent is considered to contain only unbiodegradable soluble organics. The raw wastewater, settled wastewater, PS and WAS unbiodegradable soluble organics compositions have been assumed to be identical.

A sensitivity analysis was performed to investigate the effect of data error on each method for the determination of particulate compositions. A positive 10 % adjustment was performed on each data type and the resultant change in organics compositions was observed for each method and batch test group. The analysis was performed on waste activated sludge data. The method used for the calculation of the soluble organics compositions included the assumption that $y = 7$ and $z = 2$. The sensitivity of composition subscripts x and a to changes in the z value were tested to ascertain the magnitude of impact that this assumption has on the compositions calculations. Therefore, a positive 10 % adjustment was applies to the z values of unbiodegradable soluble organics and the resultant change in x and a subscripts were observed.

Large discrepancies observed in the organics composition results prompted further data analysis. The following investigation was an attempt at isolating erroneous data. The experimental batch test investigations yielded superfluous data. This allowed the isolation and calculation of certain variables as a function of measured data. Variables were thus calculated from other data measurements and compared to measured data. The variables chosen for recalculation included %N and %H elemental analysis measurements and the laboratory TSS measurements. The % H was isolated as a measurement prone to error due to the fact that it represents a small quantity. Error in this measurement has a large impact on the final composition display since x, z and a subscripts are displayed according to the setting of $y = 7$. Thus, %H was isolated as a variable and calculated from the measured data values of C, TS, COD and N. The total suspended solids measurement directly influences the composition calculations since the calculation of elemental concentrations (C, H, N) from elemental analysis data is directly dependent on it. Thus, it was included possible source of data error and was calculated from superfluous data and compared to measured values.

% Nitrogen (%N:

%N was calculated from an independent determination of a. The following equation was used :

$$a = Ntp\ (g/l) / M_{\text{nitrogen}}$$

% Hydrogen (% H):

The following equations were used to calculate y from which %H was calculated:

$$x = (\ \%C / 100\ )\ (\ TSS\ ) / M_{\text{carbon}}$$
$$y = 2z - 4x + 1.5\ (\ Stp / Ctp)\ x + 3a$$
$$z = [\ x\ (\ (\ 12 - 1.5\ fcv\ )\ Stp / Ctp - 8\ fcv\ ) - 17\ a\ fcv\ ] / [\ 18\ fcv\ ]$$
$$a = Ntp\ (g/l) / M_{\text{nitrogen}}$$

Total suspended solids (TSS):

The following equation was used to determine TSS concentrations (Xt) from data:

$$Xt = (\ Stp - Xi\ ) / [11/3\ (\ \%C / 100\ ) + (\ 9\ (\ \%H / 100\ ) - 5/7\ (\ \%N / 100\ ) - 1\ ]$$

4. DESIGN AND EVALUATION OF AN AD BATCH TEST METHOD FOR ORGANICS COMPOSITIONS DETERMINATION: EVALUATION

The experimentation process was iterative in nature. Experience gained from previous batch tests were used to improve following batch tests. This resulted in batch test parameter adjustments. Batch test incubation periods were lengthened from an initial ~ 60 days period to a maximum period of 169 days. This renders two disadvantages, viz. (1) data accuracy at batch test setup may only be determined with batch test mass balances at batch test termination and (2) lengthy experimental time requirements. Batch tests were covered to prevent UV light penetration and subsequent algae growth. Batch test incubation temperature was increased from 22 °C to 35 °C for certain BTG'S. Batch tests were inoculated with anaerobic seed and buffered to prevent pH drop during incubation. AlumSulphate was initially used as a flocculent for raw wastewater flocculation and this was later changed to Iron(III)Chloride due to a seemingly inhibition affect of AlumSulphate on AD processes.

Batch test mass balances were performed in an attempt to validate COD, C, N and P data. Good nitrogen and phosphorus mass balances (95% - 105 %) were achieved in all cases. COD and carbon batch test mass balances were achieved for only 33 % of batch tests. Gas losses accounted for the inability to achieve mass balances for the remaining batch tests. The achievement of good mass balances for some batch tests validated the COD, carbon and gas collection as well as calculation procedures. However, the gas losses indicated that the experimental setup was prone to gas leakage.

Batch test total and residual COD, C, OrgN and VSS data comparisons were performed in an attempt to ascertain whether batch tests had reached full substrate biodegradation. Data was compared to information sourced from literature on PS and WAS biodegradability. Four PS batch tests were deemed to have reached substrate biodegradation completion. The unbiodegradable particulate fractions ($f_{PS'UP}$) of the primary sludge used in these batch tests were calculated to be 0.46, 0.31, 0.28 and 0.30 respectively. These values correspond to the results independent studies performed Wentzel et al. (2006 a) and Sötemann et al. (2005), who determined $f_{PS'UP}$ values for wastewater from the same source of 0.33 and 0.35 respectively.

Four WAS batch tests were deemed to have reached substrate biodegradation completion. The unbiodegradable particulate fractions ($f_{AS'UP}$) of the waste activated sludge used in these batch tests were calculated to be 0.75, 0.59, 0.68 and 0.49 respectively. The $f_{AS'UP}$ values of 2 batch tests correspond to the value determined by Wentzel et al. (2006 a), which was 0.63. These values, however, significantly differ from each other. This is a surprising result since the same WAS was inserted into these batch tests. The batch tests were incubated at 35 °C ± 0.5 and 22 °C ± 0.5 respectively. This may be an indication that an un-heated WAS batch test did not reach biodegradation completion as previously thought, even after a 127 day incubation period. This is unlikely and a more prudent explanation may pertain either to the accuracy of the results or to the acceptance that the result is correct and thus, that more unbiodegradable particulate COD was captured in a particular batch test at batch test setup. With no contrary information available the result was accepted as correct. The $f_{AS'UP}$ values determined for the other two batch tests were alternatively significantly higher and lower than the value determined by Wentzel et al. (2006 a). Once more, the accuracy of the results was unknown and the results were used to calculate preliminary organics compositions for these batch tests.

Organics compositions were calculated for batch tests deemed to have reached complete substrate biodegradation. The results of four different methods used for the calculation of particulate organics compositions were compared. In the absence of data error these results should be identical for a particular wastewater total or unbiodegradable organic compound. No results were found to be identical, indicating data inaccuracies to the extent that the data could not be validated.

Method sensitivity analyses indicated that the accuracy of the results of particulate organics compositions calculations were highly sensitive to data error. The results determined with method 4 showed the greatest sensitivity to data error. A + 10 % change in COD data resulted in a change in the calculated z value of 33 % - 104 %. A + 10 % change in TSS and %C data resulted in a change in the calculated z value of > 30 % in all cases. All methods were highly sensitive to error in COD data. Percentage increases in the z subscript due to a 10 % increase in COD data ranged from 13 % to 104 %. This indicates that COD error that is acceptable in normal wastewater testing and modelling applications may not be acceptable for the determination of organics compositions with the methods used in this investigation. All methods were sensitive to error in TSS data. Percentage increases in the z subscript due to a 10 % increase in TSS data were > 10 % in most cases. It is difficult to accurate measure TSS to the degree required in normal wastewater laboratories due to the use of particulate material (may be unrepresentative) and the difficulty in accurately determining ISS mass accurately with the use of crucibles. Method 1 was highly sensitive to error in %C measurements with a % change in x values > 40 % in all cases with a concomitant % change in %C data of + 10 %. It was also found to be sensitive to VSS data (> 10 % change in all cases).

The initial assumption that a y/z = 7/2 ratio may be used in soluble organics compositions calculations was discredited. Sensitivity analyses showed that soluble organics subscripts x and a calculated on the basis of this assumption were sensitive to change in the z value. Therefore, the z value needs to be accurately determined. A COD/VDS ratio may be substituted for the fcv value used in method 1 for particulate organics compositions calculations and soluble organics compositions may thereby be calculated. The VDS value needs to be accurately determined. However, the calculation of x, z and a values with this method are not sensitive to the VDS value and it is possible that the required accuracy for its determination may be achieved in normal wastewater laboratories.

Discrepancies in organics compositions calculated with different methods prompted the calculation of certain values and comparison with measured values. This was done in an attempt to determine the extent of data inaccuracy. Particulate organics compositions calculations are not sensitive to error in %H measurements. However, the accuracy of these measurements have a direct effect on final compositions representation due to the setting of y = 7, and the concomitant representation of the x, z and a values according to the y value. Thus, an error in the y value will result in a misrepresentation of the x, z and a values even though the data used for their calculation may be accurate. Therefore, the %H value as measured was compared to a %H value calculated from superfluous data. The results are displayed in Table 4 (a) below.

Table : Total %H calculated vs. measured values

	Raw wastewater		**PS**		**WAS**	
BTG	**%H measured**	**%H calculated**	**%H measured**	**%H calculated**	**%H measured**	**%H calculated**
2	4.02	6.58	6.17	5.06	5.98	4.99
3	6.44	7.68	6.71	9.47	6.00	5.41
4	3.99	6.77	3.38	4.87	5.23	4.75
5	3.61	4.96	5.68	6.57	5.23	4.79
6	4.73	6.00	6.72	8.64	6.48	5.74

The % discrepancies between measured and calculated %H values ranged from 1.24 - 2.78 % for raw wastewater, 0.89 - 2.76 % for PS and 0.44 - 0.99 % for WAS. The %H as calculated was based on COD, %C, TSS, VSS and OrgN data. Thus, the calculated value may be erroneous. This exercise was not performed to ascertain the correct %H, but serves to illustrate discrepancies between U.C.T. laboratory data and elemental analysis data. The accuracy of the COD, %C, TSS and nitrogen data was ascertained through batch test mass balances for the FS, PS and WAS batch tests of BTG 2 and the WAS batch tests of BTG's 3 and 4. Assuming that the VSS measurements were accurate, the %H measurement error was as high as 2.56 % for these batch tests. This is a significant discrepancy and is possibly due to procedural error whereby unrepresentative sludge samples were measured.

Discrepancies between elemental analysis results and laboratory measured data can be clearly seen in a TSS calculation from laboratory and elemental analysis results and measured TSS data. The results are displayed in Table 4 (b) below.

Table : Total TSS calculated vs. measured values

	Raw wastewater			PS			WAS		
BTG	**TSS meas. (g/l)**	**TSS calc. (g/l)**	**%(calc - meas.) / calc.**	**TSS meas. (g/l)**	**TSS calc. (g/l)**	**%(calc - meas.) / calc.**	**TSS meas. (g/l)**	**TSS calc. (g/l)**	**%(calc - meas.) / calc.**
2	1.50	1.30	15.6	8.01	8.45	-5.5	2.47	2.45	0.8
3	1.00	0.953	5.1	31.6	28.6	9.6	2.83	2.81	0.7
4	2.43	2.02	16.8	65.6	61.7	5.9	3.17	3.25	-2.4
5	3.78	3.37	11.0	53.0	51.1	3.7	3.17	3.25	-2.4
6	2.52	2.35	6.6	15.0	14.0	6.9	2.20	2.04	6.6

The % discrepancies between measured and calculated TSS values ranged from 5.1 - 16.8 % for raw wastewater, 3.7 - 9.6 % for PS and 0.7 - 6.6 % for WAS. Note that an adjustment of %H to the calculated values renders the difference in measured and calculated TSS values 0 %. Thus the % differences between measured and calculated values below are an indication of the discrepancies between U.C.T. laboratory data and elemental analysis data. It also important to notice that the data discrepancies for the WAS values were the lowest and that the compositions calculated for the total WAS organics showed the highest precision across different methods of calculation.

5. CONCLUSIONS

Integrated plant-wide WWTP modelling is a requirement for design optimisation. Recent approaches towards plant-wide WWTP modelling are variable. However, a common requirement in the approaches is the determination of organics compositions of the form $C_xH_yO_zN_a$. A batch test method for the determination of SB, RB, US and UP organics compositions in relevant streams over a WWTP (raw wastewater, settled wastewater, PS and WAS) has been designed and evaluated. The validity of this method was evaluated on the basis of the fulfilment of 3 research objectives.

The fractionation of raw wastewater, PS and WAS into unbiodegradable and biodegradable fractions were considered to have been achieved. Batch tests were deemed to have reached biodegradation completion due to a number of indicators sourced from PS and WAS biodegradability literature and very long incubation periods (117 - 169 days). Data deemed to characterise unbiodegradable organics was sourced from batch test contents at batch test termination. However, the accuracies of these fractionations were found to be inadequate to determine colloidal settled wastewater unbiodegradable and biodegradable fractions. Particulate organics compositions results calculated with four different methods were variable. This variability was ascribed to data inaccuracy. The determination of organics compositions was found to be highly sensitive to input variable error. Therefore, the indirect determination of particulate organics compositions requires highly accurate measured data. It is doubtful whether such accuracy may be achieved with the batch test method evaluated in this chapter. Therefore the unbiodegradable and biodegradable organics compositions for different wastewater streams could not be ascertained with the batch test method used.

The batch test method evaluation was based on the fulfilment of the research objectives, viz. the determination of (1) raw wastewater, PS and WAS unbiodegradable and biodegradable organic fractions, (2) settled wastewater colloidal unbiodegradable and biodegradable fractions and (3) organics compositions for raw wastewater, settled wastewater, PS and WAS. Thus, the validity of the batch test method was evaluated according to the fulfilment of the research objectives. The first objective was deemed to have been fulfilled on the basis of very long batch test incubation times and residual COD and VSS indicators sourced from literature. However, the inability to validate soluble and particulate organics compositions results has indicated that, although raw wastewater, PS and WAS unbiodegradable and biodegradable organic fractions could be determined with the batch test method, these fractions were not of the required accuracy to fulfil the second and third research objectives. Therefore, the batch test method designed and evaluated in this project is not valid for the determination of readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate organics compositions at links between unit operations over a WWTP.

The calculation methods discussed in this paper are valid if the data requirements are accurately determined. Direct determination of organics compositions were not possible with this method as the required mass of sludge at batch test setup and termination could not be feasibly determined for the inclusion of oxygen (> 10 g) measurement during elemental analysis. The indirect calculation methods exacerbated data error and direct measurement is therefore preferable. Accurate carbon and COD mass balances over methanogenic AD batch tests are difficult to obtain due to errors in gas volume and composition measurement. In hindsight it would have been better to use sulphidogenic AD batch tests because sewage biodegradable organics are carbon deficient for biological sulphate reduction in that they can donate more electrons than supply carbon for the alkalinity generated. In such systems, there is no H_2S and CO_2 gas generation so the C in the biodegradable organics utilized can be measured in the $H_2CO_3^*$ alkalinity generated.

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LIST OF SYMBOLS

a	Preliminary composition subscript for nitrogen
AD	Anaerobic Digestion
AerD	Aerobic Digestion
BOD	Biochemical oxygen demand
C	Carbon
Cb	Total biodegradable carbon concentration
Cbp	Residual biodegradable particulate carbon concentration
Cbs	Biodegradable soluble carbon concentration
COD	Chemical Oxygen Demand
Ct	Total carbon concentration
Cts	Total soluble carbon concentration
Ctp	Total particulate carbon concentration
Cu	Total unbiodegradable carbon concentration
Cup	Residual unbiodegradable particulate carbon
Cus	Unbiodegradable soluble carbon
d	day
DOC	Dissolved Organic Carbon
fc	Carbon (mg/l) / VSS (mg/l)
fcv	COD (mg/l) / VSS (mg/l)
fn	N (mg/l) / VSS (mg/l)
FS	Flocculated raw wastewater sludge
FSA	Free and Saline Ammonia
fup	Fraction of unbiodegradable particulate (w.r.t. total) COD in the influent wastewater
fus	Fraction of unbiodegradable soluble (w.r.t. total) COD in the influent wastewater
h	hour
ISS	Inorganic Suspended Solids
l	litre
M	Compound molar mass (g/mol)
M_{carbon}	Carbon molar mass (g/mol)
M_{hydrogen}	Hydrogen molar mass (g/mol)
M_{nitrogen}	Nitrogen molar mass (g/mol)
M_{oxygen}	Oxygen molar mass (g/mol)
mg	Milligram
MLE	Modified Ludzack-Ettinger (activated sludge system)
N	Nitrogen
Na	Ammonia concentration
Nobp	Organic biodegradable particulate nitrogen concentration
Nobs	Organic biodegradable soluble nitrogen concentration
Noup	Organic unbiodegradable particulate nitrogen concentration

Nous	Organic unbiodegradable soluble nitrogen concentration
Nt	Total nitrogen concentration
Ntp	Total particulate nitrogen concentration
Nts	Total soluble nitrogen concentration
OP	Ortho – phosphate
PS	Primary sludge
PST	Primary Settling Tank
RBCOD	Readily Biodegradable COD (Soluble biodegradable COD)
SBCOD	Slowly Biodegradable COD (Particulate biodegradable COD)
Sb	Total biodegradable COD concentration
Sbsa	VFA COD concentration
Sbp	Residual biodegradable particulate COD concentration
Sbs	Biodegradable soluble COD concentration
SCFA	Short Chain Fatty Acid
St	Total COD concentration
Sts	Total soluble COD concentration
Stp	Total particulate COD concentration
Su	Total unbiodegradable COD concentration
Sup	Residual unbiodegradable particulate COD
Sus	Unbiodegradable soluble COD
Sm	Methane concentration
SST	Secondary Settling Tank
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TS	Total Solids
TSS	Total Settleable Solids
V	Volume
VS	Volatile Solids
VSS	Volatile Suspended Solids
WAS	Waste Activated Sludge
ww	Wastewater
WWTP	Wastewater Treatment Plant
Xi	ISS concentration
Xv	VSS concentration
Xt	TSS concentration
x	Preliminary composition subscript for carbon
y	Preliminary composition subscript for hydrogen
z	Preliminary composition subscript for oxygen
%C	Percentage carbon measured in elemental analysis
%H	Percentage hydrogen measured in elemental analysis
%N	Percentage nitrogen measured in elemental analysis
%P	Percentage phosphorus measured in elemental analysis

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

Historically wastewater treatment plant models have focussed primarily on unit operation design. Until recently, little research has been done to model the whole wastewater treatment plant in an integrated or plant wide fashion (Vanrolleghem et al 2005; Wentzel et al 2006). This approach has been acceptable in the past since, traditionally, WWTP effluent were considered to be the most important focus of the WWTP and therefore also of modelling WWTPs. Recently, however, increasing pressure towards the optimisation of WWTPs has been challenging this philosophy (Wentzel et al 2006). WWTP treatment processes (unit operations) are physically integrated and impact on one another, with downstream processes affected by the working of upstream processes, e.g. biological nitrogen (N) and phosphorus (P) removal in the activated sludge process and hence the effluent N and P concentrations from it are affected by the N and P recycled from anaerobic digestion (AD) process. Thus, the integration of WWTP unit operation models is necessary for the optimisation of WWTP systems as a whole (Vanrolleghem et al 2005).

Basically two approaches towards developing integrated plant wide WWTP models have been proposed. These include the continuity based interfacing method (CBIM) or transformation approach of Vanrolleghem et al. (2005) and Volcke et al. (2006) and the 'supermodel approach' of Jones and Tákacs (2004) and Seco et al. (2004) both cited in Grau et al. (2007). These approaches differ in the way that they deal with the problem of coupling unit process models.

The CBIM or transformation approach is aimed at leaving existing unit process models unaffected. The CBIM approach focuses on the production of model interfaces wherein state variables from the upstream unit process model, such as Activated Sludge Model No 1 (ASM1, Henze et al 2000) are transformed to become compatible with state variables from the downstream unit process model, such as Anaerobic Digestion Model No 1 (ADM1, Batstone et al 2002). In the super-model approach all the compounds required in the entire WWTP are defined and the different process models track the changes in these compounds through each unit operation. This approach focuses on the construction of a very large model that integrates all components and transformations in all processes in a WWTP, even though they may not be required. A combination of both approaches has been followed by the Wentzel et al. (2006). Because their anaerobic digestion model is different to ADM1 (Sötemann et al 2005) and their finding that unbiodegradable organics as defined by the "aerobic" AS system, remain unbiodegradable under anaerobic conditions (Ekama et al 2006), the problem of incompatibility between the AS and AD models does not arise. They took this approach because carbon fluxes to the AD are required to model its gas production and composition and alkalinity generation, which the CBIM and supermodels introduce at the AD stage. One may as well model the carbon fluxes from the influent of the WWTP and include it in the AS processes also. Clearly, the above cited models impose new modelling techniques over and above the use of existing unit process models.

Unit process models such as that for the AS system, have in the past been developed in isolation. This, in conjunction with different process physical, chemical and biological functions; has resulted in the creation of different model variables (state variables). Unit process state variables may be incompatible for a number of reasons. Variables may be required in a unit process model, but be non-existent in a connected model, e.g. the IWA ASM models of Henze et al (2000) are incompatible with the ADM1 model of Batstone et al (2002) due to the exclusion of carbon in the ASM models, which is a requirement in the ADM1 model. Both models have been widely accepted and used in the development of plant-wide WWTP models. Compounds considered to be constant in a unit process model may be a state variable in a connected model, e.g. pH is considered to be constant in the ASM models but is a state variable in the AD model. Finally, the definition of variables may also differ between models, e.g. compounds considered biodegradable in a model may be considered to be unbiodegradable in a connected model (Volcke et al 2006).

1.2. DEVELOPMENT OF THE RESEARCH TOPIC

A general theme in recent integrated whole WWTP modelling approaches towards circumventing model interfacing difficulties is the use of compounds in their elemental composition forms. This approach has been encountered in the CBIM approach of Vanrolleghem et al. (2005) and Volcke et al. (2006), the transformation based approach of Grau et al. (2007) and the mass balances based whole WWTP model approach of Ekama et al. (2006 a,b), Sötemann et al. (2006) and Wentzel et al. (2006). In all of the above stated approaches biodegradable, unbiodegradable, soluble and particulate matter have been reduced to C, H, O, N, P and charge content as part of a method to transform incompatible state variables to compatible forms. The determination of compound elemental compositions requires carbon data. Although carbon is a major constituent of wastewater organic compounds, it has been sidelined as a measure of wastewater organic content due to the preference of the COD measure (Henze et al 2000) because of the difficulty of doing carbon mass balances of experimental AS systems. This has resulted in a general lack of carbon data and carbon measurement for WWTP design and operation.

This project was therefore designed to focus on the determination of wastewater compound elemental compositions, with the inclusion of carbon data, for integrated whole WWTP modelling purposes. No methods for such a determination have as yet been developed. The aims of this project were therefore two fold, viz. an investigation into current whole WWTP integration model approaches (Chapter 3) and the performance evaluation of a simple batch test method for the determination of organics elemental compositions over a standard WWTP incorporating primary settling, an AS reactor as well as primary sludge and WAS anaerobic digestion (Chapter 5).

1.3. RESEARCH PROBLEM

The elemental compositions of standard compounds, such as volatile fatty acids, proteins, lipids etc. are known. However, certain organic compounds consist of (possibly) variable and unknown compositions. These compounds comprise readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate components. Case studies performed with some of the recent integrated WWTP modelling methods have relied on assumptions regarding the compositions of these compound groups (Brink et al 2007). Thus, no experimental investigation into their determination was performed. An investigation towards the solution of this problem has been performed in Chapter 4. The objective of this research was to design and evaluate a specific, simple batch test method for the determination of the following:

1. Fractionation of raw wastewater, PS and WAS organics into biodegradable and unbiodegradable soluble and particulate components.
2. Fractionation of raw wastewater concentrations (C,N,COD,VS) into settlable and colloidal particulate organic material.
3. Determination of the organic compositions of the form $C_xH_yO_zN_a$ for the above wastewater and sludge fractions.

1.4. RESEARCH DESIGN AND METHODOLOGY

The determination of biodegradable and unbiodegradable fractions of soluble and particulate organic constituents (C,H,O,N) and parameters (COD,VSS) that compose and define organics compositions (of the form $C_xH_yO_zN_a$) is necessary for the modelling of integrated WWTP unit processes. A simple anaerobic batch test approach towards determining wastewater organics total, biodegradable and unbiodegradable as well as soluble and particulate fractions was designed and investigated in this project. Research performed by Wentzel et al. (2006) and Ekama et al (2006 b) have supported the assumption commonly made in plant wide models that organic material termed unbiodegradable from an activated sludge standpoint, i.e. the influent unbiodegradable particulate organics and the activated sludge endogenous residue, remains unbiodegradable under anaerobic digestion processes. Thus, the use of an anaerobic batch test method for determination of organic compositions over a whole WWTP was considered to be valid.

Plant wide WWTP modelling requires organics compositions in all wastewater streams through a WWTP to be known. The WWTP scheme considered in this project consisted of primary settling tank (PST), activated sludge (AS) and primary sludge (PS) and waste activated sludge (WAS) anaerobic digester (AD) unit processes. The relevant wastewater streams considered therefore consisted of raw wastewater, settled wastewater, primary sludge, waste activated sludge and plant effluent. Therefore, the determination of raw wastewater, primary sludge and waste activated sludge compositions has been investigated. The correct determination of raw wastewater and primary sludge compositions enables the determination of settled wastewater colloidal and soluble compositions through mass balances over a primary settling tank. This is based on the assumption that no substrate biodegradation occurs during the settling of primary sludge. Waste activated sludge organics compositions may be determined directly by measurement. Soluble organics compositions in WWTP effluent may be directly determined from measured data.

Wastewater organic fractions for modelling purposes have in the past typically been divided into biodegradable and unbiodegradable fractions. Biodegradable fractions have been divided into readily (RB) and slowly (SB) biodegradable components, while unbiodegradable fractions have been divided into soluble (US) and particulate (UP) components. This was done in the IWA ASM models (Henze et al 2000). These terms and definitions have been adhered to in this investigation. Furthermore, they have been applied to anaerobic digestion process results as supported by the research done by Wentzel et al. (2006) and Ekama et al. (2006 b), viz. the view that unbiodegradable organics from an "aerobic" activated sludge (AS) standpoint remain unbiodegradable during anaerobic digestion (AD).

Wastewater organics compositions have been considered in this project to consist of the elements carbon (C), hydrogen (H), oxygen (O) and nitrogen (N), i.e. $C_xH_yO_zN_a$. This is in accordance with the approaches followed by the authors of the integrated WWTP modelling approaches discussed above. Four different methods for the determination of organic compound compositions, i.e. the x, y, z and n values in $C_xH_yO_zN_a$, are described in Chapter 4. Data required for the calculation of organics compositions with these methods included COD, nitrogen (Organic N = Total Kjeldahl Nitrogen, TKN minus Free and Saline Ammonia, FSA), solids (Total Suspended Solids, TSS and Volatile Suspended Solids, VSS) and carbon (C), hydrogen (H) and nitrogen (N) data from elemental analysis. These methods may be extended to include phosphorus (P) if required. Phosphorus as a component of organics compositions has been included in this project for batch test mass balances purposes, but has been omitted in organics compositions for simplicity. This omission was considered to be valid due to the relatively small representation of phosphorus in municipal wastewater organic compounds, primary sludge ands waste activated sludge from N removal AS systems.

Data determined for the different wastewater streams, viz. raw wastewater, settled wastewater, primary sludge and waste activated sludge were organised into block characterisation diagrams (Fig. 1-1). This served as a diagrammatic representation of corresponding data sets, e.g. unbiodegradable particulate COD, TKN, C and VSS data define the unbiodegradable particulate organic compound composition for a particular wastewater stream.

It was accepted in this project that the unbiodegradable fraction of particulate or soluble organics may be derived from measurements on residual matter after biodegradation processes (aerobic or anaerobic) have degraded all biodegradable material. Data for the determination of biodegradable organic compound compositions may be derived from the difference between total and unbiodegradable data. Therefore, an attempt was made to determine total, unbiodegradable and biodegradable soluble and particulate organics compositions in raw wastewater, settled wastewater, primary sludge (PS) and waste activated sludge (WAS).

The method involved concentration measurements of relevant data on raw wastewater, settled wastewater and primary sludge (PS). Raw wastewater was settled in a settling tank (PST) to produce settled wastewater and primary sludge. Waste activated sludge (WAS) was obtained from a M.L.E. reactor at the University of Cape Town fed raw wastewater from the same source as used for raw wastewater measurements. Data was also obtained from effluent from the M.L.E. reactor. Total COD, TKN and VSS data was obtained from raw wastewater, settled wastewater, PS and WAS. Total carbon measurements were obtained from flocculated raw wastewater, PS and WAS. Settled wastewater total carbon was calculated from a mass balance over the PST. Total soluble

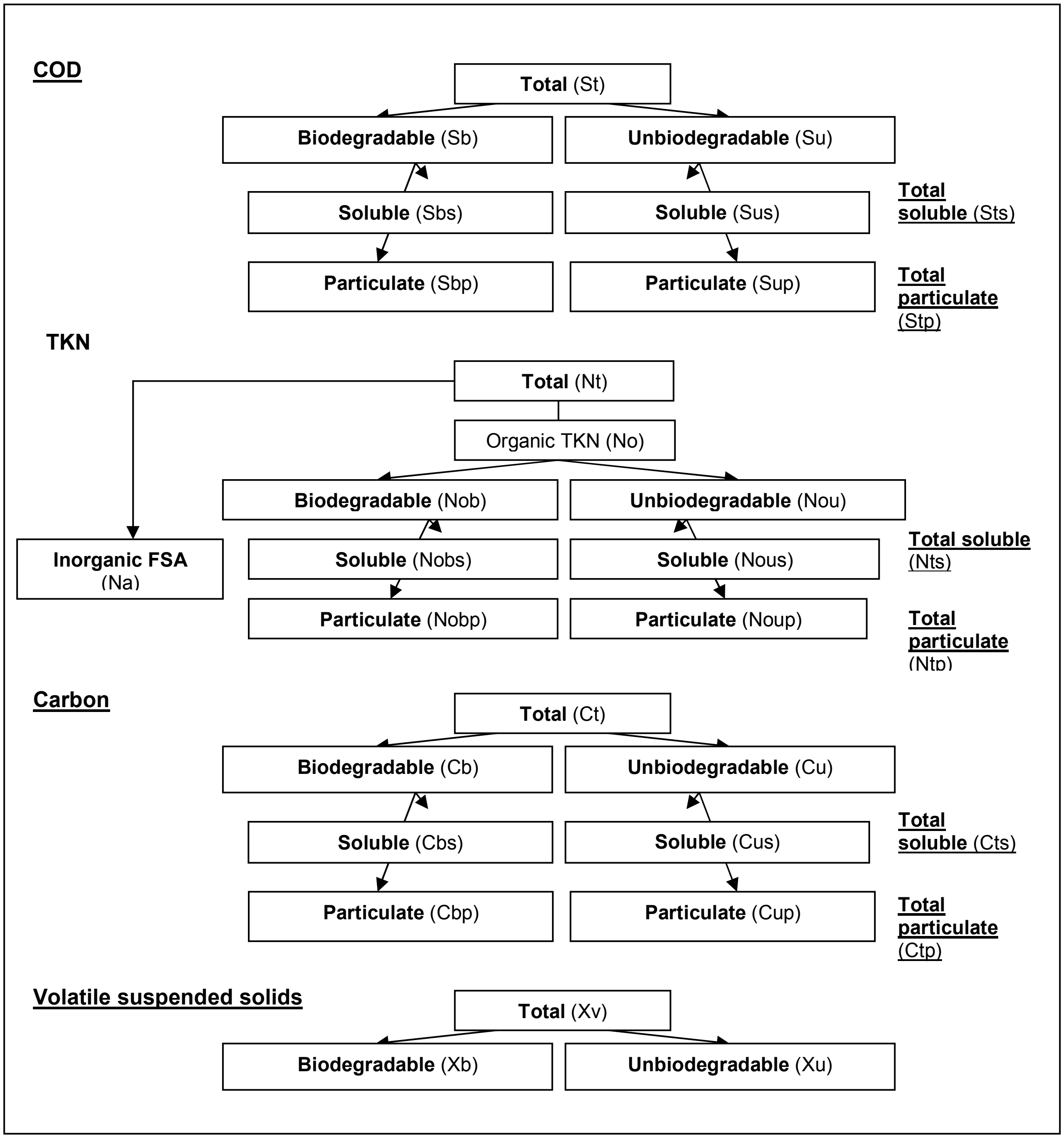


Fig. 1-1: Data block characterisation diagrams

COD, TKN and carbon (DOC) concentrations were directly measured in filtered settled wastewater samples. It was assumed that raw wastewater, settled wastewater and PS contained identical dissolved compound concentrations. Unbiodegradable soluble COD, organic TKN (OrgN) and DOC concentrations were measured on the M.L.E. system effluent and was taken as equal for all wastewater streams.

Raw wastewater was flocculated to produce sludge (FS). FS, PS and WAS were inserted into 2L Erlenmeyer flasks, closed and connected to gas capture bags. Therefore each batch test group (BTG) consisted of three batch tests. Six BTG's were set up throughout the duration of the project. The batch tests were inoculated with anaerobic seed and buffered. They were thereafter left at long standing times (> 60 days) at 22 °C or 35 °C. The residual material after completion of biodegradation processes were considered to constitute the unbiodegradable particulate components of the relevant wastewater types. COD, TKN, VSS and C measurements were therefore used to calculate unbiodegradable organics particulate compound compositions for the relevant wastewater types.

The accuracies of organics compositions results were unknown. Owing to additional tests on the samples, e.g. N from elemental analysis and OrgN from laboratory TKN and FSA tests, four different calculation methods were used to calculate organics compositions for all batch test groups, each method selecting different measure parameters from the data set. If there was no error in the data, e.g. the N from elemental analysis matched exactly that from TKN and FSA tests, the results of the different methods should yield the same organic compositions. Incompatibilities in the results prompted a sensitivity analysis of the different methods to input data error.

1.5. THESIS OUTLINE

A literature review was performed in Chapter 2. It comprised two main focus areas, viz. (1) standard unit process models that were used in integrated plant wide WWTP modelling approaches and (2) PS and WAS sludge biodegradability issues under anaerobic digestion. The first focus area was aimed at providing background information for the discussion of integrated whole WWTP modelling approaches in Chapter 3. It thus consisted of a general discussion of relevant unit process models including the IWA ASM models of Henze et al. (2000), ADM1 model of Batstone et al. (2002) and the steady state and dynamics simulation models for anaerobic digestion of sewage sludge developed by Sötemann et al. (2005). This discussion highlights important features of these models as they pertain to the discussion in Chapter 3. The second focus area of the literature review was aimed at discerning information regarding anaerobic digestion of primary and waste activated sludge that may be relevant to the batch test experimental design as discussed in Chapter 4. This included investigations into the effect of temperature and sludge retention time on sludge biodegradability during AD, the effect to solids retention time in AS processes on the anaerobic digestion performance of WAS and the biodegradability of primary sludge (PS) and waste activated sludge (WAS) under anaerobic conditions.

An investigation into current integrated whole WWTP modelling approaches was performed in Chapter 3. Current approaches include the continuity based interfacing method (CBIM) of Vanrolleghem et al. (2005) and Volcke et al. (2006) and the 'supermodel' approach of Jones and

Tákacs (2004) and Seco et al. (2004), both cited in Grau et al. (2007). A common requirement in these approaches was a transformation of organic compounds into their elemental composition form. This was a key requirement for the transformation of incompatible unit process model state variables into compatible state variables another unit process model.

A simple AD batch test method that seeks to determine the organic compound elemental compositions in relevant streams over a conventional WWTP was designed in Chapter 4. The method was designed to include investigation of compound elemental compositions in raw wastewater, primary sludge, settled wastewater, waste activated sludge and plant effluent. Organic compounds investigated included readily and slowly biodegradable organics as well as soluble and particulate unbiodegradable organics. Four different calculation methods for the determination of organics elemental compositions were devised in an attempt to evaluate data accuracy. A sensitivity analysis of the four methods to input data was performed to evaluate the sensitivity of elemental compositions results to data accuracy. Six batch test groups, each comprising of three batch tests with different contents (flocculated raw wastewater sludge (FS), PS and WAS) were set up at long incubation periods in an attempt to determine unbiodegradable organics compositions. Total organics compositions were calculated from sludge data at batch test set up times. Biodegradable organics compositions could theoretically be calculated from the difference between total and unbiodegradable organics data.

The AD batch test method designed in Chapter 4 was evaluated in Chapter 5 to establish the viability of the method for organic compound elemental compositions determination and the conclusions from the investigation are given in Chapter 6. Sections of data presentation and specific details of explanations considered to voluminous and disruptive to the reading are presented in Appendices.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

The aims of this project were two fold, viz. the investigation into current plant wide WWTP model approaches (Chapter 3) and the performance evaluation of a batch test method for the determination of organics compositions required for plant wide models (Chapter 5). All of the plant wide models include activated sludge and anaerobic digestion simulation sub-models that were to some extend based on the IWA activated sludge simulation models (IWA ASM models of Henze et al 2000) and the anaerobic digestion model no. 1 (ADM1) of Batstone et al. (2002). Thus, a short review of these two models is presented in Section 2.2. The steady state plant wide WWTP model of Ekama et al. (2006) incorporates steady state activated sludge and anaerobic digestion models linked with organic compound compositions. A review of this model is presented in Section 2.2.

The experimental investigation and performance evaluation of a batch test procedure for the determination of wastewater organics composition is presented in Chapters 4 and 5. This investigation involved a number of considerations regarding the biodegradability of primary and waste activated sludges. The literature regarding this aspect is reviewed in Section 2.3.

Finally, a brief overview of a possible different approach to the data analysis methodology used in this thesis is presented in section 2.4.

2.2. UNIT PROCESS MODELS

2.2.1. The IWA activated sludge models nos. 1, 2, 2d and 3

The activated sludge model no.1 (ASM1) is a well known and widely used model for activated sludge process simulation. It was developed by a task group set up by the International Association on Water Pollution Research and Control (IAWPRC), the predecessor to the IWA, in 1982. The purpose of its development was to create a common modelling platform for nitrogen removal activated sludge processes (ASM1, 1987). ASM1 was later extended to include other processes such as biological phosphorus removal (ASM2, 1995) and denitrification by phosphate accumulating organisms (ASM2d, 1997). This gave rise to activated sludge models Nos. 2 and 2d (Henze et al 2000). Thereafter aspects such substrate storage and the replacement of the organism death regeneration with endogenous respiration to eliminate the inter-relatedness of the bioprocesses led to the development of ASM3 (2002). There are two philosophical aspects of these models that had direct bearing on this project, viz. the choice of COD over TOC as a measure of organic content in wastewater and the classification system of organic material.

An issue that was carefully considered in the development of this model, one that had notable implications on the coupling of AS models to AD models, was the choice of a measure of organic material in wastewater. This choice was necessitated by the purpose definition of the model, viz. the reduction of energy in wastewater. Three historically accepted measures were considered viz. biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC). The COD was chosen as a measure of organics in wastewater for the ASM models due to its simple method of measurement and together with oxygen consumption the COD balance it offers over AS systems. Total organic carbon (TOC), another possible measure of organics, was rejected because of its less direct link between free energy available in organics, complex analytical equipment it requires and the difficulty of closing the carbon balance over AS systems. Thus, carbon measurements have been ignored during the development of the IWA ASM models (Henze et al 2000). Carbon is included in AD models as an important component of state variables because it is required to predict the gas flow and composition and alkalinity generated, but is rarely included or measured for AS modelling purposes. The choice of COD as an organics measure, though convenient for the ASM models, has resulted in a paucity of information on carbon compositions of wastewater organics now required when coupling AS and AD models (this is further discussed in Chapter 3).

The ASM models have 13 - 19 state variables and are built using bioprocess stoichiometry and kinetic rates combined with mass balanced continuity principles (Gernaey et al 2004). Categories of organic matter were based on biodegradability and physical state (soluble and particulate) considerations. Thus, organic matter is divided into readily biodegradable (RBO), slowly biodegradable (SBO), inert soluble (USO) and inert particulate (UPO) organic fractions. This categorisation approach and definition of organics and their fate during activated sludge treatment are used in Chapter 4 with a slight difference in terminology; viz. inert organics were referred to as unbiodegradable organics. The fate of the above organics groups was defined in the ASM models are as follows: (1) unbiodegradable soluble organics (USO) exit the activated sludge system unchanged via the effluent, (2) influent unbiodegradable particulate organics (UPO) become enmeshed in activated sludge and exit the AS reactor via waste activated sludge (WAS) flow, (3) RBO are considered soluble and are quickly degraded in the AS process to form biomass, and (4) SBO are considered particulate for modelling purposes (though some soluble organics may be slowly biodegradable) and are slowly degraded in the AS process to form biomass. Furthermore, upon death (or decay) activated sludge biomass is considered in the ASM models to become slowly biodegradable organics with an unbiodegradable particulate component. This component is termed endogenous residue. These definitions apply to carbonaceous as well as nitrogenous matter. Fractions of the above stated types of categories may be associated, e.g. US organic nitrogen may be associated with USO (as carbon or COD), RB organic nitrogen may be associated with RBO (as carbon or COD) etc (Henze et al 2000). This classification system has been used in Chapter 4.

2.2.2. The IWA Anaerobic Digestion Model No.1 (ADM1)

The Anaerobic Digestion Model No. 1 (ADM1) was developed for the same purpose as the ASM Nos. 1 to 3, viz. the development of a common framework for modelling anaerobic digestion systems. The advantages stated for the development of a generic AD model included, as for the ASM modelling framework, the provision of a common model that may be understood, used and built upon by researchers and industry alike. Variables written in a common language with common nomenclature and definition allow easier comparison and wider transfer of knowledge and experience across research and industrial groups. It is based on a variety of anaerobic digestion models that had been developed in the past and thus has many of the same state variables as historic anaerobic digestion models (Batstone et al 2002).

The ADM1 model was based on AD processes, which are further discussed here in the interest of the batch test method evaluated in Chapter 5. The ADM1 model is based on the representation of two main reactions, viz. biochemical reactions and physico-chemical reactions. Biochemical reactions include intra or extra cellular biological degradation of degradable organic material. It is accepted in the model that particulate material is transformed to soluble material extra cellular disintegration and hydrolysis. Soluble material is internalised and promotes biomass growth. Physico-chemical reactions refer to ion association/dissociation and liquid-gas transfers of material.

Precipitation considerations were not included in ADM1. The biochemical process model consists of three main steps preceded by a disintegration step wherein complex particulate organic material disintegrates into carbohydrates, proteins and lipids. This includes the waste activated sludge active biomass fraction. These materials are degraded extra-cellularly into biopolymers mono-sacharides (carbohydrates, sugars), amino acids (proteins) and long chain fatty acids (LCFA's, lipids) respectively. The resultant biopolymers are subsequently degraded through acidogenesis, acetogenesis and methanogenesis processes (Batstone et al 2002).

The process of acidogenesis converts the sugars and amino acids into volatile fatty acids (VFA's) and hydrogen (H_2). Long and short chain fatty acids (LCFA's and VFA's) are converted by acetogenesis into acetate. Two methanogenic processes feed on the previous digestion process products acetate and hydrogen (i) acetoclastic methanogenesis converts acetic acid to methane and CO_2 and (ii) hydrogenotrophic methanogenesis converts hydrogen to methane with CO_2 as electron acceptor. Inert (unbiodegradable) particulate and soluble material remains unchanged during the biochemical processes. The physico-chemical reactions include the production of CO_2 gas and its associated pH considerations. A model for these reactions is included in ADM1 as pH has a direct affect on the biochemical processes in anaerobic digestion (Batstone et al 2002).

The ADM1 model includes three main steps, viz. the biological processes (acidogenesis, acetogenesis and methanogenesis), extra cellular degradation (biological and non-biological) and extra cellular hydrolysis (Fig. 2.1). Kinetic formulations quantitatively describe all intracellular reactions, growth and biomass death/decay considerations. Inhibition factors included pH (all groups), hydrogen (acetogenic groups) and free ammonia (acetoclastic methanogens). Physico-chemical acid/base pair dissociation/association process reactions were described by algebraic equations because these are almost instantaneous relative to the bioprocess kinetic rates. Variables included in these processes include pH, free acids and bases and gas components (CO_2, CH_4 and H_2) (Batstone et al 2002).

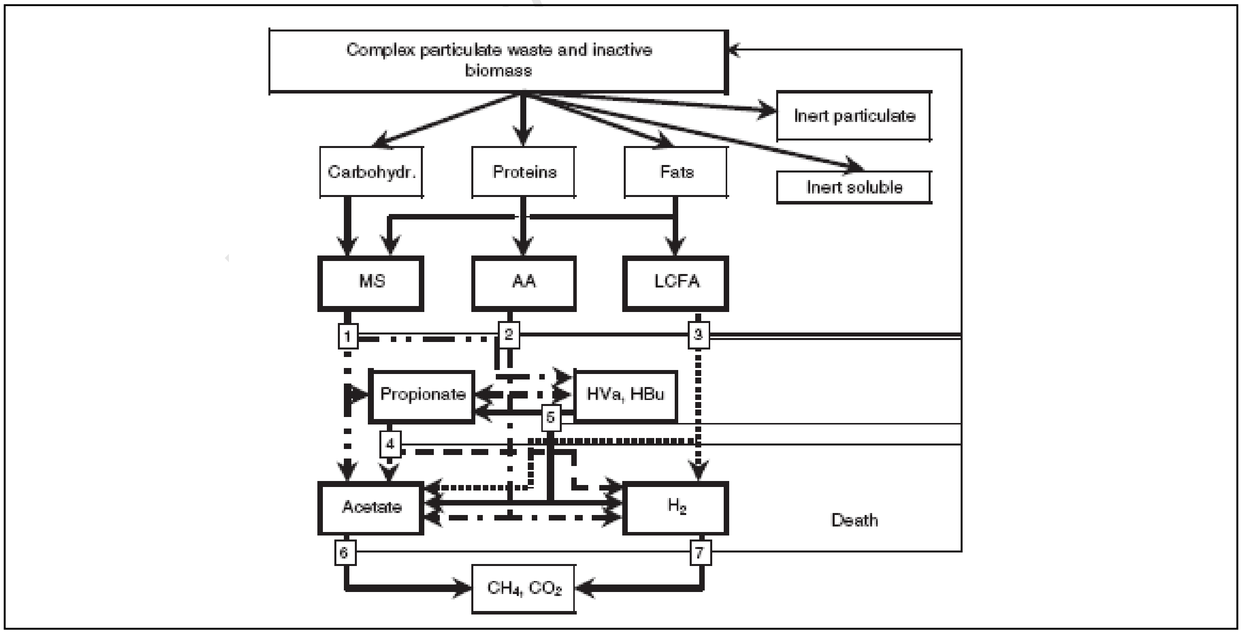


Fig. 2.1: The ADM1 model of Batstone et al. (2002, p. 67) (1) acidogenesis from sugars, (2) acidogenesis from amino acids, (3) acetogenesis from LCFA, (4) acetogenesis from propionate, (5) acetogenesis from butyrate and valerate, (6) acetoclastic methanogenesis, and (7) hydrogenotrophic methanogenesis.

The authors of the ADM1 model (Batstone et al 2002) aimed at the creation of a relatively simple model with maximum applicability. Process components chosen for this aim directly influenced the number of variables included in the model. The model may be represented by two equation sets, viz. a differential and algebraic equation (DAE) set or a differential equation only set (DE). The DAE set contains 26 dynamic state concentration variables with an additional 8 implicit algebraic variables. The DE set contains 32 dynamic state variables.

The IWA ADM1 model of Batstone et al. (2002) is a widely accepted generic framework for anaerobic digestion modelling. It involves the description of bio-chemical and physico-chemical processes of anaerobic digestion through kinetic and algebraic equations. If used as a differential and algebraic equation set it contains a total of 34 dynamic state variables. If used as a differential equation only set it contains a total of 32 dynamic state variables. It has become a popular choice of anaerobic digestion model for integration into plant wide WWTP model (Chapter 3), however, the differences in the state variables used in the ADM1 model and the ASM models make linking the models difficult. State variables between the ASM and ADM models differ not in number, i.e. ASM models have 13 - 19 whereas ADM1 has 32 - 34 but also in type, e.g. the absence of carbon in the ASM models.

2.2.3. The steady state model for anaerobic digestion of Sötemann et al (2005)

Sötemann et al (2005) developed steady state model for the anaerobic digestion (AD) of sewage sludge (primary sludge and waste activated sludge). This model comprises three sequential parts: (i) a COD based kinetic part from which the % COD removal and methane production are determined for a given sludge age, (ii) a C, H, O, N and charge balanced stoichiometry part from which the gas composition (or partial pressure of CO_2), ammonia released and alkalinity generated are calculated from the COD removal from the kinetic part and (iii) a carbonate system weak acid/base chemistry part from which the digester pH is calculated from the partial pressure of CO_2 and alkalinity generated from the stoichiometry. The model is a simplification of their dynamic simulation AD model (Sötemann et al., 2005), which is an integrated two-phase (aqueous-gas) model incorporating AD chemical, physical and biological processes. The input requirements for the steady state model include influent sludge COD characterisation (including its unbiodegradable fraction), short chain fatty acid (SCFA) content as well as the C, H, O and N content, i.e. x, y, z and a values in $C_xH_yO_zN_a$, where these denote the relative carbon, hydrogen, oxygen and nitrogen content of the biodegradable particulate organics (Sötemann et al 2005). Therefore, proteins, carbohydrates and lipids (as required as input in the ADM1 model and it's derivatives) are lumped as total biodegradable sludge organics of the generic form $C_xH_yO_zN_a$. This model thus differs from the ADM1 model regarding its simplicity of input state variables as well as the possibility of linking it to other WWTP processes (including activated sludge treatment as discussed in Chapter 3) through stoichiometric considerations. The steady state AD model is used in a plant wide WWTP mass balances based model developed by Ekama et al. (2006 a,b), Sötemann et al. (2006) and Wentzel et al. (2006) (Chapter 3). Elements of this model are also used in the batch test methodology used in this project (Chapter 4).

As consequence of the mass balanced based AD models is that all the digester outputs, i.e. gas flow and composition (partial pressure), ammonia and alkalinity generated, and therefore the digester pH, are wholly defined by the influent sludge characteristics and composition. These comprise the influent hydrolysable (biodegradable) organics sludge composition, volatile fatty acid (VFA) concentration and influent pH (i.e. the fraction of the influent VFAs ionized). The hydrolysable organics composition was represented as a chemical compound of the form $C_xH_yO_zN_a$, in which the molar masses of the different atoms are represented by x, y, z and z) and these need to be determined for PS and WAS compounds to model the AD. This is the case irrespective of the approach followed to link the AS and AD processes.

All theories used for the calculation of anaerobic digestion processes resulted from the behaviour of the organisms that are responsible for the anaerobic digestion of compounds. Thus, an understanding of the types and behaviour of these organisms is imperative to ensure an understanding of the model theoretical approach. The digestion of organics through anaerobic digestion requires a number of organism groups, viz. acidogens, acetogens, acetoclastic methanogens and hydrogenotrophic methanogens. Acidogens convert complex organics to acetic (HAc) and propionic (HPr) short chain fatty acids (SCFA's) as well as carbon dioxide (CO_2) and hydrogen (H_2). Acetogens convert the propionic acid to acetic acid and hydrogen. The acetoclastic methanogens convert acetic acid to carbon dioxide and methane (CH_4). The hydrogenotrophic methanogens convert hydrogen and carbon dioxide to methane and water (Fig. 2.2). One of the differences between this model and the ADM1 model of Batstone et al. (2002) may be seen in a comparison between Figs. 2.2 and 2.1. Proteins, lipids and sugars (and their associated derivatives amino acids, long chain fatty acids and mono-saccharides) are dealt with separately in the ADM1 model. However, in the steady state model of Sötemann et al. (2005) they are lumped together in a complex organic compound of the form $C_xH_yO_zN_a$, which is hydrolysed to acetic acid and hydrogen under low hydrogen partial pressure and to acetic and propionic acids under high hydrogen partial pressure (Sötemann et al 2005). The other AD processes are the same as in ADM1.

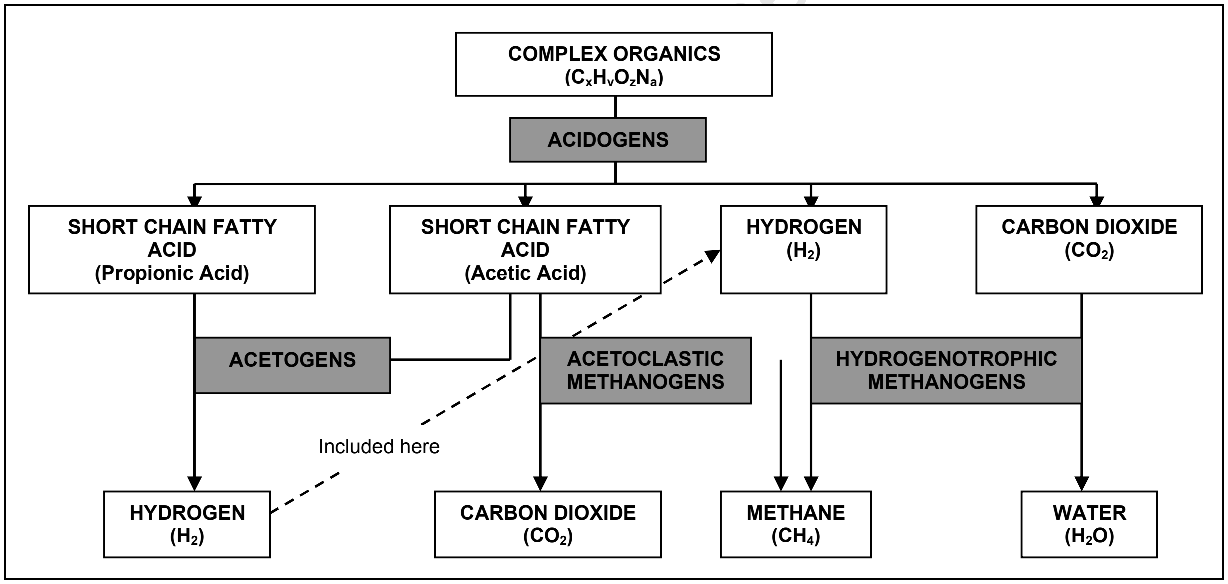


Fig.2.2: Diagrammatic representation of organism groups and their functions in anaerobic digestion (Adapted from Sötemann et al 2005)

It was stated that PS influent COD contains biodegradable as well as unbiodegradable compounds. As in activated sludge theory (Ekama et al 1980), these compounds were subdivided into particulate and soluble parts. For the anaerobic digestion (AD) model, the influent fermentable rapidly biodegradable soluble organics (FRBO), which is the difference between the total RBO as COD and the VFA as COD concentrations, was grouped with biodegradable particulate organics (SBO). This was necessary because both FRBO and SBO are hydrolysed by the same bioprocess (acidogenesis) (Sötemann et al 2005).

A diagrammatic representation of the wastewater characterisation described above is given in Fig. 2.3. This characterisation approach was adopted for wastewater characterisation in this research also (Chapter 4) with the exception of fermentable readily biodegradable COD inclusion in particulate biodegradable COD, which was considered separate in this investigation. It was also followed in the characterisation of carbonaceous and nitrogenous wastewater compounds.

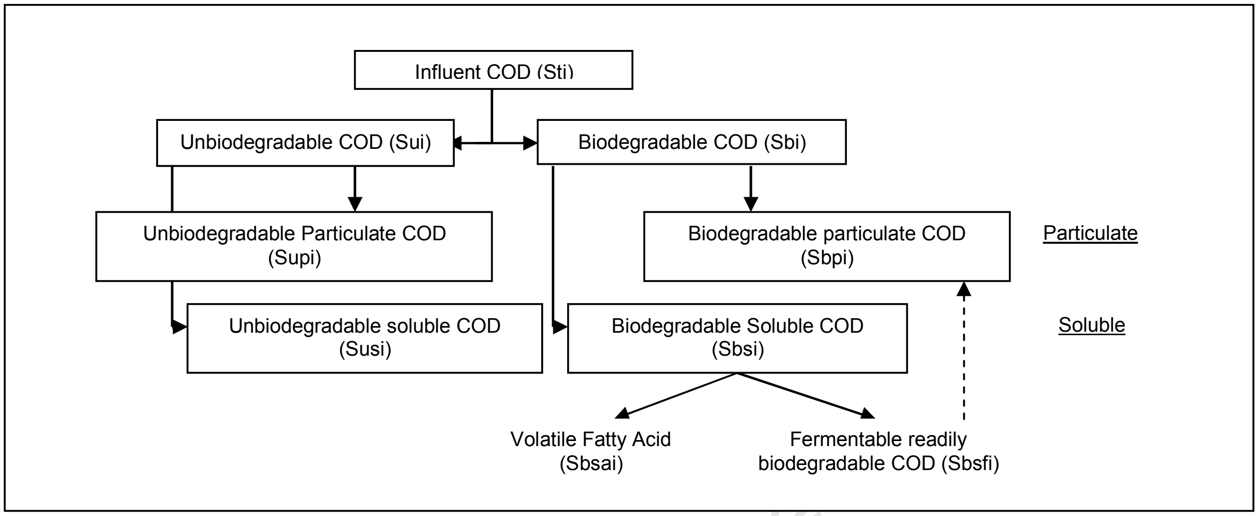


Fig.2.3: Diagrammatic representation of sludge COD characterisation (Sötemann et al 2005, p. 514).

For a particular raw (unsettled) wastewater, the readily biodegradable (RB), unbiodegradable soluble (US) and particulate (UP) COD concentrations were calculated from estimated RBCOD, USCOD and UPCOD fractions, viz. fs'bs, fs'us and fs'up. These concentrations were similarly calculated for settled waste water, subject to the proviso that the soluble concentrations remain unchanged in raw and settled waste water. The raw and settled waste water characteristics were used to calculate the primary sludge (PS) characteristics. This may be done through a mass balance around the primary settling tank (PST) for given fractions of COD, TKN and TP removal in the PST. Sötemann et al. (2005a and Wentzel et al. (2006) showed that the unbiodegradable fraction of the particulate PS (fps'up) calculated in this way closely matched that observed experimentally in PS anaerobic digestion (AD) testing. This implies that particulate influent organics that are determined to be unbiodegradable from the activated sludge system behaviour are also unbiodegradable under anaerobic conditions (Wentzel et al 2006). A similar approach to PS characterisation was adopted in Chapter 4, with the exception that total raw and settled wastewater concentrations were measured. The batch test procedure evaluated in Chapter 4 was used in an attempt to find raw and PS unbiodegradable organics COD, N and C concentrations.

From the COD based kinetic part of the steady state ADS model, the effluent methane COD concentration (Sm) (as if it were dissolved in the effluent flow) can be calculated. The volume of methane gas and, subsequently, the total volume of gas produced during digestion (including carbon dioxide, CO_2) can be determined with the stoichiometry part of the AD model (Sötemann et al 2005). Therefore, this model enables carbon mass balances over the anaerobic digester to be made. The influent COD was taken as a sum of the influent soluble and particulate COD entering the anaerobic digester. COD, C, H, O N and charge masses cannot be destroyed and thus the masses of these materials exiting the AD must equal the masses entering the AD. For the effluent, the effluent COD concentration was taken as a sum of the residual biodegradable COD (Sbp) not hydrolysed, the AD organism concentration (Z_{AD}), the unbiodegradable particulate COD (Sup) and the methane concentration (Sm). The methane and biomass concentrations represent the total amount of COD broken down in the AD and the effluent methane concentration represents the COD removed during anaerobic digestion. The difference is small because biomass production is very low under anaerobic conditions. The amount of biodegradable COD removed during digestion was taken as the influent biodegradable COD (Sbpi) minus the residual biodegradable COD (Sbp) (Sötemann et al 2005). These considerations are based on the COD mass balance over the anaerobic digester.

The input required for the stead state AD model and their sources of information were:

1. Unbiodegradable fraction of PS particulate organics – mass balance over a PST for given raw and settled waste water characteristics and percentage COD removal in the PST.
2. Organics composition ($C_XH_YO_ZN_A$) of PS biodegradable particulate organics – in the model this was calculated from COD/VSS (fcv) and N/COD ($f_{ZB'N}$) ratio's obtained from raw and settled waste water characteristics and percentage COD and TKN removals. This calculation fixes y = 7. If only two measurements are available (e.g. COD/VSS ratio and TKN/VSS ratio, a third has to be assumed, e.g. z = 2. This assumption is not ideal as there is no evidence to suggest that the y/z ratio in any wastewater organics composition is 7/2. From the mass balances over the AD systems operated by Izzett et al. (1992), the biodegradable particulate organics (BPO) composition of was determined to be $C_{3.5}H_7O_{1.96}N_{0.196}$. This was validated with elemental analysis on primary sludge from two WWTPs - the measured C, H, O and N contents were within 5% of $C_{3.5}H_yO_{1.96}N_{0.196}$. However, it is not known whether this composition can be applied to any PBO. Therefore a batch test method for the determination of this composition, and the other influent organic groups, was evaluated in Chapter 5. The y/z ratio = 2 observation above was retained for soluble organics compositions determinations because a VSS (or molar mass) measurement is not possible. This was considered reasonable because the soluble concentrations are low compared with the particulate concentrations.
3. Fermentable RBCOD and volatile fatty acid (VFA) concentrations. Compositions for these were assumed for the purpose of the steady state AD modelling task (Chapter3). Attempts to measure these concentrations are made in Chapter 4.
4. The characterisation method used in this steady state AD model was utilised in the batch test method described in Chapter 4, without the inclusion of readily biodegradable (RB) organics concentrations in biodegradable particulate (SB) concentrations.

2.3. ANAEROBIC DIGESTION OF PRIMARY SLUDGE AND WASTE ACTIVATED (SECONDARY) SLUDGE

An anaerobic digestion (AD) batch test method for the determination of primary sludge (PS), waste activated sludge (WAS) and raw wastewater biodegradable, unbiodegradable and total organics compositions of the form $C_xH_yO_zN_a$ is evaluated in Chapter 4. The lumping of organics groups into a complex organic form represented as $C_xH_yO_zN_a$ is not a new concep, which is now widely employed to include carbon in in the plant wide WWTP models reviewed in Chapter 3. Literature pertaining to physical measurements of biodegradable and unbiodegradable organics in this form does not exist. Relevant literature pertaining to the biodegradability of sludge (PS and WAS) i.t.o. COD and volatile solids (VS) removal in AD as well as physical process parameter effects on sludge biodegradability is reviewed in this section. The knowledge gained from the review was employed in the batch test process design and evaluation of Chapter 4 and 5.

2.3.1. Effect of temperature and sludge retention time on sludge biodegradability during AD

Mahmoud et al. (2004) performed an experiment to investigate the effect of sludge retention time and process temperature on primary sludge anaerobic digestion processes. Hydrolysis, acidification and methanogenesis process effects in completely stirred reactors at different sludge ages (10, 15, 20 and 30 days) and temperatures (25 ºC and 35 ºC) were investigated. In the same period, batch tests were used to assess hydrolysis rates and primary sludge biodegradability at different temperatures (15 ºC, 25 ºC and 35 ºC). For the completely stirred reactors it was found that the most sludge stabilisation (high COD removals) occurred before 10 days at 35 ºC and between 10 and 15 days at 25 ºC. It was also found that the biodegradability of primary sludge (COD or VSS) was around 60 %.

Mahmoud et al. (2004) stated that the batch test hydrolysis process may be described by first order kinetics that involves biodegradable organic matter as well as a constant temperature and pH. The batch test results revealed that solids retention time need to be increased at decreased temperature to achieve the same degree of organics degradation. Gas production stopped around the 60^{th} day for the batch tests incubated at 35 ºC and around the 75th day for batch tests incubated at 25 ºC. The batch tests incubated at 15 ºC did not reach complete degradation even after 135 days. Thus, the rate of biodegradation increased with increased temperature. These timeframes were used as a starting point for incubation times for the batch test method designed in Chapter 4. Accordingly an initial incubation length of > 60 days was set.

2.3.2. Effect to solids retention time in AS processes on the anaerobic digestion performance of WAS

Gossett and Belser (1982) have investigated the effect of activated sludge process solids retention time on the performances of anaerobic digestion of waste activated sludge (WAS). The experimental setup for their investigation included six laboratory scale activated sludge reactors run at different sludge ages (5, 10, 15, 20, 25 and 30 days) fed a synthetic sewage with negligible VSS content for experimental convenience. Samples from each of these activated sludges were digested in anaerobic batch tests for long time periods (128 days) for determination of ultimate digestibilities.

Gosset and Belser (1982) have divided the organic fraction of WAS (volatile suspended solids, VSS) into three parts, viz. unbiodegradable VSS originating from the influent and accumulating in the system, active biomass VSS synthesized during the activated sludge process and inert VSS remains of decayed cells (endogenous residue). This approach is similar to the ASM models approach of Henze et al. (2000) as reviewed above. Gosset and Belser (1982) stated that unutilized influent biodegradable VSS and biodegradable VSS cell remains could be ignored in any efficient activated sludge process (i.e. with very high BOD removal). This was also accepted in the theoretical determination of organics compositions in Chapter 4.

From their study, Gosset and Belser (1982) concluded that the ultimate biodegradability of viable biomass is equal under aerobic and anaerobic conditions. From the activated sludge reactors they measured a net biodegradable fraction of active biomass (f_H) of 0.683, which they found to correspond with other literature data. This value was also found to correspond to the ultimate digestibility of WAS under anaerobic conditions found from their experiments. They also found that decreasing AS system sludge age resulted in a WAS with increasing digestibility for anaerobic digestion processes, which is in conformity with AS theory. Therefore, they have stated, that AS models predicting the aerobic biodegradability of WAS will also predict the anaerobic biodegradability. However, the biodegradable fraction of the AS biomass of 0.683 seems very low compared with that widely accepted in the ASMs: (1-f)=0.80 for endogenous respiration and 0.92 for death-regeneration (Ekama et al 2006 b), possible due to using synthetic wastewater in their experiments.

2.3.3. Biodegradability of primary sludge (PS) and waste activated sludge (WAS) under anaerobic conditions

As mentioned above, Sötemann et al. (2005) developed a mass balances (COD, C,H,O and N) steady state model for the anaerobic digestion of sewage sludge. In the validation of this model, they determined an unbiodegradable organics particulate COD fraction $f_{PS'up}$ for primary sludge of 0.33 and an BPO composition of $C_{3.5}H_7O_{0.197}N_{0.190}$.

Typical South African raw and settled municipal wastewaters have $f_{S'up}$ fractions of approximately 0.15 and 0.04 respectively (Wentzel et al 2006 cited in Wiechers 1984). From a mass balance around the primary settling tank, these $f_{S'up}$ fractions yield a primary sludge unbiodegradable fraction $f_{PS'up}$ of 0.35. VS removals in AD have been determined to be around 0.60-0.65 (Wentzel et al 2006 cited in Eckenfelder 1980). From this Wentzel et al. (2006) concluded that the influent unbiodegradable organics (UPO) as defined by the "aerobic" AS system remain unbiodegradable under anaerobic conditions.

To check whether or not this also applies to the unbiodegradable organics generated by the biomass, i.e. the endogenous residue, Ekama et al. (2006 b) evaluated the data of van Haandel et al. (1998). van Haandel et al. operated a pilot scale wastewater treatment plant scheme at 25°C in which 500ℓ/d raw municipal wastewater was fed to a 2 day retention time aerated lagoon (R0). All the daily WAS from the aerated lagoon was thickened into 30ℓ which served as feed to a series of four aerobic digesters (R1 to R4) at retention times of 1.73d, 2.14d, 3.00d and 5.63d respectively. From the feed to each aerobic digester, 4, 5, 6, 7 and 8 ℓ/d of sludge volume respectively was withdrawn, thickened to a volume of 0.40 ℓ/d and fed to five anaerobic digesters (AD0 to AD4) each at 20d retention time. Each AD was therefore fed WAS with a different fraction of unbiodegradable particulate organics depending on the extent of aerobic digestion before anaerobic digestion. From modelling this data with their steady state and simulation models, they concluded that unbiodegradable organics determined from an activated sludge reactor including the endogenous residue, remain unbiodegradable during anaerobic digestion - the theoretically calculated and experimentally measured unbiodegradable WAS fractions corresponded well. Furthermore, in order to predict the correct unbiodegradable fraction of the WAS (f_H), the value from the death –

regeneration model (f_H=0.08) has to be selected, not the value from the endogenous respiration model (f_H=0.20).

Ekama et al. (2006 b) conducted an experimental investigation to determine the biodegradability of WAS under anaerobic conditions. They operated an activated sludge reactor at laboratory scale at 15 days retention time. The WAS produced by the reactor was fed to a 60 day laboratory scale anaerobic digester. The unbiodegradable fraction of the WAS ($f_{AS'up}$ = 0.637) was found to be similar to the effluent unbiodegradable COD fraction determined from the anaerobic digester ($f_{AS'up}$ = 0.627). This was considered to be support the observation that the unbiodegradable organics from activated sludge systems remain unbiodegradable under anaerobic conditions.

Arnaiz et al. (2006) performed an investigation into the stabilisation of wastewater sludge (PS and WAS) biomass in anaerobic treatment. From this study the found a primary sludge volatile solids biodegradability of 87 % and a WAS volatile solids biodegradability of 43 %. The PS biodegradability differs significantly from the 60 % VSS biodegradability found by Mahmoud et al. (2004) and Wentzel et al. (2006). This indicates that PS biodegradability varies probably due to PS source and content.

2.4. DATA RECONCILIATION

Data reconciliation is a well established technique used for data processing and much litterature is available on the subject. A brief overview of litterature relevant to the methodologies used for data processing in this project has been presented below.

Measurement error in the form of avoidable, systematic or random error affect the plausibility of measured data. The principle of data reconciliation consists of the use of all measured variables, including redundant data, and the minimal correction of variables to satisfy relevant balances or constraints. Thus, the maximum, rather than the minimum, amount of measurements are used to find a solution. Measured data, data uncertainties and conservation laws are combined during the reconciliation process to produce a reconciled data set. Conservation laws consist of mass, energy and material (stoichiometric) balances and these form the boundary conditions which the true values must meet. Reconciled data, in waste water treatment modelling, will therefore fullfill mass, energy and material balances. Uncertainties pertaining to these values are therefore reduced. Values that do not conform to conservation laws may also be identified as values that contain gross error (Laipple & Langenstein 2007).

The method of data reconciliation is of specific use in wastewater treatement plant modelling in that it may be used as a method for mass and energy accounting. (Laipple & Langenstein). A study performed by Meijer et al (2002) highlighted the possibility of gross error detection before implementation of operational data for modelling purposes. Meijer et al (2002) performed a full scale WWTP modelling study in which they demonstrated the use of data reconciliation methodology to minimise mass balance residuals. They made use of redundant measurements and mass balance constraints to determine the accuracy of measured data by analising mass balance residuals. Gross errors were detected and reduced to minimise mass balance residuals, and therefore bring measured data in line with mass balance constraints. The reconciled data set was considered to contain fewer errors and therefore considered to be of higher accuracy than an unreconciled data set.

The methodology of data reconciliation, though having a very similar approach to the data analysis method followed in this thesis (Chapter 4), differs in its method objectives. The objective of the data analysis methodology in this thesis was not to correct variables to satisfy conservation laws, but to evaluate the batch test methodology for the determination of organics compositions. Therefore, data was not changed in any way to produce data of higher accuracy or precision but, rather, the discrepencies in data evaluated from different data bases were used to highlight flaws in the batch test methodology investigated in this thesis. However, it is possible that the use of data reconcilation methodology may have reduced gross error to such an extent that data of the necessary accuracy for organics compositions may have been determined. This would have, in effect, validated the batch test method evaluated in this thesis and affected the conclusions reached in Chapte 6.

2.5. CONCLUSIONS

The conclusions from the literature review sort into two groups, viz. (1) relevant points pertaining to the investigation into wastewater treatment models and their use during further investigations in this project and (2) conclusions pertaining to anaerobic digestion of primary and waste activated sludge. These are listed below:

(1) Unit process models:
The following relevant points are reiterated:

- The IWA activated sludge models (ASM1, ASM2, ASM2d and ASM3) of Henze et al. (2002) and the ADM1 model of Batstone et al. (2002) are widely used in integrated plant wide WWTP modelling approaches as reviewed in Chapter 3.
- The ADM1 model requires carbon as a constituent of its input variables proteins, lipids and sugars (and their derivatives amino acids, long chain fatty acids and mono-saccharides). The steady state AD model of Sötemann et al (2005) requires carbon insofar as the determination of organics compositions of the form $C_xH_yO_zN_a$ is concerned. The ASM models use COD as a measure of organics and due to the advantages of the COD from practical and modelling points of view, the TOC measurements have been ignored during the AS model development. This has resulted in a paucity of carbon data and makes linking AS models and AD models based on ADM1 model difficult.
- The ADM1 model of Batstone et al. (2002) and the steady state (and dynamic simulation) AD model Sötemann et al (2005) differ (among other things) in the description of input variables. The ADM1 model incorporates input variables in the form proteins, lipids and sugars; whereas the AD models of Sötemann et al (2005) use a lumped biodegradable organic compound of the form $C_xH_yO_zN_a$ and acetic acid ($C_2H_4O_2N_0$ for associated and $C_2H_3O_2N_0^-$ for associated). Neither proteins, lipids and sugars nor the composition of $C_xH_yO_zN_a$ are commonly measured in wastewater testing, but the x, y, z and a values can be calculated from the common COD, TKN, VSS, TSS measures and an additional measure for carbon, which could be TOC or elemental analysis. A batch test method for the determination of the various organics groups (biodegradable soluble, BSO; biodegradable particulate, BPO; unbiodegradable soluble, USO; unbiodegradable particulate, UPO) in wastewater streams in a WWTP is evaluated in Chapter 5.
- The IWA ASM models use an approach based on biodegradability and physical states (soluble and particulate) for organic material characterisation. Thus, organic material is divided into readily biodegradable (soluble), slowly biodegradable (particulate), unbiodegradable soluble and unbiodegradable particulate categories. Wastewater COD, N and C concentrations may be characterised in a similar way. This organics characterisation framework will also be used in this research (Chapter 4).

(2) Anaerobic digestion of sewage sludge:

- Mahmoud et al. (2004) found that retention times in PS anaerobic digesters need to be increased to compensate for a decrease in temperature to achieve the same degree of VSS removal and that PS biodegradability was not temperature dependent. Also, they found that gas production stopped (indicating biodegradation processes were complete) after 60 days and 75 days for batch tests incubated at 35 °C and 25 °C respectively. Batch tests incubated at 15 °C did not reach process completion even after 135 days.

- Sötemann et al (2005) found that influent unbiodegradable organics, as defined by the “aerobic” activated sludge system, remained unbiodegradable under anaerobic conditions.
- Gossett and Belser (1982) found that decreasing AS sludge age results in a WAS with an increased biodegradable fraction under AD conditions, which is in conformity with AS models. This is probably the reason for differences in WAS biodegradabilities found in literature. Arnaiz et al. (2006) found 43 % VS destruction in WAS under AD, Ekama et al. (2006) found 36% COD removal.
- Using literature and their own data, Ekama et al. (2006) concluded that the aerobic biodegradability of WAS was equal to its anaerobic biodegradability, which implied that the unbiodegradable endogenous residue generated by the AS system remains unbiodegradable under anaerobic digestion conditions.

(3) Data reconciliation

A data processing approach using the methodology of data reconciliation is a possible alternative to the data analysis approach used in this thesis. The possibility remains that data error may have been reduced to such an extent, that the batch test method evaluated in this thesis may have been considered valid. Therefore the conclusions reached in this thesis may have been proven to be incorrect.

CHAPTER 3
WWTP PLANT-WIDE SIMULATION MODELS

3.1. INTRODUCTION

Historically wastewater treatment plant models have focussed primarily on unit operation design. The main focus has been on the modelling of the activated sludge system incorporating nitrogen and phosphorus removal. Until recently, relatively little research has been done to model the wastewater treatment plant as a whole in an integrated fashion (Wentzel et al 2006).

Plant wide WWTP models can have a number of potential advantages. These may include the tracking of compounds through the WWTP in order to identify the characteristics of streams between different links in order to assess the impact on downstream unit operations. This may include an assessment of the impact of recycled flows such as sludge thickening and dewatering liquors from downstream on upstream unit operations. Other advantages may include the possibility of identifying the potential of overloading unit operations, optimisation of unit operations, prediction of mineral precipitation problems and the identification of parameters that do not conform to mass balance and continuity principles such as flow rate which is often a problem at WWTPs (Wentzel et al 2006).

Historically wastewater treatment unit process models have been developed in isolation. For particular unit operations such as AS considerable success has been made at creating common platform models, which would allow modellers to speak a common language when researching wastewater treatment modelling. Thus, the activated sludge models ASM1, ASM2, ASM2d and ASM3 and the anaerobic digestion model ADM1 have been developed and widely accepted. These models have been commonly used as a basis for further model development (Vanrolleghem et al 2005). However, only recently, have attempts been made at integrating different models into a plant wide WWTP simulation model. WWTP effluents were traditionally considered to be the most important focus of WWTP modelling. However, this view is changing due to increasing pressure towards the optimisation of wastewater treatment systems. WWTP unit processes are physically integrated and have an impact on one another, e.g. N and P removals in activated sludge processes are affected by the sludge treatment liquors recycled back to the AS reactor. Thus, the integration of WWTP unit operation models is necessary for the optimisation of WWTP systems as a whole.

Unit operations in wastewater treatment have different functions and are thus inherently different in the physical, chemical and biological processes they promote. Process differences have resulted in the development of models that rely on different variables (state variables). The use of different state variables has meant that modelling incompatibilities exist in linking different unit operation process models. So difficulties have been experienced in developing plant wide WWTP models due to a number of factors. One such factor is that state variables required in one model may be non-existent in other models e.g. carbon is usually not included in activated sludge models, but is of high importance in anaerobic digestion models. The definition of state variables may also be different between different unit process models e.g. biodegradable components in one model may not be biodegradable in another (Vanrolleghem et al 2005). Compounds that are considered constant in a unit process model may be a state-variable in another unit process model e.g. pH is considered to be constant in the ASM models but is a state variable in the anaerobic digestion and SHARON models (Volcke et al 2006). Thus the difficulties in coupling different unit process models are mainly due to differences in the number and type of state variables in different unit process models.

Recent proposals towards overcoming these difficulties are the continuity based interfacing method (CBIM) of Vanrolleghem et al. (2005) and Volcke et al. (2006), the ‘supermodel approach’ of Jones and Tákacs (2004) and Seco et al. (2004), both cited in Grau et al. (2007), and the transformation based approach of Grau et al. (2007), which is a combination of the CBIM and supermodel approaches. All three of these approaches leave the original unit operations models unchanged and are aimed at circumventing the model interfacing difficulties caused by state variable incompatibilities. A general theme in the model approaches is the use of compounds in their elemental composition forms, viz. C, H, O, N, P and charge content, as part of a method to transform incompatible unit process state variables into compatible forms. There is a fourth approach of Ekama et al (2006), which is similar to the three above in that it also uses compound elemental composition, but different because the problems id sate variable incompatibility does not arise because it uses a different AD feed characterization structure one that is more aligned with hat used in activated sludge models. The different Plant wide modelling approaches are further discussed below:

3.2. THE CONTINUITY BASED INTERFACING METHOD (CBIM)

3.2.1. Introduction

The CBIM approach is based on the idea of creating interfacing models between unit process sub-models in which state variables are transformed from the origin model to those required in the destination model. The origin and destination models respectively refer to the unit operations from which, and to which, WWTP streams flow. With this method, model interfaces are set between different sub-models, which are thus left unchanged. State variables from the origin model are transformed in the model interfaces to become compatible with state variables required in the destination model. Mass conservation is adhered to in variables e.g. C, H, O, N, P, COD and charge. Thus, state variable compositions and units are transformed in the interface models to ensure compatibility between origin and destination models (Volcke et al 2006).

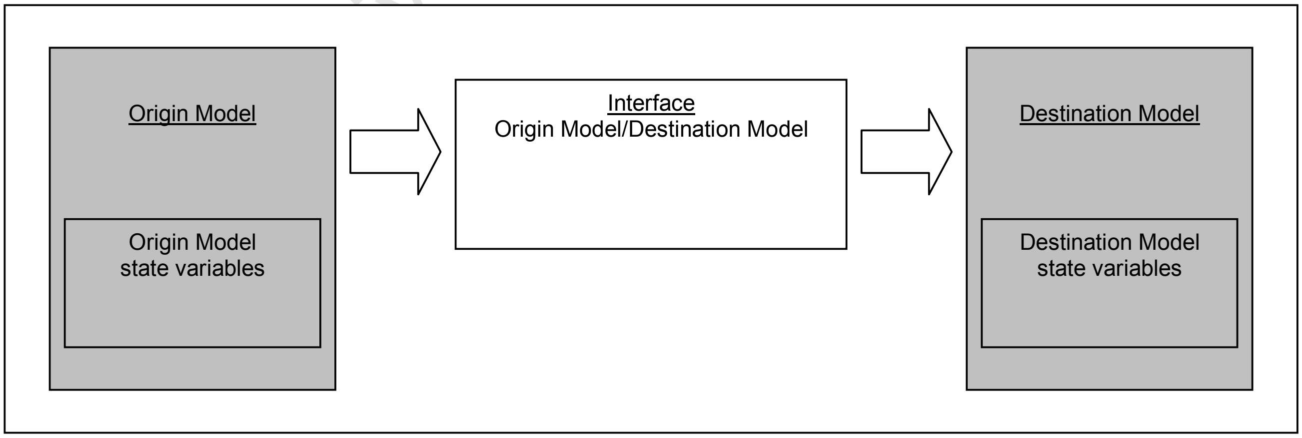


Fig.3.1: Model interfacing approach (adapted from Volcke et al 2006)

3.2.2. A general approach to CBIM modelling

Volcke et al. (2006) indicated a general approach towards continuity-based interface modelling as a further development of the CBIM approach described by Petersen matrices proposed by Vanrolleghem et al. (2005). The approach has been illustrated by means of three different interfacing case-studies, viz. the creation of interfaces between the ASM1 and SHARON models, SHARON and Annamox models as well as Annamox and ASM1 models. This study was done by implementing the SHARON and Annamox models in the Benchmark Simulation Model No.2 (BSM2, Jeppson et al., 2006). The BSM2 contains the ASM1 (Henze et al., 2000) and ADM1 (Batstone et al., 2002) models as well as interfaces between these two sub-models. The BSM2 interfaces differ from the CBIM approach in that only conservation of COD and N are ensured by them.

General approach: Step 1

The CBIM general approach consists of four main steps. The first step comprises the formulation of elemental mass fractions (α = g element / g component) for all unit operation state variables (origin as well as destination models). This is done to convert state variables into a compatible form of model components. This step relies on the assumption that the mass of all components consist of constant mass fractions of elements C, H, O, N, P and charge i.e. $\alpha^{C}_{k} + \alpha^{H}_{k} + \alpha^{O}_{k} + \alpha^{N}_{k} + \alpha^{P}_{k} = 1$. From here a general formula for 1g of a model component is proposed:

$$[C_{(\alpha^{C}_{k}/12)} H_{(\alpha^{H}_{k}/12)} O_{(\alpha^{O}_{k}/12)} N_{(\alpha^{N}_{k}/12)} P_{(\alpha^{P}_{k}/12)}]^{\alpha Ch} \qquad (3.1)$$

Where: α denotes the elemental mass fraction (g element / g component)
k denotes the model component
ch denotes the component net charge

Elemental compositions of most components are unknown in this study so the following assumptions regarding ASM1 components (compounds) were made (Volcke et al 2006):

1. Autotrophic and heterotrophic biomass elemental compositions for ASM1 were assumed to be the same equal. The C, H, O and N content were sourced from the stoichiometric formula $C_5H_7O_2N$, also used by Henze et al. (2000) in ASM1 and Batstone et al. (2002) in ADM1. P content was an assumed fraction of 0.03 mg P/mg biomass. The α values were calculated from this composition and yields α^C, α^H α^O α^N α^P values of 0.516, 0.060, 0.28, 0.114 and 0.03 g element/g biomass respectively.
2. The N and P content of unbiodegradable soluble and readily biodegradable organic (US- and RB organics) compounds were assumed values for ASM1. N content was assumed to be zero. Hydrogen and oxygen contents were assumed from RWQM1 (Reichert et al 2001). Carbon content was calculated from the assumed values above.
3. The N,H and O content of unbiodegradable particulate (UP organics) compounds were assumed to be similar to those used in ADM1. The P content was assumed. Carbon content was calculated from these values.
4. The composition of slowly biodegradable organics (SB organics) was assumed to be the same as that of readily biodegradable organics (RB organics).
5. Organism endogenous residue composition was assumed to be the same as that of the heterotrophic biomass i.e. $C_5H_7O_2N$.

Thus the following compositions (mass fractions in g/g component) were used:

Table 3.1: Composition mass fractions

Description	**α^C**	**α^N**	**α^H**	**α^O**	**α^P**	**α^{Ch}**
US organic compounds	0.65	0	0.07	0.28	0	0
RB organic compounds	0.62	0	0.08	0.28	0.02	0
UP organic compounds	0.56	0.09	0.06	0.28	0.01	0
SB organic compounds	0.62	0	0.08	0.28	0.02	0
Heterotrophic biomass	0.516	0.114	0.06	0.28	0.03	0
Autotrophic biomass	0.516	0.114	0.06	0.28	0.03	0
Particulate products from biomass decay (endogenous residue)	0.5575	0.0925	0.06	0.28	0.01	0

(Volcke et al 2006)

All influent organic components in this study were thus based on assumptions. It must be noted here that unbiodegradable particulate components for the activated sludge model ASM1 were assumed to have similar values to components used in the anaerobic digestion model ADM1. Thus, it was assumed that activated sludge unbiodegradable particulate organics were also unbiodegradable in AD systems. This was later validated by Ekama et al. (2006).

General approach: step 2

Once the elemental compositions and mass fractions have been determined, composition matrices need to be set up for each unit process model. This comprises step 2 of the CBIM procedure. The interface method uses a Petersen matrix description to transform the components (compounds) of one model to those of another with the compounds of the source model across the top of the matrix (columns) and the "process" transforming the source model compounds to the destination model compounds as rows and with the stoichiometric conversion factor of one compound to the another at the intersection cell of the row and column. To ensure that element mass is conserved, HCO_3^- is added to close the C balance, NH_4^+ to close the N balance, HPO_4^- to close the P balance, H_2O to close the O balance and H^+ to close the charge balance, which will automatically close the H balance. The set of algebraic equations that are to be used to transform the compounds in the interface are developed from the Petersen matrix "stoichiometry". Component descriptions are done in the form of the α compositions, which include carbon, nitrogen, COD, charge etc., i.e. components are shown in elemental compositions (Vanrolleghem et al 2005).

General approach: step 3

The third step of the CBIM approach comprises the definition of transformation matrices. Interface inputs consist of output state-variable fluxes from the origin sub-model. Conversely, interface outputs consist of input state-variable fluxes to the destination model. Thus, the interface must be used to transform output state-variables from the origin sub-model to input state-variables of the destination model.

General approach: step 4

The fourth step of the CBIM approach comprises the development of component transformation equations. Transformation equations are defined by stoichiometric considerations, i.e. quantitative aspects of chemical formulas and reactions, and transformation rates. These equations thus specify the amount of an origin model component that is transformed to a destination model component per unit time (Vanrolleghem et al 2005).

Vanrolleghem et al. (2005) proposed that the transformations are to be performed by the user, based on process knowledge and insight. Elemental continuity (COD, C, N, P, charge etc.) for components are to be guaranteed by all transformation equations. Once transformation equations have been designed, the unknowns (stoichiometric coefficients and transformation rates) may be calculated through a set of linear equations. These unknowns may then be used to calculate the destination model influx components with the transformation equations. Thus, the onus is on the user to specify the transformation equations correctly to ensure correct destination model influx components. This proposal leaves possibilities of high degrees of variability in transformation approaches by different users. This may prove to become a problem as independent validation of transformations may be difficult to perform by users who disagree with the methods of transformation chosen. In other words, a large degree of freedom is left to the user of the CBIM method which will influence the final model solution for a specific WWTP problem and thus model solutions for a specific problem may vary greatly from user to user.

3.2.3. ADM1-ASM1 case study

Zaher et al. (2007) performed a case study in which the CBIM approach was used to build transformers between the ASM1 model of Henze et al. (2000) and the ADM1 model of Batstone et al. (2002). The general procedure as discussed above was followed.

The formulation of elemental mass fractions was performed as stated above. Organic components for the ASM1 model were based on the same assumptions as made by Volcke et al. (2006). The values for organics elemental mass fractions for the ADM1 model were also based on assumptions e.g. all phosphorus content was assumed. Thus no practical investigation into the determination of these compound mass fractions was performed. Unbiodegradable soluble and particulate organics were assumed to have the same elemental mass fractions as the unbiodegradable particulate organics in the ASM1 model. Biodegradable soluble organics were defined as monomers and volatile fatty acids in accordance with the ADM1 model. Biodegradable particulate organics were defined as composite particulates, proteins, lipids and carbohydrates (Zaher et al 2007). Once the elemental mass fractions were defined, the composition and transformation matrices were built.

The transformation matrices were based on a number of assumptions regarding the transformation of activated sludge organics in anaerobic digestion and v.v. Some of the transformations were uncomplicated e.g. ASM1 unbiodegradable material (soluble and particulate) were directly transformed to unbiodegradable in the ADM1 model and endogenous residue was taken to remain unbiodegradable in the ADM1 model in accordance with the findings of Ekama et al. (2006 b). Transformations where an origin model state variable may split into more than one destination model state variables were more complicated and were subjective to the user's knowledge and insight e.g. the conversion of soluble organic nitrogen and readily biodegradable organics into sugars, volatile fatty acids and amino acids. This transformation was performed based on a number of assumptions s.a. the COD fraction to sugars and fatty acids were assumed to be 0.3 and 0.2 respectively (Zaher et al 2007).

The case study performed by Zaher et al. (2007) was done in accordance with the general CBIM method of Volcke et al. (2006). Transformation interfaces were constructed between the ASM1 and ADM1 models. These transformations were based on a large number of assumptions including the elemental compositions of organics as well as the nature of transformation of compounds between the two unit process models.

3.2.4. Conclusions

The CBIM approach was designed to create unit process model interfaces through which origin and destination model state variables may be transformed into compatible versions. The approach leaves the origin and destination models unchanged. State variables are transformed into elemental mass fractions (g element / g compound) based on the hypothesis that the mass of an organic compound consists of stable masses of C, H, O, N and P, with a specific net charge. The elemental mass fractions used in this study for all organic compounds (readily biodegradable, slowly biodegradable, unbiodegradable soluble, unbiodegradable particulate, organisms and endogenous residue) were assumed. Thus no indication towards the determination of these compounds for future simulations was provided.

The CBIM approach leaves a large degree of freedom to the user of the approach in the definition of transformation matrices. It is proposed that such definitions are performed based on process knowledge and insight. This may result in different solutions to specific WWTP simulation problems solved by different users.

3.3. THE ‘SUPERMODEL’ APPROACH

The ‘supermodel’ approach aims to construct a model that integrates all components and transformations in all processes in a WWTP. Thus all components and transformations are included in all unit process models, even though they may not be required. This increases the size of all unit process models and thus increases computation time. State-variable transforming interfaces are not required between unit process models. This approach may result in a model that is very difficult and time consuming to compute due to its complexity (Grau et al 2007).

3.4. THE TRANSFORMATION-BASED APPROACH

3.4.1. Introduction

Grau et al. (2007) have proposed a whole WWTP simulation methodology that aims to use a problem specific approach, which focuses on the most suitable transformations for each unique case study. The transformation-based approach to whole WWTP simulation modelling has been designed to include aspects from both the interfacing method and the ‘supermodel’ approach. The need for transforming interfaces between unit operation models has been eliminated and has been replaced by a requirement for the selection of process transformations for specific WWTP simulations.

3.4.2. The transformation-based approach methodology

The proposed transformation-based methodology consists of three main steps, viz. (1)the creation of a general list of transformations (LT) with the resultant construction of a specific plant transformation model, (2) the construction of a set of compatible unit process models (UPM's) and (3) the construction of a plant-wide model (PWM) through direct interfacing of UPM's. A preliminary step is required wherein a compilation list of stoichiometry and kinetics of the most relevant biochemical, chemical and physico-chemical transformations is constructed in the form of a Petersen matrix (Grau et al 2007).

Grau et al. (2007) have proposed the use of the ASM models of Henze et al. (2000) and the ADM1 model of Batstone et al. (2002) for the selection of transformations in activated sludge treatment and anaerobic treatment. As for the CBIM approach, model components must be re-defined i.t.o. their elemental compositions (C,H,O,N,P and charge) to ensure continuity between different unit process models. Components are summarised according to the following general formula:

$$[\, C_{(\alpha C,i\,/\,12)}\, H_{(\alpha H,i\,/\,1)}\, O_{(\alpha O,i\,/\,16)}\, N_{(\alpha N,i\,/\,14)}\, P_{(\alpha P,i\,/\,31)}\, X_{(\alpha X,i\,/\,Mx)} \,]^{\alpha Ch,i} \qquad (3.2)$$

Where: α denotes the element mass per compound mass (g/g)
X denotes all other elements
Mx denotes the molar mass of X

(Grau et al 2007).

This formulation is similar to the one proposed by Vanrolleghem et al. (2005) and Volcke et al. (2006). The formulation has been expanded to include other elements under the X notation.

The ASM models of Henze et al. (2000) do not include carbon explicitly, nor does it include compound elemental compositions. Rather, COD is used as a measure of organic material (biodegradable or unbiodegradable), while nitrogen and phosphorus inherent in organic material is treated separately. Grau et al. (2007) have proposed that biodegradable material be described in its constituent forms that have known elemental compositions in the LT e.g. monomers and VFA's for soluble compounds and proteins, lipids and carbohydrates for particulate compounds in accordance with the ADM1 model. Organic nitrogen, phosphorus and theoretical COD (thCOD) are included in the constituent compound forms. It is unclear how the ASM models are to be adapted to conform to the new component representations.

A specific plant transformation model (PTM) may be constructed for each unique whole WWTP simulation problem. This step in the methodology includes the selection of the relevant transformation processes to be considered in the plant wide model. Thus the biological processes, micro organism population groups and biochemical transformations have to be selected (See Fig. 3.2). In addition, acid-base and liquid-gas equilibrium have to be incorporated into the PTM. The plant components vector (PCV), a set of model components, including component elemental compositions, must be also be constructed. Thus the plant components vector and the list of transformations constitute the plant transformation model (Grau et al 2007).

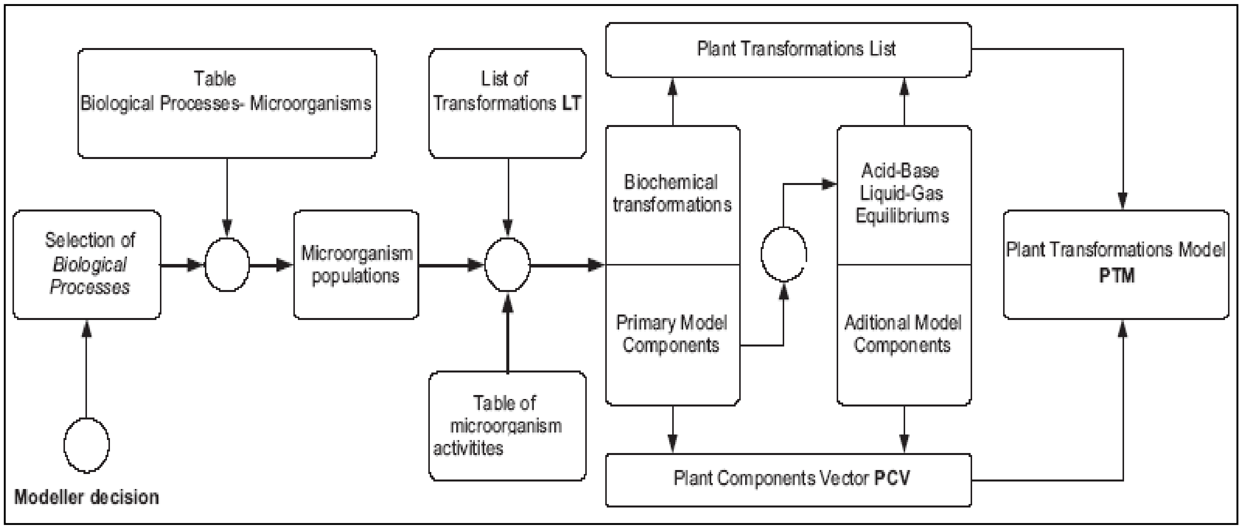


Fig.3.2: Diagrammatic representation of the PTM construction (adapted from Grau et al 2007, p. 4364)

Once relevant transformations are defined and a set of model components defined, a plant-wide model may be constructed. This requires the construction of compatible unit-process models that describe all WWTP sections. UPM's must be so composed as to incorporate mass transport and internal compound transformations. Internal compound transformations are an extension of the LT and must be composed into a common set of transformations for all UPM's. The resultant model complexity of this step may be reduced by the following steps: (1) the use of mass transport considerations only in processes where biochemical activity is not assumed to exist (e.g. clarifiers), (2) elimination of transformations where irrelevant e.g. anaerobic processes during activated sludge treatment and (3) the lumping of variables where required e.g. TSS requirements in clarifiers (Grau et al 2007).

The plant-wide model may be easily constructed from the UPM's through direct interfacing between models. The PCV must be used as a common base upon which these interfaces occur. Once mass and charge conservation has been included in all UPM's the resultant plant-wide model will conform to total plant mass and charge balances (Grau et al 2007).

3.4.3. Conclusions

The transformation-based approach incorporates a selection of process transformations that may be used to model all unit process elements in a specific WWTP. Unit process transformations need to be compatible among different unit processes and thus a requirement of this approach is the re-writing of current unit process models (Grau et al 2007). This is a major requirement as many current unit process models are generally accepted and well known. Much work has gone into the development of current unit process models with the result that they are good representations of real processes. The re-writing of adequate existing models may become highly time consuming with little or no gain in unit process optimisation. Thus, the requirement that current unit process models are re-written to conform to a standardised set of process elements and transformations seems to be nonsensical.

As in the CBIM approach, the transformation-based approach requires the transformation of unit process state variables into elemental mass compositions. Grau et al. (2007) have proposed that the ASM1 model biodegradable substrate state variables be redefined as monomers, volatile fatty acids (readily biodegradable organics) as well as proteins, lipids and carbohydrates (slowly biodegradable organics). It is unclear how the ASM1 model must be re-written to be able to use state variables in this form.

3.5. MASS BALANCES BASED WHOLE WWTP MODELING

3.5.1. Introduction

As indicated above when the reviewing the interfacing (CBIM) method of linking activated sludge and anaerobic digestion models, influent carbon fluxes are required to model the anaerobic digester - COD alone does not allow gas production and composition and alkalinity generated to be calculated. Ekama et al. (2006 b) took the view that if one is going to invent carbon fluxes to model the AD at the AD, one may as well create carbon fluxes at the WWTP influent and track the carbon throughout the WWTP including the AD. For this purpose Brink et al. (2007) developed bioprocess stoichiometry for all the WWTP bioprocesses such as organics removal by activated sludge under aerobic and anoxic conditions (for denitrification), nitrification and anoxic aerobic digestion of primary or waste activated sludges. This bioprocess stoichiometry, together with that developed for the AD model by Sötemann et al (2005) allows tracking of the C, H, O, N and COD around the WWTP and determine how much of these elements exit the various unit operations in gaseous, dissolved and solid forms (Brink et al 2007)

The C, H, O, N and COD mass balance bioprocess stoichiometry was linked to the existing COD mass balance kinetic models and applied to various linked unit operations making up different WWTP layouts, all under steady state conditions. To use this plant wide WWTP model structure, the C, H, O, N and COD composition of the different influent wastewater organic groups need to be known, i.e. the x, y, z, and a values in $C_xH_yO_zN_a$ defining the composition of the unbiodegradable particulate (UPO), unbiodegradable soluble organics (USO), biodegradable particulate organics (BPO) and biodegradable soluble organics (BSO), the last subdivided into fermentable biodegradable soluble organics (F-BSO) and volatile fatty acids (VFA) represented by acetic acid, the composition of which of course is known. Like Volcke et al. (2006), Brink et al. (2007) also assumed some composition values from previous experience with municipal wastewater and activated sludge systems.

A very important question that needed to be answered when linking AS and AD models is whether or not unbiodegradable organics from the influent and that endogenous generated, as defined by the "aerobic" activated sludge system, remain unbiodegradable in the AD. In all plant wide models developed, it was simply assumed that unbiodegradable organics in the AS system are also unbiodegradable in the AD. To check whether or not this assumption is valid (and also addressing various other questions such as the continuity of the inorganic suspended solids (ISS) around the WWTP), Wentzel et al. (2006), Ekama et al. (2006a,b) and Sötemann et al. (2006) undertook a plant wide modelling study using their own and literature data. This research is briefly reviewed below.

Ekama et al. (2006) etc. investigated continuity of wastewater organic compound elements COD and N over a number of unit process links, viz. (1) the primary settling tank (PST) - N removal activated sludge process link, (2) the PST - anaerobic digester link, (3) the PST - aerobic digester link, (4) the activated sludge (AS) reactor - anaerobic digester link and (5) the AS reactor - aerobic digester link. From these investigations it was found that mass balances may be used to calculate primary sludge (PS) biodegradable and unbiodegradable COD and N compounds over the PST. It was also found that unbiodegradable organics as defined in AS treatment may also be defined as such in anaerobic digestion. Added to this the activated sludge endogenous residue is unbiodegradable under anaerobic digestion with the result that biodegradable organics in waste activated sludge (WAS) in anaerobic digestion may be calculated from the WAS active fraction.

3.5.2. Investigation into unit process links by Ekama et al. (2006)

Link 1: Primary settling tank (PST) – anaerobic digester (AD) link

Investigation into important materials characterisation and the validity of existing models relating to this link focussed on the unbiodegradable particulate COD fraction of the primary sludge (PS) and primary sludge organics. An investigation into the conservation of inorganic solids during anaerobic digestion was also performed.

A validated AD model of Sötemann et al. (2005) was included in the investigation of important materials characteristics in this link. The model was designed to determine the unbiodegradable COD fraction of primary sludge in order to predict a number of materials inputs and outputs from anaerobic digestion. The result was a good comparison between theoretical COD removal and methane production and measured data. Two sewage sludge types were investigated and their unbiodegradable particulate COD fractions ($f_{PS'up}$) were measured, viz primary sludge had a $f_{PS'up}$ = 0.33 and a primary and humus sludge mixture had a $f_{PS'up}$= 0.36. The AD model also predicted a number of materials characteristics such as gas composition and effluent free and saline ammonia (FSA), which were closely correlated to independent measurement of the relevant feed characteristics. Thus, the model was validated and the $f_{PS'up}$ values are considered to be acceptable for further investigation into unbiodegradable particulate COD fractions in the PST – AD link.

A mass balance around the primary settling tank was performed. A simplified equation was used to predict the unbiodegradable particulate COD fraction of primary sludge ($f_{PS'up}$) from the raw and settled wastewater unbiodegradable particulate COD fractions ($f_{S'up\ R}$, $f_{S'up\ S}$), both as determined from activated sludge systems, and the fraction of COD removed in the primary settling tank (f_{PSR}). $f_{S'up}$ fractions for typical South African raw and settled waste water and an assumed COD removal in the PST of 35 % resulted in a $f_{PS'up}$ = 0.36. This value is reasonably close to the $f_{PS'up}$ values obtained in the validated AD model of Sötemann et al. above and values obtained from literature. The results demonstrate that it is possible to determine the unbiodegradable particulate COD fraction of PS for AD from a mass balance around the primary settling tank. It also signifies that the influent unbiodegradable organics, as defined by the "aerobic" activated sludge system remain unbiodegradable during anaerobic digestion.

An attempt was made to calculate the COD/VSS and N/COD ratio's for primary sludge from the particulate COD and VSS removals and the FSA release during anaerobic digestion. The results of calculated COD/VSS and N/COD ratios of biodegradable organics were compared to those of the unbiodegradable organics. Significant differences were found between the ratios for biodegradable and unbiodegradable organics. It was established that these differences need further investigation as they can affect the simulation of the COD and N input into activated sludge and primary sludge treatment as well as the calculated pH in the primary sludge anaerobic digester.

The investigation into the PST – AD link has led to the establishment that a mass balance approach may be used around the primary settling tank in order to establish the unbiodegradable particulate organics COD fraction ($f_{PS'up}$) and the VSS/TSS ratio. These parameters may be incorporated into the anaerobic digestion model. It was also established that the unbiodegradable particulate organics in the primary sludge remains unbiodegradable during anaerobic digestion.

Link 2: The nitrogen removal activated sludge system – aerobic digester link

The ISS content of the activated sludge may not be presumed to be only entering the reactor from the influent wastewater. A model was developed by Ekama and Wentzel (2004) to predict the ISS concentration in the reactor. The model is based on the addition of an ordinary heterotrophic organism (OHO) ISS content as well as the accumulation of influent ISS in the reactor. A constant OHO ISS content of 0.15 mg ISS/mg OHO VSS was established from a very large AS data set. This OHO ISS is not real ISS in the reactor but intracellular dissolved inorganics which precipitate in the VSS-TSS test drying procedure. The prediction of ISS output from the reactor requires an ISS influent measurement into the reactor with an improved test procedure developed by Ekama and Wentzel (2004) for low ISS concentrations.

Data collected in a different experiment by van Haandel et al (1998) was used in the investigation of the AS – Aerobic digester link. A difference was made to the analysis of the data, viz. a death – regeneration approach was used to model the data with the effect that the unbiodegradable fraction estimate of OHO's was changed from $f_{EH} = 0.20$ to $f'_{EH} = 0.08$. This fraction was only used in the case of waste activated sludge (WAS) fed to an aerobic digester. The estimate may not be used in the case that WAS is fed to an anaerobic digester because a different group of organisms with different characteristics is active in such a digester.

An aerobic digestion model of Ekama and Wentzel (2004) was used to analyse the data generated by van Haandel et al (1998). The theoretical values of oxygen utilisation rate (OUR), volatile suspended solids (VSS), VSS/TSS ratios and ISS concentration correlated closely to the measured data in the experiment.

The validated aerobic digestion model of Ekama and Wentzel (2004) may thus be used to analyse the nitrogen removal activated sludge system – aerobic digester link.

Link 3: The activated sludge (AS) system – anaerobic digester (AD) link

The data that was acquired in the experiment by van Haandel et al (1998) was again used in the determination of important material characteristics in this link. The unbiodegradable COD fraction ($f_{AS'up}$) in the outflow from the aerobic digestion part of the van Haandel experiment was set as input into the Sötemann steady state AD model.

The AD model was used to theoretically calculate the unbiodegradable COD fraction of the waste activated sludge (WAS) and the experimentally measured data was closely correlated for some of the anaerobic digesters used in the van Haandel et al (1998) experiment. However, for some of the anaerobic digesters the unbiodegradable organic COD fraction was higher than that measured from the aerobic digesters and thus more organics were biodegradable in the anaerobic digester than in the aerobic digester. It was accepted that these errors are small enough to continue accepting the theory that unbiodegradable organics in aerobic digestion remain unbiodegradable during anaerobic digestion. This result was independently checked and the assumption that the unbiodegradable particulate organics from the WAS remains unbiodegradable during anaerobic digestion was validated.

The composition of waste activated sludge (WAS) was calculated from measured COD/VSS and N/COD ratios from the WAS and the result was very close to the generally accepted composition of waste activated sludge. The result was set as input to the AD model and a number of waste water parameters were predicted. The COD removal and FSA were closely predicted to the measured values. The methane production and alkalinity were over-predicted. The reason for the over prediction of the alkalinity was unclear. The pH was under–predicted and the reasons for this have also not been determined. The carbon content of the WAS was unconfirmed because the gas composition was not fully measured by van Haandel et al (1998).

Link 4: The primary settling tank (PST) – aerobic digester link

The steady state model for WAS as used in link 3 was applied to the aerobic stabilisation of primary sludge. Two WWTP schemes were modelled to investigate the link between the PST and anaerobic digester viz. an extended aeration activated sludge system treating raw sewage at a long sludge age and a PST – settled wastewater activated sludge system with a short sludge age (8d) and aerobic digestion of primary and waste activated sludges to the same active fraction as the raw waste water system.

The unbiodegradable particulate organics was calculated through a mass balance around the primary settling tank. The discrepancies between COD/VSS and N/COD ratios that were found in the investigation of Link 1 has prompted the use of commonly accepted ratios that are used in activated sludge theory. The utilisation of biodegradable organics in the aerobic digester occurs in the same way as in an activated sludge system. The oxygen utilisation, however, is different in that it is an accumulation of that used for endogenous respiration and organism anabolism. ISS concentrations decrease due to endogenous respiration and the VSS/TSS ratio changes accordingly.

A number of relevant factors were calculated for aerobic digestion of primary sludge. It was established that COD is conserved, but VSS changes due to OHO formation. Influent ISS from the PST to the aerobic digester remains unchanged, but the total ISS concentration changes during aerobic digestion.

In order to model blends of waste activated sludge and primary sludge the different characteristics has been defined. These characteristics may be used with WAS aerobic digestion model steady state equations based on the steady state activated sludge model of Marais and Ekama (1976) and the ISS model of Ekama and Wentzel (2004). The results from the steady state model calculations for the two WWTP schemes were compared with the results from ASM1 simulations, modified to include the ISS model of Ekama and Wentzel (2004), for the same two schemes. The results were very closely correlated with the effect that the aerobic digestion model may be used for further investigation into the PST – Aerobic digester link for an integrated WWTP model.

3.5.3. WWTP stoichiometry

As mentioned above, Brink et al. (2007) developed a set of stoichiometric equations for all the common bioprocesses in activated sludge and anaerobic digestion systems. This stoichiometry requires the composition of wastewater and biomass biodegradable organic compounds. Compound compositions may be calculated from assumed COD, N, VSS (TSS), P and C characteristics of the different influent biodegradable organics.

Wastewater treatment plant influent organics are commonly characterised in terms of unbiodegradable, biodegradable, soluble and particulate fractions. This characterisation may be done for the COD, carbon, nitrogen and phosphorus content of a wastewater. This characterisation scheme is shown diagrammatically in Figs.3.3 below.

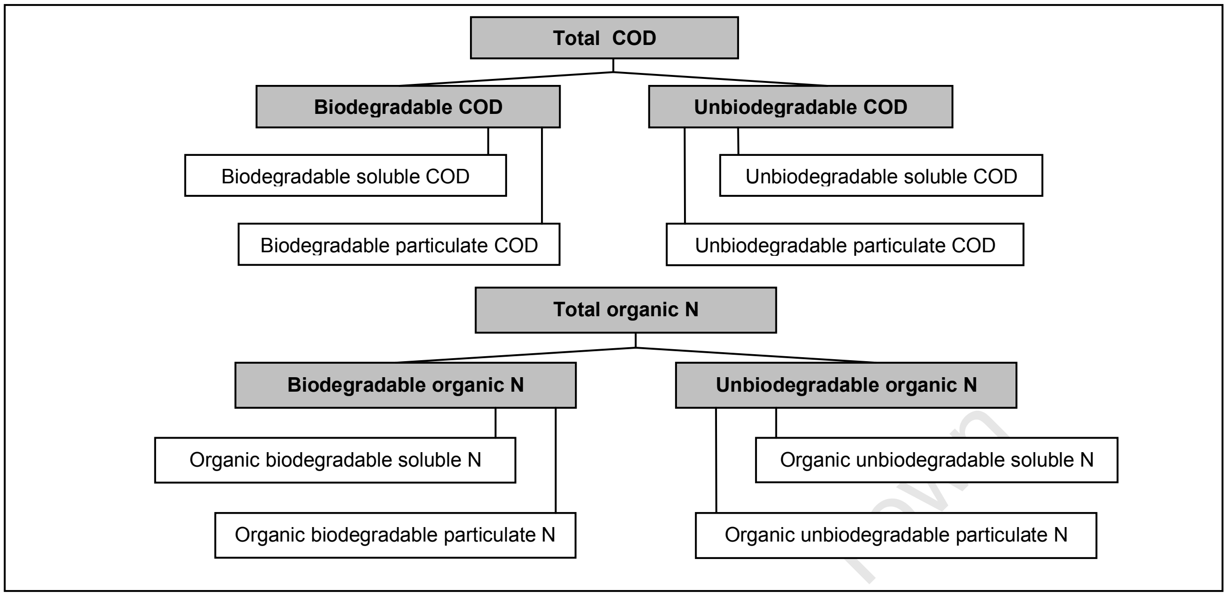


Fig. 3.3: Diagrammatic representation of organic compound COD and nitrogen (N) characterisation

The COD, N, C, and P fractions into which the organics are characterised above are related. The unbiodegradable COD and TKN concentrations form part of the same unbiodegradable organics in the wastewater. This applies to all the organic types in the wastewater. So it is possible to characterise the carbon (C) content of biodegradable, unbiodegradable, soluble and particulate organics in the same way as is used above for COD and TKN (Fig.3.4). Such characterisation will provide necessary information for the determination of the stoichiometric compositions of biodegradable, unbiodegradable, soluble and particulate wastewater compounds required in stoichiometric and plant wide models.

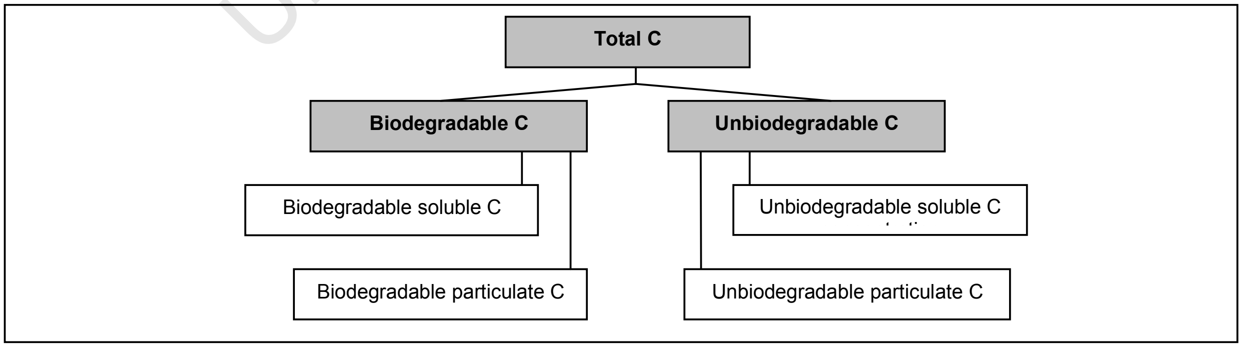


Fig.3.4: Diagrammatic representation of organic carbon (C) characterisation

Organics compositions in wastewater are generally accepted to be primarily composed of the following elements: carbon (C), hydrogen (H), oxygen (O) and nitrogen (N) and phosphorus (P).

Compositions differ according to the proportions of carbon, hydrogen, oxygen and nitrogen they contain. Thus, compositions are given in the form $C_xH_yO_zN_aP_b$ where x, y, z, a and b signify the molar C, H, O, N (and P if included) proportions in a specific compound type. In this investigation P is ignored because only sludge from N removal activated sludge systems were investigated.

The x, y, z, a and b composition values are related to the COD, VSS, TKN TP and TOC measurement on organics samples and so the x, y, z, a and b values can be expressed in terms of these parameters (Brink et al 2007), viz.

$x = fc (y + 16 z) / [(12 (1 - fc – fn - fp)]$
$y = 7$
$z = [y (1 - fcv/8 - 8fc/12 - 17fn/14 – 26fp/31)] / [2 (1 + fcv - 44fc/12 + 10fn/14 – 71fp/31)]$
$a = [fn (y + 16z)] / [(14 (1 - fc - fn - fp)]$
$b = [fp (y + 16z)] / [(14 (1 - fc - fn - fp)]$

Where: fcv = COD / VSS or COD/molar mass (MM) ratio
fn = TKN / VSS or TKN/molar mass (MM) ratio
fc = TOC / VSS or TOC/molar mass (MM) ratio
fp = TP / VSS or TP/molar mass (MM) ratio (3.3)

This format may be adapted to the elemental mass compositions (g element / g compound) of Vanrolleghem et al. (2005), Volcke et al. (2006) and Grau et al. (2007) by calculating the mass of element per mass of compound (α) from the use of the stoichiometric formula expressed as $C_xH_yO_zN_aPb$. It can be shown that the x, y, z, a and b composition values are linearly related to the α values of Volcke et al. (2006), viz. $fc = \alpha^C$, $fh = \alpha^H$, $fo = \alpha^O$, $fn = \alpha^N$, $fp = \alpha^P$. Because COD is available as a measure, and a mass balance requires that $\alpha^C + \alpha^H + \alpha^O + \alpha^N + \alpha^P = 1$ or equivalently $fc + fh + fo + fn + fp = 1$, the $\alpha^H + \alpha^O$ and fh and fo ratios can be eliminated and replaced by the COD parameters, fcv or α^{COD}, and is the reason that fh and fo do not appear in the x, y, z, a and b equations above, viz.

$fh = 1/9\ (1+ fcv -44\ fc/12 + 10\ fn/14 – 71\ fp/31)$ or $\alpha^H = 1/9\ (1+ \alpha^{COD} - 44\alpha^C /12 + 10\alpha^N /14 – 71\alpha^P /31)$ (3.4)

$fo = 8/9\ (1- fcv/8 – 8\ fc/12 - 17\ fn/14 – 26\ fp/31)$ or $\alpha^O = 8/9\ (1+ \alpha^{COD}/8 - 8\alpha^C /12 - 17\alpha^N /14 – 26\alpha^P /31)$ (3.5)

All the above information can be made available once a particular wastewater has been characterised in terms of COD, nitrogen, carbon and VSS (and P if included. The plant stoichiometry of Brink et al. (2007) consists of bioprocess stoichiometric transformation equations for aerobic and anaerobic processes and may be used once the organics elemental compositions and concentrations (mol/l) are known. Thus a CHON and P mass balance over the whole WWTP may be performed.

3.5.4. Conclusions

Wentzel et al. (2006), Ekama et al. (2006a,b) and Sötemann et al. (2006) have performed investigations into unit operation WWTP links for the purpose of developing a plant wide WWTP mass balances based integrated models. Investigated links included the PST - anaerobic and anaerobic digester links and the nitrogen removal activated sludge (AS) reactor - aerobic and anaerobic digester links. Brink et al. (2007) developed bioprocess stoichiometry for all the common WWTP bioprocesses to allow CHON (and P if included) mass balances over the whole WWTP and determine how much of these elements exit the various unit operations in gaseous, dissolved and solid forms.

From investigating the PST – AD link, it was found that mass balances may be used to determine biodegradable and unbiodegradable organic compounds over a PST because the influent unbiodegradable organics as defined by the activated sludge processes remain unbiodegradable during anaerobic digestion processes. From investigating the AS – AD link, it was found that the endogenously generated unbiodegradable organics also remain unbiodegradable during anaerobic digestion processes. Thus a classification of unbiodegradable organics compositions in raw wastewater and AS may be used unchanged throughout the WWTP including AS systems and AD models.

3.5. CONCLUSIONS

The development of an integrated plant wide WWTP simulation model is necessary for process optimisation. Different unit processes contain different chemical, bio-chemical and physical processes. This, together with their isolated development in the past, has resulted in significant differences in state variable between processes. These differences have hampered the coupling of different unit process models for the purpose of creating a whole WWTP simulation model.

A number of different approaches towards the development of integrated whole WWTP simulation models have been proposed. The two basic approaches are the continuity based interfacing method (CBIM) of Vanrolleghem et al. (2005) and Volcke et al. (2006), and the ‘supermodel approach’ of Jones and Tákacs (2004) and Seco et al. (2004), which leave the unit operation models unchanged. Related approaches are the transformation based approach of Grau et al. (2007), which also leaves the unit operation models unchanged, and the mass balances based plant wide approach of Brink et al. (2007), which establishes a common compound characterization for the influent wastewater and all the unit operations in the WWTP.

All of the simulation strategies discussed above require compound elemental compositions. The elemental compositions of standard compounds, such as volatile fatty acids, simple proteins and lipids etc. are known. However, most organic compounds in wastewater consist of (possibly) variable and unknown compositions. These compounds comprise readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate components. Plant wide WWTP modelling case studies to date have relied on assumed compositions of these compound groups. Thus, no practical investigation into compound composition determination was performed. An investigation that seeks to measure organic compound composition is described in Chapter 4: Investigation of a batch test method for organics compositions determination.

CHAPTER 4
DESIGN AND EVALUATION OF A BATCH TEST METHOD FOR ORGANICS COMPOSITIONS DETERMINATION:
METHODOLOGY

4.1. INTRODUCTION

Integrated whole WWTP modelling is a relatively new concept and a number of approaches towards it have been proposed (Chapter 3). Unit process models have, in the past, been developed in isolation (Wentzel et al 2006). They typically describe different biological, chemical and physical processes. This has resulted in different unit process model state variables with resultant difficulties in the coupling of different models. These differences are dictated by model history, purpose and application (Volcke et al 2006).

Proposals and approaches towards overcoming the difficulties in linking unit process models such as ASM1 and ADM1 are variable and have been reviewed in Chapter 3. Current approaches include the continuity based interfacing method (CBIM) of Volcke et al. (2006) and Vanrolleghem et al. (2005), the 'supermodel' approach of Jones and Tákacs (2004) and Seco et al. (2004) and the transformation based approach of Grau et al. (2007).Instead creating the carbon inflow to the AD required to model the AD at the interface where the AD is the destination model, Ekama et al. (2006) established CHON elemental compositions for the different groups of organics in the WWTP influent and developed complementary bio-process stoichiometry for the different unit operations making up the WWTP. From their own and literature experimental data they established that unbiodegradable particulate organics for the influent wastewater and that generated by the endogenous process as defined by the aerobic activated sludge system, remain unbiodegradable under anaerobic conditions, an assumption that had been made in all the earlier theoretical plant wide modelling research.

Although these approaches to plant-wide modelling are different, they have a common requirement, viz. the determination of biodegradable and unbiodegradable organics compositions of the form $C_xH_yO_zN_a$ in the relevant WWTP streams. The focus of this chapter is the design of a batch test method for the experimental determination of the organics compositions, i.e. the α^C, α^H, α^O, α^N, α^P of Volcke et al (2006) or the x, y, z, a and b values of Ekama at el. (2006), which are linearly related (Chapter 3). No literature on practical determination of these ratios was found in the literature. Being ratios, these 5 unknowns involve 6 parameters. There is one mass balance equation (i.e. $\alpha^C + \alpha^H + \alpha^O + \alpha^N + \alpha^P = 1$) and therefore 5 measurements need to be made to determine them. There are 4 measurements readily available, viz., COD, VSS (or TSS), TKN, TP, leaving one additional parameter to be measured, i.e. the carbon as TOC. This can be done by elemental analysis. In fact the problem of compound composition determination is no so much a problem of element measurement but one of compound type isolation to be able to measure the composition of biodegradable soluble organics (BSO), unbiodegradable soluble organics (USO), biodegradable particulate organics (BPO), unbiodegradable particulate organics (UPO). Literature pertaining to the biodegradability of sewage sludge has been reviewed in Chapter 2 and relevant information has been used in the batch test experiment design to attempt to measure compound group compositions.

Wastewater organics compositions have been considered in this thesis to consist mainly of the elements carbon, hydrogen, oxygen and nitrogen. This approach has been followed by the authors of the plant wide WWTP modelling approaches reviewed in Chapters 2 and 3. The methods described in these Chapters for the determination of organics compositions from measured data may be easily extended to include Phosphorus. Phosphorus as a component of organics compositions has been omitted in this project because wastewater fed to and sludge harvested from a N removal activated sludge system was tested. The content of the elements CHON in specific wastewater fractions may be tested for and derived in a variety of ways. Wastewater organic fractions for modelling purposes have in the past typically been divided into biodegradable and unbiodegradable fractions. Furthermore, biodegradable fractions have been divided into soluble readily (RB or BSO) and particulate slowly (SB or BPO) biodegradable components, while unbiodegradable fractions have been divided into soluble (USO) and particulate (UPO) components as was done in the ASM models (Henze et al 2000). The BSO (or RBCOD) is subdivided into volatile fatty acids (VFA) and fermentable F-BSO (or F-RBCOD). This subdivision is required both for biological excess P removal activated sludge and anaerobic digestion (AD). For AD, the VFAs are further subdivided into dissociated (ionized) and undissociated (unionized) forms, which is important for pH prediction in the AD. These terms and definitions have been retained in this investigation. From a stoichiometric point of view, two additional organics groups and their composition need to be recognized, the biomass and the endogenous residue formed by it. Furthermore, the experimental observation of Ekama et al. (2006 b) will be accepted to apply, i.e. that unbiodegradable organics as defined by the "aerobic" activated sludge (AS) system remain unbiodegradable under anaerobic digestion conditions.

Total wastewater particulate or soluble organics, i.e. total raw wastewater organics, primary sludge organics and waste activated sludge organics, may theoretically be directly measured or derived via a number of methods as discussed in this Chapter. It was hypothesized in this project that the unbiodegradable fraction of particulate or soluble organics may be derived from the residual matter after biodegradation processes (aerobic or anaerobic) have degraded all biodegradable material. Once particulate and soluble organics compositions and molar concentrations have been obtained, total organics compositions may be calculated. There is, however, as yet no practical method for obtaining organics compositions of the form $C_xH_yO_zN_a$. The aim of this investigation was therefore to design and evaluate a simple batch test method for determination of organics compositions in wastewater streams over a WWTP. Therefore, an attempt was made to determine total, unbiodegradable and biodegradable soluble and particulate organics compositions in raw wastewater, settled wastewater, primary sludge (PS) and waste activated sludge (WAS).

4.2. THEORETICAL APPROACH

The determination of biodegradable and unbiodegradable fractions of soluble and particulate organic constituents (C,H,O,N) and parameters (COD,VSS) that quantitatively define organics compositions of the form $C_xH_yO_zN_a$ is necessary for plant wide WWTP modelling. A simple anaerobic batch test approach towards determining wastewater organics total, biodegradable and unbiodegradable as well as soluble and particulate fractions was investigated. The use of an anaerobic batch test method for determination of organic compositions for the whole WWTP was considered valid because Ekama et al. (2006 b) showed that organic material termed unbiodegradable from an activated sludge standpoint remain unbiodegradable under anaerobic digestion condition.

Plant-wide WWTP integrated modelling requires organics compositions in all wastewater streams, thus raw wastewater, primary sludge (PS) and waste activated sludge (WAS) compositions determination have been investigated. Correct determination of raw wastewater and PS compositions enable the determination of settled wastewater colloidal and soluble compositions via mass balances over a primary settling tank. This is based on the assumption that no substrate biodegradation occurs during the settling of primary sludge.

4.2.1. Determination of the biodegradable organic fraction

There is, as yet, no method for the determination of the biodegradable organic fraction and it's relative constituents (C,H,O,N,COD,VS) directly in wastewater streams. The total organic fraction of a wastewater stream may be determined with direct constituent measurement. The unbiodegradable fraction (taken in this project to be equal from an aerobic and anaerobic standpoint as discussed above) is the remaining fraction after all biodegradable material has been degraded. Therefore, the biodegradable fraction of a wastewater type (raw wastewater, settled wastewater, primary sludge, waste activated sludge) is the difference between it's total and unbiodegradable fraction.

An anaerobic digestion batch test method with long standing times was used in an attempt to obtain the total (particulate and soluble) and unbiodegradable particulate organics fraction of raw wastewater, primary sludge and waste activated sludge. Successful determination of these fractions enables the determination of the biodegradable fraction of the above stated wastewater types as discussed above. The settled wastewater (colloidal) total, biodegradable and unbiodegradable particulate fractions were considered to be obtainable as the difference between raw wastewater and primary sludge total, biodegradable and unbiodegradable particulate fractions (Refer to Fig.4.1).

Waste activated sludge for the experiment was obtained from a 16 day sludge age laboratory Modified Ludzack-Ettinger (MLE) system operated in the University of Cape Town Water Research Laboratory. This system was fed raw wastewater from the same source as used for the raw wastewater and primary sludge batch tests. The unbiodegradable soluble organics concentration of the raw wastewater, settled wastewater, primary sludge and waste activated sludge was assumed equal because the wastewater was obtained from the same WWTP (Mitchells Plain, Cape, South Africa) - it is obtainable from organics constituent measurements on the treatment system effluent (Fig. 4.1).

4.2.2. Organics compositions

Organic compounds over a WWTP were taken to consist mainly of carbon, hydrogen, oxygen and nitrogen. Current integrated whole WWTP modelling approaches require organics compositions to be expressed in the form $C_xH_yO_zN_a$, where x, y, z and a are the molar subscripts of carbon (C), hydrogen (H), oxygen (O) and nitrogen (N) respectively or in the form α^C, α^H, α^O, α^N, α^P where these are the mass fraction compositions in gC, gH, gO, gN and gP per g organic compound (Volcke et al., 2006). The relationships between organic compositions in molar form (x, y, z, a, b) and the mass ratio form was set out in Chapter 3.

Because more parameters can be measured than are required to calculate the x, y, z and a (or α) values, there are a number of methods available for the determination of organics compositions in the stated forms, e.g. the N content can be measured via the TKN method and elemental analysis. The approach followed in this project involved using standard measurements made in a normal wastewater laboratory, i.e. COD, VSS, (TSS), TKN and TP. Three other methods with data measured by other methods were used in Section 4.6.4 below to evaluate the organics compositions calculated with different methods. The choice of data for calculation of the organics compositions is dependent on the accuracy of the different test methods.

4.2.2.1. Data Acquisition

Ignoring the P content of organics, the determination of organics compositions requires four measurements, viz. the COD, VSS (TSS), TKN and C concentrations for particulate, soluble, biodegradable and unbiodegradable wastewater organic fractions. A schematic of the experimental approach and data acquisition points during the experimental procedure is presented in Fig.4.1 below. The data acquired in the experimental procedure may be combined to characterise each wastewater type and may thereafter be used to calculate the organics compositions.

Data measured at the different data acquisition points were combined to produce total, soluble, particulate, biodegradable and unbiodegradable organics composition constituents and parameters (C, N, COD, VS) for raw wastewater, settled wastewater, primary sludge (PS) and waste activated sludge (WAS). Concentrations to be measured at the different data acquisition points are set out below:

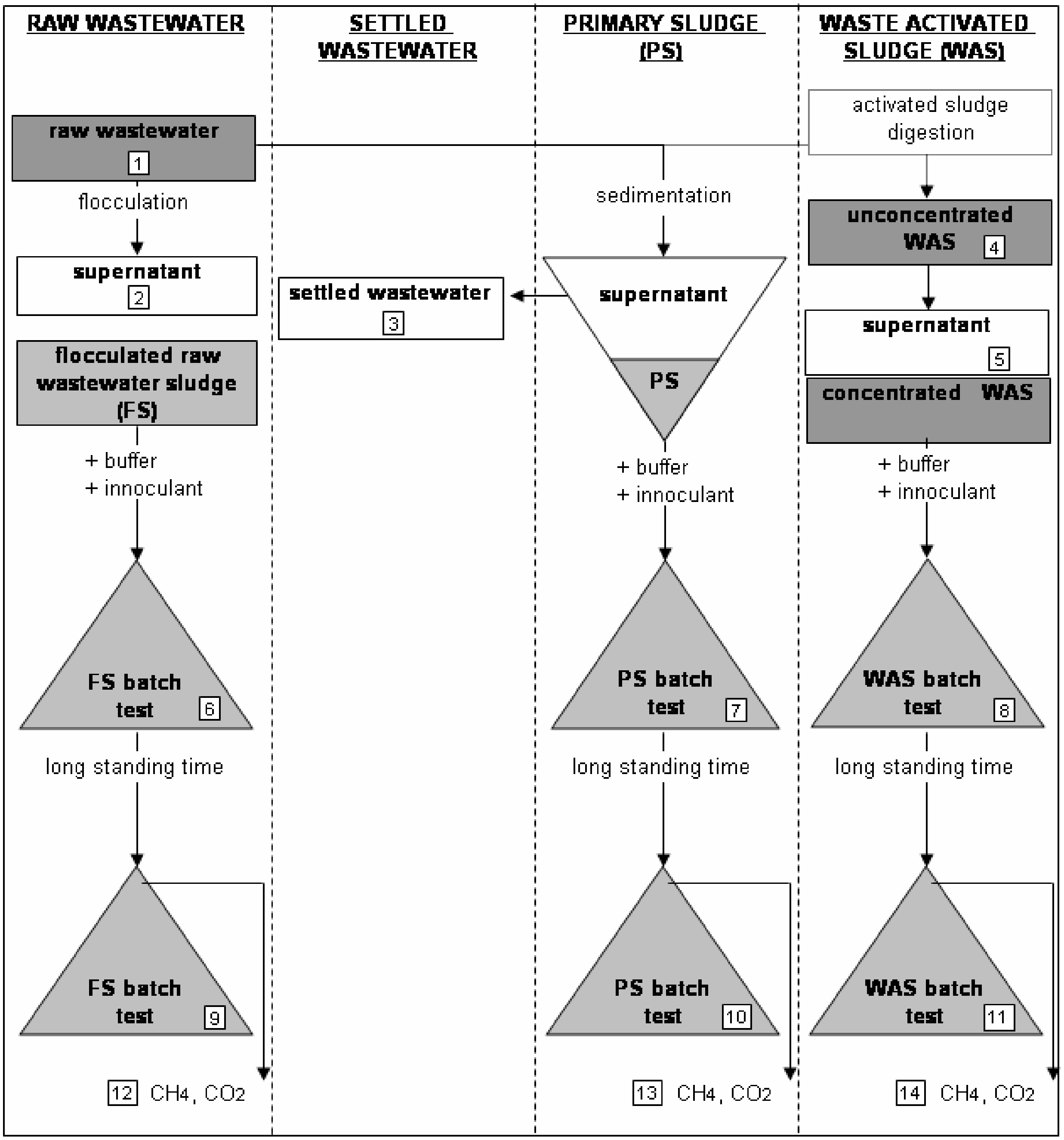


Fig.4.1: Schematic of experimental layout and data acquisitions points (refer to data acquisition point description below)

Point 1: Direct measurement of raw wastewater total COD and TKN. TP may be included.
Point 2: Direct measurement of raw wastewater, settled wastewater and PS (values are equal) soluble total COD, DOC, TKN and FSA on 0.45 μm filtered samples. Soluble TP and OP may be included.
Point 3: Direct measurement of settled wastewater total COD and TKN. TP may be included.
Point 4: Direct measurement of WAS total COD, TKN and Solids (total, volatile and inorganic). TP may be included.
Point 5: Direct measurement of WAS, raw wastewater, settled wastewater and PS (values assumed equal) unbiodegradable soluble COD and TKN on 0.45 μm measured samples. Include FSA for unbiodegradable organic TKN determination. TP and OP measurements may be included.
Point 6: Indirect measurement of raw wastewater solids (total, volatile and inorganic). Measurement of raw wastewater particulate carbon mass fractions with elemental analysis.
Point 7: Indirect measurement of primary sludge solids (total, volatile and inorganic). Measurement of primary sludge particulate carbon mass fractions with elemental analysis.
Point 8: Measurement of waste activated sludge particulate carbon mass fractions with elemental analysis.
Point 9: Indirect measurement of raw wastewater unbiodegradable particulate COD, TKN, and volatile solids. TP may be included. Measurement of raw wastewater unbiodegradable particulate carbon mass fractions with elemental analysis.
Point 10: Indirect measurement of primary sludge unbiodegradable particulate COD, TKN, and volatile solids. TP may be included. Measurement of primary sludge unbiodegradable particulate carbon mass fractions with elemental analysis.
Point 11: Indirect measurement of waste activated sludge unbiodegradable particulate COD, TKN, and volatile solids. TP may be included. Measurement of waste activated sludge unbiodegradable particulate carbon mass fractions with elemental analysis.
Points 12, 13, 14: Measurement of batch test methane (CH_4) and carbon dioxide (CO_2) gas production.

4.2.2.2. Wastewater characterisation

Measured data were characterised (ordered and presented) in block characterisation diagrams as laid out below. The points during the data collection procedure (Fig.4.1), where data may be measured, are displayed in the characterisation diagrams. Data that is calculated from measured data are also indicated in the diagrams.

Total COD and TKN concentrations for raw and settled wastewater as well as for WAS may be directly measured in wastewater samples. PS total COD and TKN concentrations may be calculated from the mass difference between raw and settled wastewater COD and TKN masses. Total soluble COD and TKN concentrations for raw wastewater, settled wastewater and PS may be directly measured in the flocculated raw wastewater supernatant. These values are assumed equal since it is assumed that no biodegradation takes place during raw wastewater settling for PS and settled wastewater production. Total particulate values are taken as the difference between total and soluble COD and TKN values (Refer to Figs.4.2 and 4.4).

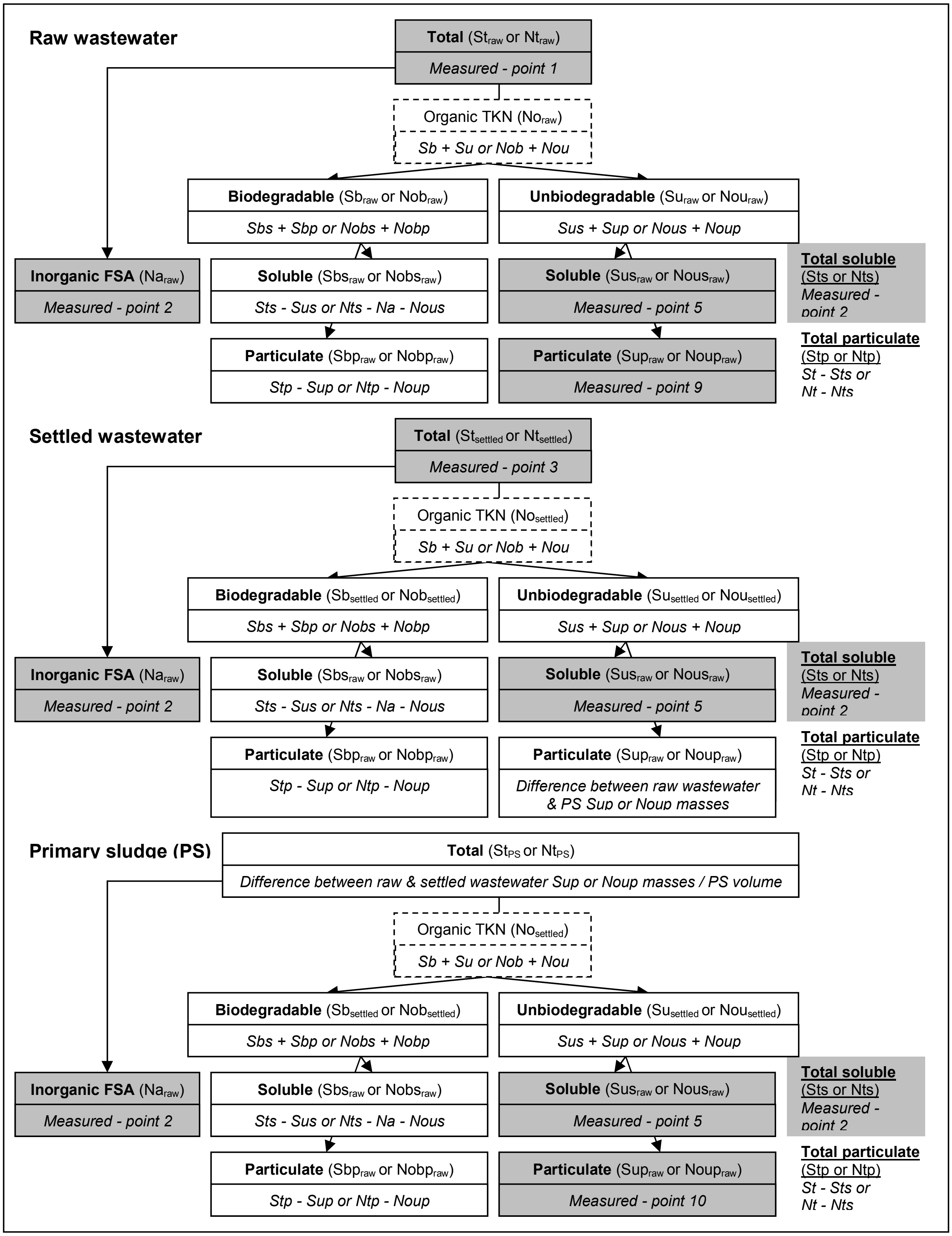


Fig.4.2: COD and N concentration characterisation for raw wastewater, settled wastewater and primary sludge. Measured concentrations are indicated in grey blocks (include measurement points - refer to Fig.4.1)

Unbiodegradable particulate COD and TKN values are measured at the end of the batch test digestion period in the relevant batch test for raw wastewater, PS and WAS. Settled wastewater unbiodegradable particulate concentrations are calculated from the difference between the unbiodegradable particulate raw wastewater and PS masses. Biodegradable particulate concentrations are calculated as the difference between total and unbiodegradable particulate concentrations. Similarly biodegradable soluble COD concentrations are calculated as the difference between the total and unbiodegradable soluble COD concentrations. Biodegradable organic nitrogen soluble concentrations are calculated as the remaining fraction after subtraction of FSA and unbiodegradable soluble concentration measurements from the total soluble TKN concentrations (Refer to Figs. 4.2 and 4.4).

Carbon concentrations may be similarly calculated for raw wastewater, PS and WAS. Total particulate carbon concentrations may be calculated from the elemental analysis %carbon measurement (by mass) and the total solids values measured in the batch tests at batch test setup. Unbiodegradable particulate carbon concentrations may be calculated from the elemental analysis %carbon measurement (by mass) and the total solids values measured in the batch tests at batch test termination after completion of batch test digestion processes. Total soluble (dissolved) organic carbon (DOC) may be measured in the flocculated raw wastewater supernatant (0.45 µm membrane filtered) for raw wastewater, settled wastewater and primary sludge. DOC for WAS may be measured directly in 0.45 µm filtered WAS samples. Unbiodegradable DOC is taken as the DOC measured in WAS for raw wastewater, settled wastewater, PS and WAS. Biodegradable DOC is calculated as the difference between total and unbiodegradable DOC. Total carbon is calculated as the addition of total soluble and total particulate carbon. Settled wastewater carbon fractions may be calculated from the difference between raw wastewater and PS carbon mass fractions (Refer to Fig.4.3).

Volatile suspended solids (VSS) concentrations are measured in the batch tests at setup (total concentrations) and termination (unbiodegradable concentrations) for raw wastewater, PS and WAS. Biodegradable concentrations are calculated as the difference between total and unbiodegradable concentrations. Settled wastewater VSS fractions may be calculated from the difference between raw wastewater and PS volatile solids mass fractions (Refer to Fig.4.5).

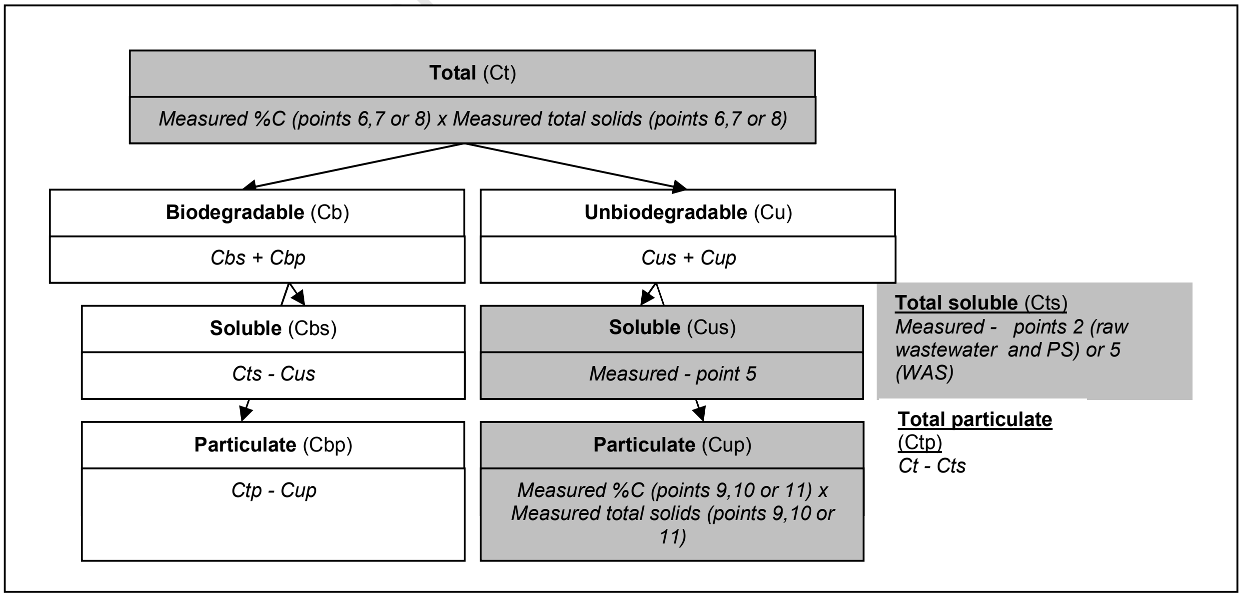


Fig.4.3: COD and N concentration characterisation for waste activated sludge. Measured concentrations are indicated in grey blocks (includes measurement points - Fig.4.1)

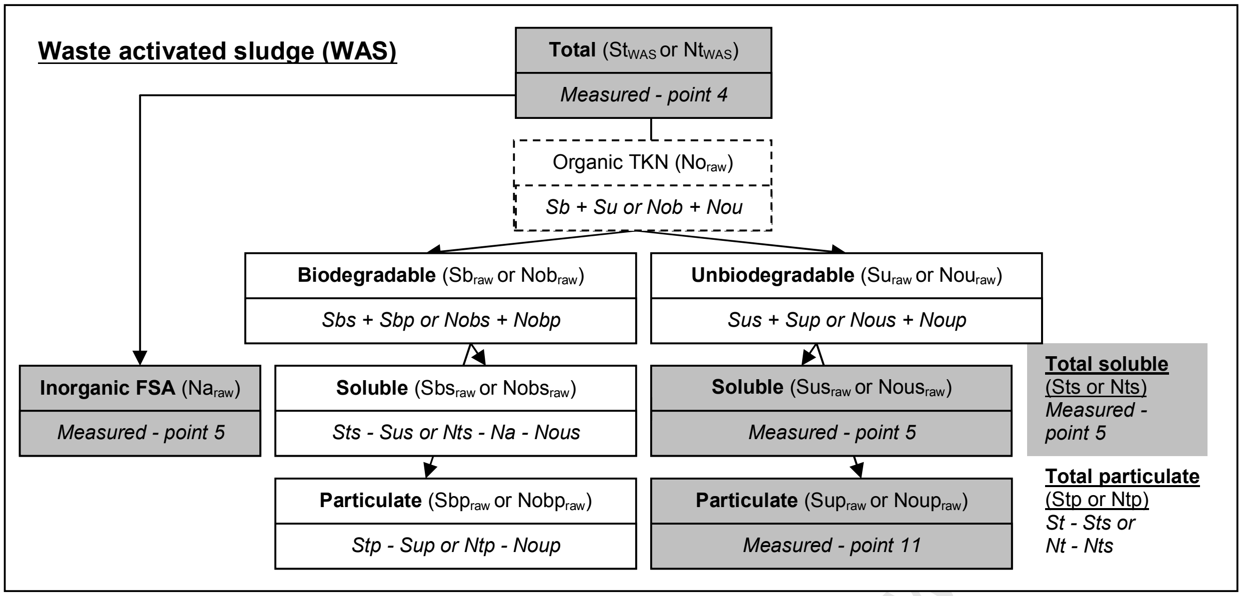


Fig.4.4: Carbon (C) concentration characterisation for raw wastewater, PS and WAS. Measured concentrations are indicated in grey blocks (includes measurement points - refer to Fig.4.1)

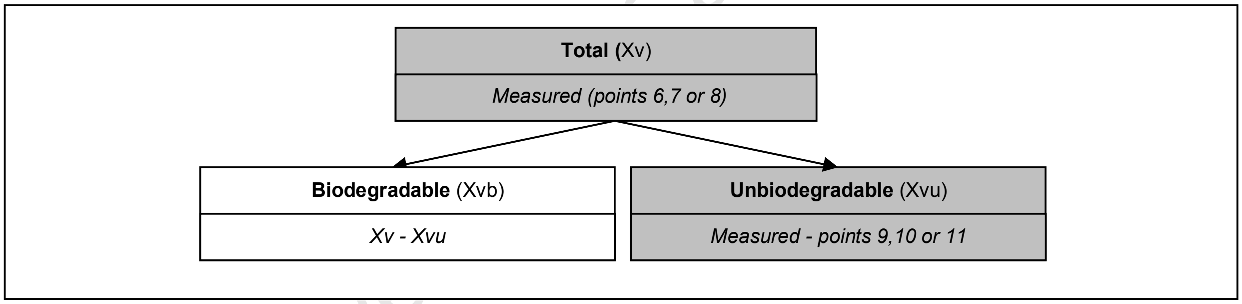


Fig.4.5: Volatile solids (Xv) concentration characterisation for raw wastewater, PS and WAS. Measured concentrations are indicated in grey blocks (includes measurement points - refer to Fig.4.1)

4.2.2.3. Calculation of organics compositions from characterised data

COD, carbon, nitrogen and volatile solids data may be used to calculate organics compositions for different wastewater fractions with the method suggested by Brink et al. (2007). This method is laid out in detail in section 4.6.4. and will not be discussed here. This is not the only available method for organics calculation and three other methods that are dependent on different data sets are also discussed.

4.3. RESEARCH DESIGN AND THEORY

4.3.1. Research objectives

The objective of this research project was to design and evaluate a specific, simple batch test method for the determination of the following:

1. Fractionation of raw wastewater, PS and WAS organics into biodegradable and unbiodegradable soluble and particulate components.
2. Fractionation of raw wastewater concentrations (C,N,COD,VS) into settlable and colloidal particulate organic material.
3. Calculation and evaluation of organics compositions of the form $C_xH_yO_zN_a$ for the above organics groups.

4.3.2. Key concepts

There are three key concepts in the approach followed in this investigation. The first is the observation by Ekama et al (2006 b) that unbiodegradable organics from an activated sludge standpoint remain unbiodegradable during anaerobic processes. This concept enabled the design of an AD batch test method for the determination of unbiodegradable organic fractions over a whole WWTP.

The second and third concepts pertain to the modelling form of organics compositions in this project. They are stated as follows:

1. Organic compositions are assumed, for the purpose of modelling, to consist solely of carbon, hydrogen, oxygen, nitrogen and phosphorus. Phosphorus has been omitted in this study. This is permissible because phosphorus typically is a very small percentage of organics compositions. It can be added when biological excess P removal systems are considered.
2. Organic compositions are represented in the form $C_xH_yO_zN_a$, where x,y,z and a represent the molar element compositions in the organics and indicate the molar ratio's between different elements in a compound. These can easily be converted to the α values of Volcke et al. (2006) – see Chapter 3.

4.3.3. Main assumptions

A number of assumptions have been made in this research. Some of these assumptions have proven to be incorrect and have been rejected as new information was obtained. The main assumptions made are stated below:

1. A long anaerobic batch test incubation time (time was varied according to data obtained from previous batch tests, see Appendix A.1.) was sufficient to ensure complete degradation of all biodegradable material at laboratory temperature (22 ± 0.5 °C) or heated temperature (35 ± 0.5 °C).
2. The unbiodegradable soluble effluent data from the MLE AS reactor may be used to characterise raw wastewater, settled wastewater and PS and WAS unbiodegradable soluble organics parameters (COD, C, and N).
3. Particulate organics y = 7. This assumption is not aimed at accurately reflecting the true hydrogen molar subscript for a particular organic compound. The true organic compound subscripts could not be ascertained in this experiment as the true compound molar masses (M, g compound/mol) were unknown. The actual y value selected is not important because it serves as

a reference for the other 3 composition values (x,z,a). In fact the main difference between the x,y,z and a values of Sötemann et al (2006) and the α values of Volcke et al (2006) is the reference with respect to which the compositions are expressed - the former uses y=7 and the latter mass element per mass compound (g/g). It is however, important to ascertain the correct molar subscript ratio's, i.e. moles of carbon to moles of hydrogen (x/y) etc. This is possible with accurate COD, TKN, TOC and VSS (and TSS) data. Therefore, y may be set equal to any number as this will not affect the molar ratio's of a particular compound. 7 was chosen because it allows comparison with the widely accepted WAS composition of $C_5H_7O_2N$ and PS compositions determinations made by Sötemann et al. (2005) and Wentzel et al. (2006).

4. For soluble organics y = 7 and z = 2. Contrary to the assumption above, this assumption has a considerable impact on the accuracy of organics composition calculations because it assumes a y/z ratio of 7/2. It was made due to insufficient measurable data of soluble organics compositions, since the volatile dissolved solids (VDS) (the VSS equivalent for dissolved organics) of the investigated wastewaters was not measured. This assumption is unsupported. Analysis to ascertain the validity of this assumption was performed in Chapter 5.

4.3.5. Measurement and procedural error

Error refers to the deviation of a measured value from it's true value. Measurement error is unavoidable ant it's magnitude and impact must be assessed for data quality evaluation. Procedural error pertains to the impact that the procedure for data sourcing has on the accuracy and precision of the data obtained. The occurrence and magnitude of such impacts are difficult to quantify. Procedural stages prone to error incursion have been identified below.

4.3.5.1. Measurement Error

Measurement error may occur due to faulty instruments or incorrect readings. Instrument accuracy also adds to measurement error. Measurement error due to faulty instruments and incorrect readings were minimised through instrument calibration prior to use and observance of diligence. All parameter testing was subject to Standard methods (1985).

C,H,N data obtained from Sasol was measured with a Leco CHN-2000 analyser. Instruments were calibrated and instrument accuracy was believed to be high. However, very small sample sizes (0.09 – 0.1 g) were used in the analysis and this may have introduced error due to inadequate sample representation. No information on sample accuracy or precision was obtained. If the approach of data reconciliation, with the objective of changing data to find the most probable correct answer, had been followed then such information would have been necessary. The result that carbon and nitrogen balances were obtained within the range 95 % - 105 % over batch tests for a number of tests indicates that C,H,N measurements were in an accuracy range considered acceptable for normal wastewater treatment modelling purposes.

TOC measurements were performed with a Tekmar Apollo 13 TOC analyser. Samples were performed in triplicate and results, including standard deviation, were obtained from Sasol but were not included in this dissertaion. These results may have been used in data reconciliation techniques.

4.3.5.2. Procedural error

The unbiodegradable fraction of the batch test sludges were unknown at the outset of the experiment. Indicators to asses the stage of biodegradation were sourced from literature data and used. A very long sludge age was used as the main indicator of biodegradation completion. The possibility that this assumption is incorrect exists. This is possible since other factors (AD bacterial growth inhibition due to various known or unknown reasons) may have impacted on the stage of biodegradation completion. Thus a systematic error may have occurred if residual sludge, assumed to consist solely of unbiodegradable material, may have contained an un-degraded but biodegradable component.

Procedural errors in gas measurement were possible due to the following factors:

1. Gas losses during duration of batch test may have included losses due to material permeability and connections that are not completely airtight. While steps to ensure gas tight seals were made, there was no guarantee that they were in fact gas tight.
2. Gas remaining in batch test containers may not have been included in the tests. The low nitrogen levels in most gas collection bags indicate that little air was present in the gas collection bags. The increase in volume due to anaerobic digestion was reflected in the increase in volume in the gas bags. It was assumed that the bag contents consisted only of CO_2 and CH_4 gas. Thus the ratio of CO_2 to CH_4 gas was all that was necessary to calculate the gas produced. The good COD balances achieved indicate that the CH_4 measurements were accurate and useable.
3. Gas calculations were based on ideal gas laws. This may have introduced error due to differences in real and ideal gasses. This error was deemed negligible; since good mass balances (95 % - 105 %) was achieved in batch test experiments. The standard molar volume (22.4 l/mol gas) is relevant at standard conditions (i.e. 273.15 K and 1 atm).

4.4. BATCH TEST EXPERIMENT DESIGN AND METHODOLOGY

The batch test procedure was purposefully chosen to be of a simple design with measurement procedures that may be performed in normal wastewater laboratories. Because studies measuring organic composition could not be found in the literature, there was little previous experience in the literature to draw from. For this experiment it was hypothesized that wastewater inserted into an airtight container, with the subsequent absence of oxygen, will develop anaerobic digestion processes. It was further hypothesized that these processes will result in the degradation of all biodegradable material with a resultant unbiodegradable remaining fraction after a long sludge age.

The experimental investigation encompassed six batch test groups. Each batch test group consisted of three batch tests; each of which contained a different wastewater type, viz. flocculated raw wastewater, primary sludge and waste activated sludge. The sludge age was initially defined as > 60 days at laboratory temperature (22^{o}C). This definition was later re-adjusted to include heating, buffering, inoculation and sulphur inhibition considerations.

4.4.1. Experimental setup

4.4.1.1. Batch test configuration

The batch test apparatus consisted of 2 L glass Erlenmeyer flasks that were connected to gas impermeable bags (Fig 4.6). The apparatus was purposefully chosen to be a simple design in an attempt to reduce procedural error. This is a result of a lack of experience in the determination of wastewater organics compositions experimentally. A simple apparatus was also seemingly advantageous in the attempt at the curbing of gas losses due to fewer connections between apparatus parts.

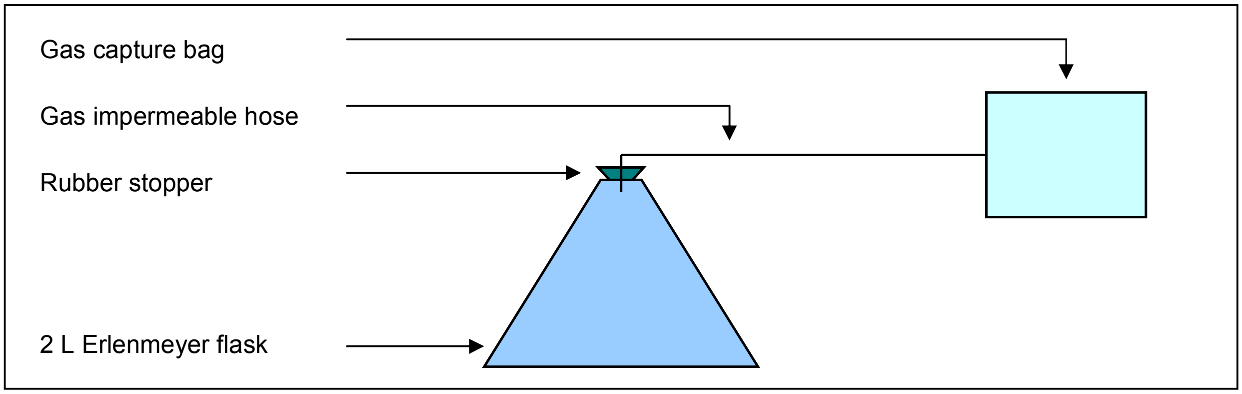


Fig.4.6: Diagrammatic representation of batch test apparatus

4.4.1.2. Wastewater sources

1. Raw wastewater was obtained from the Mitchell's Plain Treatment Plant, Cape Town (South Africa).
2. Waste activated sludge was obtained from the University of Cape Town M.L.E. system. This system was fed raw wastewater from the same source as 1. above.

4.4.1.3. Batch test sludge preparation

Flocculated raw wastewater sludge:

1. A sample of raw wastewater was tested for Total Suspended Solids (TSS) content. The required volume of raw wastewater to be flocculated was estimated from the TSS test with a focus on ensuring adequate amounts of solids remaining at the end of the batch test digestion period for further testing.
2. The required volume of raw wastewater was flocculated with the flocculation method described below.
3. The supernatant was siphoned off and the volume of flocculated sludge was recorded.
4. 0.45 µm membrane filtered samples and unfiltered samples of supernatant COD content were tested and compared to ensure that supernatant contained only dissolved matter, i.e. that all particulate matter was flocculated.

Aluminium sulphate was used as a flocculent for the flocculated raw wastewater batch tests in BTG's 1 - 5. Low gas production and seemingly retarded biodegradation was observed in these batch tests. It was believed that this may be due to sulphedogenic activity in the batch tests. Thus, a final batch test group (6) was set up with the use of iron (III) chloride instead of aluminium sulphate as a flocculent. The flocculation procedure as used in batch test groups 1 to 5 has been used in the flocculation of raw wastewater in batch test group 6. The amount of flocculent used was calculated to be the same as that of aluminium sulphate on a molar basis. This is justified by the fact that aluminium and iron have equal charges (3 +).

A. Flocculation with aluminium sulphate ($Al_2(SO_4)_3 . 18H_2O$) as flocculent (Method sourced from Muller et al., 2003):

1. The required amount of flocculent was created by dissolving 50g/l aluminium sulphate in distilled water.
2. 10ml flocculent / L of raw wastewater was used.
3. The raw wastewater was fast mixed (~ 250 rpm) for 5 minutes and slow mixed (~ 25 rpm) for a subsequent 20 minutes.
4. Mixing was stopped and the wastewater flocs were allowed to settle for minimum 30 minutes.

B. Flocculation with iron (III) chloride ($FeCl_3$):
The amount of flocculent was calculated as follows:

($Al_2(SO_4)_3 . 18H_2O$) as flocculent: M = 666.5 g/mol
50 g/l used in 10 ml / L gives 0.5 g AlumSulphate / L raw wastewater
Moles of compound used = 0.5 g / L ÷ 666.5 g/mol = 0.00075 mol/l
Moles of Aluminium used = 0.00075 mol/l x 2 = 0.0015 mol/l

$FeCl_3$ as flocculent: M = 162.2 g/mol
Moles of Iron required = 0.0015 mol/l
Concentration of $FeCl_3$ required = 0.0015 ÷ 1 x 162.2 = 0.2434 g/L wastewater
Concentration of $FeCl_3$ required per 100 ml of stock solution ~ 25 g/L with 10 ml stock used per 1L wastewater
Solubility of $FeCl_3$ = 92 g / 100 ml (20 °C)

1. The required amount of flocculent was created by dissolving 25g/l iron (III) chloride in distilled water.
2. The flocculation procedure was performed as in A. above.

Primary sludge:

1. A sample of raw wastewater was tested for total suspended solids (TSS) content. The required amount of raw wastewater to be flocculated was estimated from the TS test with a focus on ensuring adequate amounts of solids remaining at the end of the batch test digestion period for further testing.
2. The required amount of raw wastewater was collected and allowed to settle in a conical shaped settling container for > 1hr.
3. The supernatant was carefully decanted and a sample was obtained for further testing.
4. The primary sludge was decanted into a graduated cylinder and the volume recorded. In the event that distilled water was required to remove all sludge from the conical container, the volume of distilled water used was recorded.
5. The (diluted) primary sludge was inserted into a batch test container.

Waste activated sludge:

1. A known volume of un-concentrated waste activated sludge (WAS) was obtained from the U.C.T. MLE system.
2. Effluent from the MLE system was collected for further testing.

3. The WAS was concentrated to a known volume and the supernatant was siphoned off.
4. The concentrated WAS was inserted into a batch test container.

4.4.1.4. Batch test setup procedure

All batch tests were setup according to the following procedure:

1. Known volumes of sludge were inserted into each batch test container after batch test sludge preparation.
2. Batch tests were sealed with gas impermeable rubber stoppers.
3. Gas impermeable hoses were connected to the batch tests with connection pipes.
4. Impermeable gas collection bags were connected to the gas hoses and elevated above the batch tests to prohibit condensation water (in the heated batch test groups) from collecting in the bags).
5. All pipe connections were sealed with silicone gel and pipe clamps.
6. All batch tests (except for those that formed part of batch test group 1) were covered with three layers of black plastic to ensure minimal UV light penetration (and subsequent algae growth) into the batch tests. This was done after algal growth occurred in batch test group 1, which was not covered.
7. Heated batch test groups were immersed in water baths of which the temperature was kept at 35 °C ± 0.5 °C for the duration of the batch test standing period. Unheated batch test groups remained at laboratory temperature (22 ºC ± 0.5)

Batch test buffering:

All batch tests were buffered with $NaHCO_3$. The concentration of $NaHCO_3$ in all batch tests required in order to obtain an alkalinity in the range 2500 - 5500 mg/l as $CaCO_3$ was calculated with the following formula:

$$\begin{aligned} NaHCO_3\ (mg/l) &= \text{Alkalinity as } CaCO_3 \text{ required x } 84 / 50 \\ &= 4500\ mg/l \times 84 / 50 = 7\,560\ mg/l\ NaHCO_3 \end{aligned}$$

(University of Cape Town 2006)

An initial estimate of the final batch test volume was made. The mass of $NaHCO_3$ required was calculated as follows:

$NaHCO_3$ (mg) = 7 560 mg/l $NaHCO_3$ x initial batch test volume estimate (l)

4.4.1.5. Batch test timeframe and estimation of stage of completion

A timeframe for the spacing of the batch test groups (Appendix A-1) was setup to allow for improvement of subsequent batch tests according to information obtained from previous batch tests. This was done within the time restraints imposed by the project total allowed time.

It must be noted that the purpose of this investigation did not include the establishment of digestion rates. The only timeframe objective was the completion of the digestion process. Thus, no standard timeframes were observed. Timeframes were chosen according to available time and information from previous batch tests to try and ensure batch test digestion process completion. Thus, the exact establishment of batch test digestion process completion times was not deemed important and subsequently some timeframes may have been longer than strictly necessary.

Literature regarding experimentation of the form used in this project was not obtained. There are a number of qualitative and quantitative indicators that were used to determine whether the process of biodegradation of organics in a batch test has reached completion. These include batch test VFA, batch test residual COD and VSS, WAS active fraction and batch test standing time.

Volatile fatty acid (VFA) concentrations:

The hydrolysis process during anaerobic digestion transforms complex organics to volatile fatty acids. These acids are then degraded by other anaerobic bacterial groups. It is possible that the VFA's are consumed by other bacterial groups in the batch test as fast as they are produced during hydrolysis (Sötemann et al 2005). Thus, a low VFA concentration may not be used as a reliable indicator of process completion. However, it may be used as an indication towards the general health of the bacterial populations that reduce the VFA concentrations in the batch test.

Unbiodegradable COD fractions:

Sötemann et al. (2005) determined an unbiodegradable particulate fraction ($f_{PS'up}$) for PS of 0.33. Typical South African raw and settled wastewaters have $f_{S'up}$ fractions of around 0.15 and 0.04 respectively (Wentzel et al., 2006 cited from Wiechers 1984). Wentzel et al. (2006) demonstrated that the PS VSS removal during AD is around 0.35. Ekama et al. (2006) determined an unbiodegradable particulate COD fraction ($f_{AS,up}$) of activated sludge (from a 15 day sludge age activated sludge reactor) of ~ 0.63. These values may be used as indicators of PS, FS and WAS batch test digestion process completion at batch test termination. However, due to the variability of raw wastewater and PS content, these values are not set guidelines.

Batch test VSS at setup and termination:

Mahmoud et al. (2004) found a primary sludge biodegradability of around 60 %. Wentzel et al. (2006) found the same result from data produced by Eckenfelder et al. (1980). Arnaiz et al. (2006) found a PS VSS biodegradability of 87 % and a WAS biodegradability of 43 %. These values may be used as indicators of PS, FS and WAS batch test digestion process completion at batch test termination. However, due to the variability of raw wastewater and PS content, these values are not set guidelines.

Waste activated sludge active fraction:

The active fraction of waste activated sludge (fav) may be determined from measured data. The requisite data spanning the batch test period was determined for the U.C.T. MLE system. In this theses the endogenous residue fraction used in the death – regeneration model ($f_{EH} = 0.08$) was used to determine the unbiodegradable particulate organics COD fraction ($f_{AS'up}$) of WAS for the U.C.T. MLE system according to Ekama et al. (2006 b). This fraction was determined to be 0.567 with a raw wastewater $f_{S'us}$ and $f_{S'up}$ determination of 0.05 and 0.15 respectively. It was assumed that this fraction was biodegradable under anaerobic digestion as shown by Ekama et al. (2006 b) and Gosset and Belser (1982). Therefore, an indicator of WAS batch test AD digestion process completion is a remaining VSS fraction at batch test termination of ~ 0.57.

Batch test standing time:

Mahmoud et al. (2004) determined that gas production ended around the 60th day for AD batch test biodegradation of primary sludge at 35 °C, and around the 75th day at 25 ºC. Batch tests incubated at 15 °C did not reach complete degradation even after 135 days. Gosset and Belser (1982) used very long AD batch test standing times (128 days) for WAS ultimate digestion. Initial batch test standing times for the experimentation of this project was > 60 days for batch tests incubated at 35 °C and 22 °C. These standing times were later adjusted upwards with standing times as high as 169 days (Appendix. A-1). Refer to Chapter 5 for batch test standing time adjustment and reasoning.

4.4.1.6. Batch test termination procedure

1. Batch tests were terminated when biological digestion processes were deemed complete according to indicators from literature data (section 4.4.1.5.)
2. Gas bags were sealed, disconnected and captured gas was analysed (CO_2 and CH_4 content and total volumes).
3. Samples for testing were collected as described in section 4.4.2.

4.4.2. Data collection

4.4.2.1. Test procedures

1. COD, TKN, FSA, TP, OP and solids (TSS, VSS and ISS) tests were performed according to Standard Methods (1985).
2. Gas analysis was performed by Scientific Services, Stellenbosch (South Africa)
3. Elemental analysis of particulate organics and DOC testing was performed by Sasol (South Africa). C,H,N analysis was performed with a Leco CHN 2000. TOC analysis was performed with a Techno Dorman Apollo 13.

4.4.2.2. Sampling and testing profile at batch test setup

Flocculated raw wastewater

1. 200 ml raw wastewater samples were collected and tested for COD, TKN and TP
2. 200 ml Supernatant was collected from the flocculated raw wastewater for COD, TKN, TP, FSA and OP testing. 500 ml Supernatant was collected from the flocculated raw wastewater, filtered and stabilised (stabilising agent used: mercuric chloride) for DOC testing.

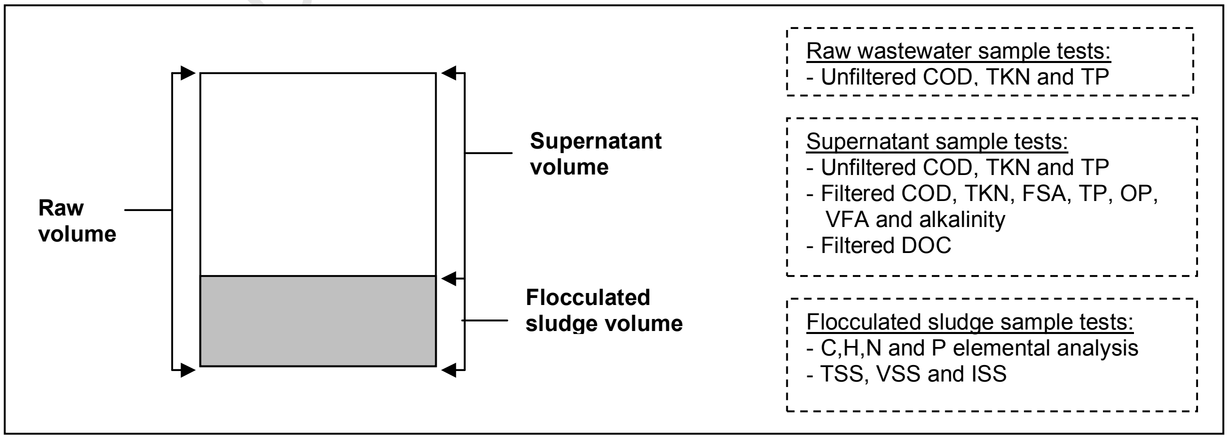


Fig. 4.7: Diagrammatic representation of sampling and testing areas during raw wastewater flocculation

Settled wastewater

200 ml settled wastewater (PS settling cone supernatant) was collected for COD, TKN and TP testing.

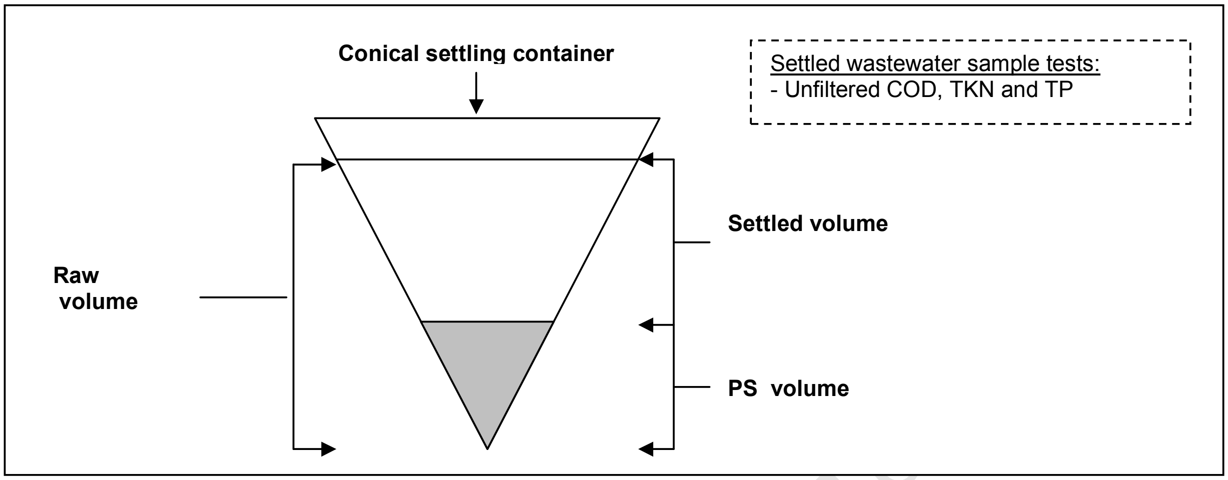


Fig. 4.8: Diagrammatic representation of sampling and testing areas during PS settling

Waste activated sludge

1. 200 ml un-concentrated or concentrated WAS was collected for COD, TKN, TP and solids testing.
2. 200 ml effluent from the MLE system was collected and 0.45 µm membrane filtered for COD, TKN, FSA, TP and OP testing.
3. 500 ml MLE system effluent was collected for DOC testing.
4. A known volume of sludge was collected for TSS, VSS and ISS testing.

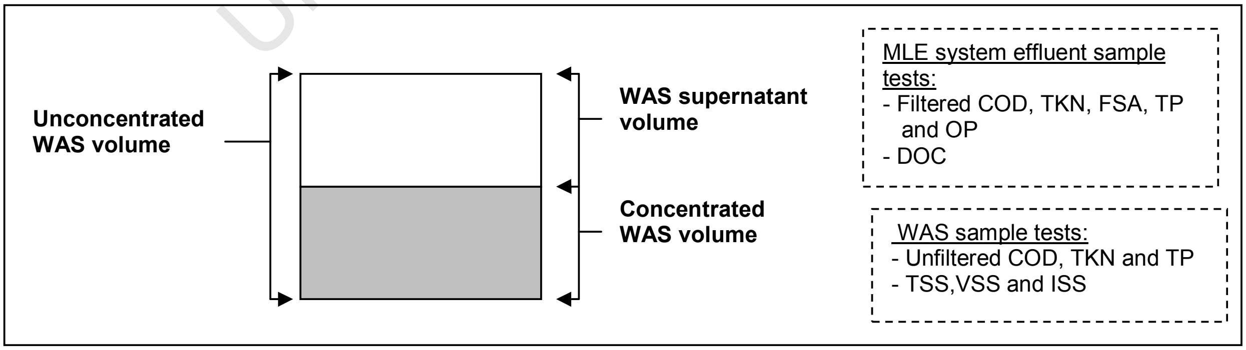


Fig. 4.9: Diagrammatic representation of sampling and testing areas during WAS concentration

Batch test contents:

1. A known volume of sludge was collected and dried at 90 °C for C,H,N and P elemental analysis.
2. 10 ml batch test content was collected, 0.45 µm membrane filtered and tested for VFA content and alkalinity.
3. A known volume of sludge was collected and tested for total solids, volatile solids and inorganic solids content.

4.4.2.3. Sampling and testing profile at batch test termination

Sampling:

The following procedure applied to all batch tests:

1. The batch test contents were well mixed and 200 ml samples were collected for total COD, TKN, TP and solids testing.
2. The sludge was allowed to settle and the maximum amount of supernatant was siphoned off.
3. 200 ml supernatant was collected and 0.45 µm membrane filtered for dissolved COD, TKN, FSA, TP, OP, VFA and alkalinity testing.
4. 500 ml supernatant was 0.45 µm membrane filtered and tested for DOC content.
5. The concentrated remaining sludge content was dried at 90 °C and tested for C,H,N and P content by elemental analysis.

Gas capturing and component analysis:

Gas was collected over the full batch test retention time. The volume of gas in each bag was measured after each batch test was opened at the end of the digestion period. The gas bags were sealed, disconnected and connected to a Ritter Drum type gas measuring device. The gas bag nozzles were opened and the volume of gas in the bags (L) were measured by manually expelling all gas contained in a specific bag through the gas measuring device. All gas was analysed for Carbon Dioxide (CO_2) and methane (CH_4) content.

4.5. DATA CAPTURING PROCEDURES

Laboratory data was captured and entered into Excel spreadsheets (See Appendix C.1. Laboratory data). The following data was captured:

1. Buffers were calculated and the amount of $NaHCO_3$ estimated and used was recorded as a mass (mg). The batch test alkalinities were tested as mg CaCO3 / l and recorded before batch test setup to ensure alkalinity within the correct range.
2. Wastewater, sludge, samples, buffer and innoculant volumes were measured and recorded in litres (L). The volumetric measuring equipment used were noted for equipment error investigation purposes.
3. COD concentrations were calculated in mg/l. Sample dilution (ml per 100 ml distilled water), titrated FAS volumes (ml) and FAS normality were recorded for this purpose. Volumetric measuring equipment for dilution purposes were noted for equipment error investigation purposes.
4. TKN and FSA concentrations were calculated in mg/l. Sample dilution (ml per 100 ml distilled water), titrated H_2SO_4 volumes (ml) and H_2SO_4 normality were recorded for this purpose. Volumetric measuring equipment for dilution purposes were noted for equipment error investigation purposes.
5. Solids concentrations were calculated in mg/l. Container weights (g) and sample volumes (ml) were recorded for this purpose. Volumetric measuring equipment for sample volumes were noted for equipment error investigation purposes.
6. TP and OP concentrations were calculated in mg/l. Sample dilution (ml per 100 ml distilled water) and spectrometer readings were recorded for this purpose. Volumetric measuring equipment for dilution purposes were noted for equipment error investigation purposes.
7. VFA and alkalinity tests involved the recording of the titrant normality and titration volumes as well as pH values. VFA concentrations were calculated as mg/l acetic acid. Alkalinity concentrations were calculated as mg/l $CaCO_3$.
8. Elemental analysis results were obtained from Sasol and were recorded as percentage elements per total solids mass.
9. Dissolved organic carbon (DOC) results were obtained from Sasol and were recorded in mg/l.
10. Total gas volumes were recorded in litres (L). CO_2 , CH_4 and N components were obtained sent for analysis and were recorded as percentages (the total must equal 100 %).

4.6. DATA ANALYSIS PROCEDURES

4.6.1. Batch test mass balances

Batch test mass balances of COD, C, N and P at setup and termination were required to check the validity of the experimental results. Mass balances were calculated over the flocculated raw wastewater sludge (FS), primary sludge (PS) and waste activated sludge (WAS) batch tests for batch test groups (BTG's) 2 - 6. BTG 1 failed to produce any organic degradation and a mass balance was thus considered unnecessary since the data served no useable purpose. Refer to Appendix B: BATCH TEST MASS BALANCES for a complete theoretical calculations layout and data analysis results.

The preparation of wastewater sludge for the experiments necessitated the dilution of PS and the concentration as well as subsequent dilution of raw wastewater and WAS. This necessitated, in some cases, the reversion of data to un-concentrated / un-diluted forms by multiplying by the dilution factor.

Raw wastewater, settled wastewater and WAS COD, TKN, FSA, TP, OP and DOC measurements at batch test setup were made directly and required no further calculation. PS parameters of the above form were calculated with mass balance considerations over the settling container (Appendix B).

Total solids data was required for the calculation of wastewater carbon content. Sludge from batch tests were used in most cases for this measurement in an attempt to reduce measurement error (greater sludge weight due to higher concentration reduces the chance of error). This data was reverted to un-concentrated raw wastewater, undiluted PS and un-concentrated WAS solids data (Appendix B.)

Calculation of COD and C content in gas produced during the anaerobic digestion processes at batch test termination was essential for COD and carbon mass balances. The moles of CH_4 and CO_2 produced were calculated with laboratory data and the ideal gas law. It was assumed that the laboratory air pressure was 1 atm. The gas temperature was taken to be equal to laboratory temperature (22 º C = 295.15 K) at the time of gas volume measurement. The COD content of methane was taken as 64 g COD / mol methane (Appendix H). The carbon content in CO_2 and CH_4 was taken as 12.01 g C / mol compound.

Batch test component mass balances were based on the fact that the mass of an element (or COD) into the batch test must equal the mass leaving the batch test. Thus all COD, C, N and P masses at batch test setup and termination were calculated and compared (Appendix B).

4.6.2. Data editing

Data editing was performed for the purpose of wastewater characterisation into biodegradable, unbiodegradable, soluble and particulate components. As for the batch test balances, concentrated / diluted sludge data had to be transformed into raw wastewater, PS and WAS data. Settled wastewater data was added. Refer to Appendix C: DATA EDITING for complete theoretical calculations layout and data analysis results.

Raw wastewater, settled wastewater and WAS total and soluble COD, TKN, FSA, TP, OP and DOC measurements at batch test setup were made directly and required no further calculation. PS parameters of the above form were calculated with mass balance considerations over the settling container (Appendix B).

Total solids data was required for the calculation of wastewater carbon content. Sludge from batch tests were used in most cases for this measurement in an attempt to reduce measurement error (greater sludge weight due to higher concentration reduces the chance of error). This data was reverted to un-concentrated raw wastewater, undiluted PS and un-concentrated WAS solids data. Volatile solids data was required for calculation of particulate organics compositions. This data was obtained measured and edited as the total solids data (Appendix B).

Measurements at batch test termination were considered to constitute unbiodegradable organics data in cases where the batch test anaerobic digestion processes were deemed complete. These parameters (COD, TKN, FSA, TP, OP, C, DOC, Solids) were in concentrated/diluted form at measurement and so further calculation was thus required to revert them to raw wastewater, settled wastewater, PS and WAS concentrations (See Appendix C.2.).

Total and soluble COD, TKN and TP parameter concentrations were directly measured and batch test setup and termination. Particulate concentrations were calculated as the difference between the total and soluble measurements. Similarly, biodegradable organics parameters were calculated as the difference between total parameters (particulate or soluble) and unbiodegradable parameters (particulate or soluble).

Particulate carbon at batch test setup and termination was calculated as a measured percentage of the measured total FS, PS or WAS suspended solids (TSS). Total carbon was calculated as the addition of calculated particulate carbon and measured dissolved organic carbon (DOC). Biodegradable organics parameters were calculated as the difference between total carbon (particulate or soluble) and unbiodegradable carbon (particulate or soluble).

4.6.3. Wastewater characterisation

Wastewater characterisation was done in accordance with the approach laid out in the ASM1, ASM2, ASM2d and ASM3 models. Therefore organic matter was divided into two main fractions, viz. biodegradable and unbiodegradable (inert) matter. These two fractions were further subdivided into soluble and particulate physical state fractions. All soluble biodegradable matter was termed readily biodegradable, though it must be noted that in actuality some soluble organics may be slowly biodegradable (Henze et al 2000). Furthermore, readily biodegradable organics were subdivided into fermentable readily biodegradable organics and volatile fatty acids (VFA's) in accordance with the steady state anaerobic sludge digestion model of Sötemann et al. (2005). Refer to Appendix D: WASTEWATER CHARACTERISATION for block characterisation diagrams.

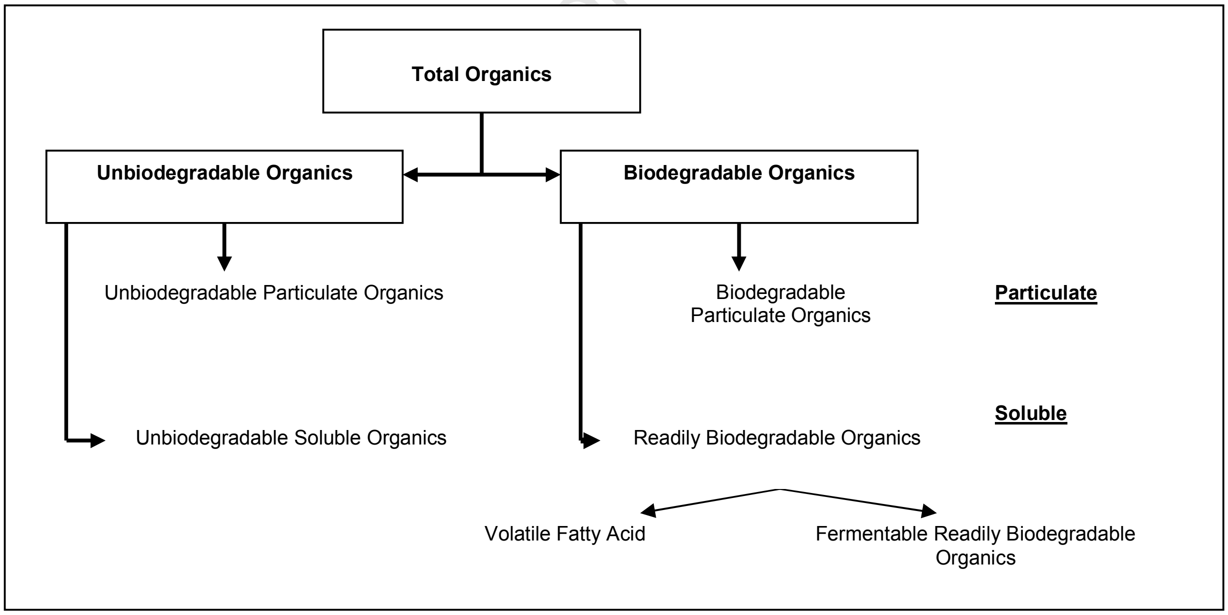


Fig. 4.10: Diagrammatic representation of wastewater organics characterisation

4.6.4. Organics compositions

4.6.4.1. Particulate organics compositions

Table 4.1: Key variables and nomenclature for the determination of particulate organics compositions

Variable	Definition	Nomenclature
Wastewater ratio's		
COD to Volatile suspended solids (VSS)	Relevant particulate COD / VSS ratio	fcv
Carbon to Volatile suspended solids (VSS)	Relevant particulate COD / VSS ratio	fc
Nitrogen to Volatile suspended solids (VSS)	Relevant particulate organic nitrogen / VSS ratio	fn
% Element		
% Carbon	The % carbon mass per total suspended solids (TSS) mass as measured with elemental analysis	%C
% Hydrogen	The % hydrogen mass per total suspended solids (TSS) mass as measured with elemental analysis	%H
% Nitrogen	The % nitrogen mass per total suspended solids (TSS) mass as measured with elemental analysis	%N
% Phosphorus	The % phosphorus mass per total suspended solids (TSS) mass as measured with elemental analysis	%P
Wastewater parameters		
Total	Relevant total parameter concentration	(*)t
Soluble	Relevant soluble parameter concentration (may be biodegraded or residual)	(*)s
Particulate	Relevant particulate parameter concentration (may be biodegraded or residual)	(*)p
Elemental preliminary subscripts		
Carbon	Preliminary composition subscript for carbon (C)	x
Hydrogen	Preliminary composition subscript for hydrogen (H)	y
Oxygen	Preliminary composition subscript for oxygen (O)	z
Nitrogen	Preliminary composition subscript for nitrogen (N)	a
Other		
Element molar mass	Elemental molar mass (g element / mol)	*M*
Compound preliminary molar mass	Compound preliminary molar mass as calculated - note: this must not be confused with actual (unknown) compound molar mass	*M'*

* Relevant wastewater parameter, i.e. S (COD), C (carbon), N (nitrogen), P (phosphorus), H (hydrogen), O (oxygen), Xt (total suspended solids) or Xv (volatile suspended solids)

Total and unbiodegradable particulate organics composition formulae were calculated from measured batch test data. Total compositions formulae were calculated from particulate organics measurements at batch test setup and unbiodegradable compositions formulae were calculated from particulate organics measurements at batch test termination. Biodegradable organics compositions formulae were calculated from a difference between total and unbiodegradable compositions parameters.

There are a number of methods that may be used in the determination of particulate organics compositions from measured data. The choice of method depends on the data set available. All methods must yield the same result and discrepancies in results indicate significant error in some or all of the data sets. Four different methods were used in this project to calculate organics compositions.

Organics compositions in wastewater are generally accepted to be primarily composed of the following elements: carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). Compositions differ according to the proportions of carbon, hydrogen, oxygen and nitrogen they contain. Thus, compositions are given in the form CxHyOzNa, where x, y, z and a signify the relevant C, H, O and N proportional moles in a specific compound.

In this project, the aim was to investigate biodegradable, unbiodegradable, soluble and particulate organics compositions at certain links in a conventional wastewater treatment plant system.

The C,H,N and P content of dried samples of a particular compound were measured by elemental analysis. The results were displayed as a percentage composition by mass of the compound. In this project it was assumed that the majority of the mass of any organic compound in municipal wastewater is composed of carbon, hydrogen, nitrogen and oxygen. The compound compositions of all particulate compounds were calculated with the following equations and assumptions:

Method 1: Composition determination with COD, TKN, VSS and TSS measurements and TOC data (Sourced from Brink et al. (2007):

<u>Requisite information:</u>

The following concentrations and percentage mass analysis data were required for the organics composition calculation of a particulate wastewater type i.e. raw wastewater, settled wastewater etc.:

1. The total particulate COD concentration (Stp, mg/l).
2. The total particulate organic nitrogen (OrgN=TKN-FSA) concentration (Ntp, mg/l).
3. The total carbon % by mass.
4. The total suspended solids (TSS) concentration (Xt, mg/l).
5. The particulate organic mass concentration measured as VSS (Xv, mg/l).

The information was available once a particular water type was characterised i.t.o. COD, nitrogen, carbon and VSS.

<u>Formulae :</u>

Particulate organics compositions were determined with the following formulae:

1. $x = fc (y + 16 z) / [(12 (1 - fc - fn)]$
2. $y = 7$
3. $z = [y (1 - fcv/8 - 8fc/12 - 17fn/14)] / [2 (1 + fcv - 44fc/12 + 10fn/14)]$
4. $a = [fn (y + 16z)] / [(14 (1 - fc - fn)]$ (3.3)

where: fcv = Stp / Xv
fn = Ntp / Xv
fc = Ctp / Xv and Ctp = %C (measured in particulate compounds with elemental analysis) x Xt

It must be noted that y is set equal to 7 in this method. This is because the x, y, z and a values in $C_xH_yO_zN_a$ are calculated relative to some unknown molar mass. Any one of the x, y, z and a values can be selected as the reference element. Sötemann et al (2005) selected y=7 for comparative purposes with the well known $C_5H_7O_2N$ for activated sludge. In chapter 3 it was shown that the α values of Volcke et al. (2006) are linearly related to the x, y, z and a values and express the same elemental composition on a mg element/mg compound basis. To calculate x, y, z and a, four data are required but when the data is reduced to ratios, then only three data need to be known, viz. fc, fcv and fn. The setting of y = 7 has no effect on the final outcome of elemental compositions in the stoichiometry as the compound parameters (x, z, a and *M'*) adjust proportionally. However, it must be noted that these are x, y, z, a and *M'* molar values calculated are not the actual absolute molar masses for this substance (which is unknown), although it does provide the correct elemental proportions in the organic type.

Method 2: Composition determination with COD, TS and VS measurements and substance elemental analysis: See Appendix H for derivation of equations.

Requisite information:
The following concentrations and percentage mass analysis data were required for the organics composition calculation of a particulate wastewater type i.e. raw wastewater, settled wastewater etc.:

1. The total particulate COD concentration (Stp, mg/l).
2. The total suspended solids (TSS) concentration (Xt, g/l).
3. The particulate organic mass concentration measured as VSS (Xv, mg/l).
4. The % carbon by mass (% C).
5. The % hydrogen by mass (% H).
6. The % nitrogen by mass (% N).

Formulae:

1. $x = (\%C / 100) (Xt) / M_{carbon}$
2. $y = (\%H / 100) (Xt) / M_{hydrogen}$
3. $z = [x (32 - 12\ fcv) + y (8 - fcv) - a (24 + 14\ fcv)] / [16\ fcv + 16]$
4. $a = (\%N / 100) (Xt) / M_{nitrogen}$ (4.1)

where: fcv = Stp / Xv

Method 3: Composition determination with TS and VS measurements and substance elemental analysis: See Appendix H for derivation of equations.

Requisite information:
The following concentrations and percentage mass analysis data were required for the organics composition calculation of a particulate wastewater type i.e. raw wastewater, settled wastewater etc.:

1. The total suspended solids (TSS) concentration (Xt, g/l).
2. The particulate organic mass concentration measured as VSS (Xv, g/l).
3. The % carbon by mass (% C).

4. The % hydrogen by mass (% H).
5. The % nitrogen by mass (% N).
6. The % phosphorus by mass (% P)

Formulae:

1. $x = (\%C / 100) (Xt) / M_{carbon}$
2. $y = (\%H / 100) (Xt) / M_{hydrogen}$
3. $z = [Xv - Xt (\%C + \%H + \%N + \%P)] / (M_{oxygen} \times 100)$
4. $a = (\%N / 100) (Xt) / M_{nitrogen}$ (4.2)

where: fcv = Stp / Xv

Method 4: Composition determination with COD and TS measurements and substance elemental analysis:

See Appendix H for derivation of equations.

Requisite information:
The following concentrations and percentage mass analysis data were required for the organics composition calculation of a particulate wastewater type i.e. raw wastewater, settled wastewater etc.:

1. The total particulate COD concentration (Stp, g/l).
2. The total solids (TS) concentration (Xt, g/l).
3. The % carbon by mass (% C).
4. The % hydrogen by mass (% H).
5. The % nitrogen by mass (% N).

Formulae:

1. $x = (\%C / 100) (Xt) / M_{carbon}$
2. $y = (\%H / 100) (Xt) / M_{hydrogen}$
3. $z = [(8 - 3\ Stp / Ctp) x + 2 y - 6 a] / 4$
4. $a = (\%N / 100) (Xt) / M_{nitrogen}$ (4.3)

4.6.4.2. Soluble organics compositions

The determination of soluble organics compositions was based on the assumption that y/z = 7/2. This assumption was evaluated in Chapter 5. Raw wastewater, settled wastewater and PS soluble (total, biodegradable and unbiodegradable) soluble compositions were considered to be identical. This is based on the assumption that no biodegradation occurs during primary sludge settling. WAS total and unbiodegradable soluble organics compositions were considered to be identical. This was based on the assumption that the MLE aerobic reactor effluent is considered to contain only unbiodegradable soluble organics. The raw wastewater, settled wastewater, PS and WAS unbiodegradable soluble organics compositions have been assumed to be identical.

Requisite information:

1. The soluble COD concentration (Sts, Sus or Sbs (mg/l)).
2. The soluble organic nitrogen concentration (Nos, Nous or Nobs (mg/l)).
3. The dissolved organic carbon concentration (Cts, Cus or Cbs (mg/l))
4. The volatile dissolved solids (VDS) concentration (mg/l) - for use in the Brink et al (2007) method.

Formulae :

Soluble organics compositions were determined with the following formulae (See Appendix H for derivation of equations):

1. 1. $x = (14y - 28z) / (21\ COD/DOC + 36\ OrgN/DOC - 56)$
2. $y = 7$
3. $z = 2$
4. $a = [\ OrgN/DOC\ (12y - 24z)\ ] / (21\ COD/DOC + 36\ OrgN / DOC - 56)$ (4.4)

Soluble organics compositions may also be determined with the formulae proposed by Brink et al (2007) as used in method 1 for particulate organics compositions determination above. This method then requires the determination of volatile dissolved solids (VDS) concentrations in the relevant wastewater types. Such measurements were not performed in this project. Rather, an assumption was made that y = 7 and z = 2. With this information formulae for the determination of x and a from COD, DOC and soluble orgN data were derived (Appendix H). The calculation theory is laid out below.

4.6.4.3. Total organics compositions

Total organics composition subscripts may be calculated with the method proposed by Brink et al. (2007) once the relevant total, unbiodegradable and biodegradable COD, TKN, TOC and VS fractions are known. The total VS concentration may be taken as the addition of volatile suspended solids (VSS) and volatile dissolved solids (VDS). Alternatively, total organics composition subscripts may be calculated with the addition of particulate and soluble organics components on a molar basis.

4.6.5. Error analysis

Large discrepancies were observed in the organics composition results (see Chapter 5). This prompted further data analysis, in particular it was attempted to identify and isolate the erroneous data. The experimental batch test investigations yielded more data than required to calculate the x, y, z and a composition values. This allowed the isolation and calculation of certain variables as a function of measured data. Variables were thus calculated from other data measurements and compared to measured data. The variables chosen for recalculation included %N and %H elemental analysis measurements and the laboratory TSS measurements.

Discrepancies between elemental analysis % particulate nitrogen and laboratory particulate nitrogen concentration (Ntp) measured by the TKN method were observed. Composition values were calculated from laboratory measured particulate nitrogen concentrations and compared with elemental analysis results.

The % H was isolated as a measurement prone to error due to the fact that it represents a small quantity in the dried solids. Error in this measurement appeared to have a large impact on the composition values. Thus, %H was isolated as a variable and calculated from the other measured data for C, TS, COD and N.

The total suspended solids measurement directly influences the composition calculations since the calculation of elemental concentrations (C, H, N) from elemental analysis data is directly dependent on it. Thus, it was included as a possible source of data error and was calculated with the aid of the additional data and compared to measured values.

% Nitrogen (%N) isolation and comparison:

The following equation was used for the determination of a:

$$a = \text{Ntp (g/l)} / M_{\text{nitrogen}} \tag{4.5}$$

% Hydrogen (% H) isolation and comparison:

The following equations were used to calculate organics compositions with adjusted % H values:
1. $x = (\%C / 100) (\text{TSS}) / M_{\text{carbon}}$
2. $y = 2z - 4x + 1.5 (\text{Stp} / \text{Ctp}) x + 3a$
3. $z = [x ((12 - 1.5 \text{ fcv}) \text{Stp} / \text{Ctp} - 8 \text{ fcv}) - 17 a \text{ fcv}] / [18 \text{ fcv}]$
4. $a = \text{Ntp (g/l)} / M_{\text{nitrogen}}$ (4.6)

Total suspended solids (TSS):

The following equation was used to determine TSS concentrations (Xt) from data:

$$\text{Xt} = (\text{Stp} - \text{Xi}) / [11 / 3 (\% C / 100) + (9 (\% H / 100) - 5 / 7 (\% N / 100) - 1] \tag{4.7}$$

4.6.6. Sensitivity analysis

Four different methods were obtained for calculation of particulate organics preliminary compositions. The experimental batch test investigation yielded superfluous data which enabled the methods to be based on different data sets. A sensitivity analysis was performed to investigate the effect of data error on each method. A positive 10 % adjustment was performed on each data type and the resultant change in organics compositions was observed for each method and batch test group. The analysis was performed on waste activated sludge data.

The method used for the calculation of the soluble organics compositions included the assumption that y = 7 and z = 2. The sensitivity of composition subscripts x and a to changes in the z value were tested to ascertain the magnitude of impact that this assumption has on the compositions calculations. Therefore, a positive 10 % adjustment was applies to the z values of unbiodegradable soluble organics for BTG's 2 - 6 and the resultant change in x and a relative to y=7 and z=2 were observed.

CHAPTER 5
EVALUATION OF A BATCH TEST METHOD FOR ORGANICS COMPOSITIONS DETERMINATION:
RESULTS AND DISCUSSION

5.1. INTRODUCTION

A batch test method for the determination of organics compositions in the form $C_xH_yO_zN_a$ was discussed in Chapter 4. The results obtained by this method for raw wastewater, settled wastewater, PS and WAS organics compositions are evaluated in this Chapter and conclusions towards the viability of the method are drawn. The research objectives of this project comprised the evaluation of a batch test method for the determination of the following: (1) raw wastewater, PS and WAS unbiodegradable and biodegradable organic fractions, (2) settled wastewater colloidal unbiodegradable and biodegradable fractions and (3) organics compositions for raw wastewater, settled wastewater, PS and WAS. Thus, the validity of the batch test method was evaluated according to the fulfilment of the research objectives.

The experimentation process was iterative in nature. Experience gained from previous batch test groups were used to improve following batch test groups (BTGs). This resulted in batch test parameter adjustments. Batch test incubation periods were lengthened from an initial ~ 60 days period to a maximum period of 169 days. Batch tests were covered to prevent UV light penetration and possible algae growth. Batch test incubation temperature was increased from 22 °C to 35 °C for certain batch test groups (BTG's). Batch tests were inoculated with anaerobic seed and buffered to prevent pH drop during incubation. Aluminium Sulphate was initially used as a flocculent for raw wastewater flocculation but this was later changed to Iron(III)Chloride due to the possibility of sulphide inhibition (from the sulphate) on the methanogenic activity.

Batch test mass balances were checked to validate COD, C, N and P data reliability. Gas losses accounted for an inability to obtain good (95 % - 105 % range) COD and C mass balances for most batch tests. Good nitrogen and phosphorus mass balances were achieved in most cases.

Batch test total and residual COD, C, OrgN and VSS data comparisons were performed in an attempt to ascertain whether batch tests had reached full substrate biodegradation. The results were compared with information sourced from literature on PS and WAS biodegradability (Chapter 2). Organics compositions were calculated for batch tests deemed to have reached complete substrate biodegradation. The results of four different methods used for the calculation of particulate organics compositions were compared. In the absence of data error these results should be identical for a particular wastewater total or unbiodegradable organic compound. No results were found to be identical, indicating data inaccuracies or variability even for batch tests with good COD, N and P mass balances. Method sensitivity analyses indicated that organic composition results are highly sensitive to data error and variation.

Sensitivity analysed on the method used for soluble organics composition calculations indicated that organics composition values x and z were highly sensitive to changes in the z value. A z value had to be assumed for soluble organics because the volatile dissolved solids (VDS) concentration could not be reliably measured. Calculation of the soluble organics compositions with the inclusion of a known volatile dissolved solids (VDS) concentration was analysed for sensitivity to the z value. It was ascertained that the results of a method incorporating the VDS value for soluble organics composition calculations are not sensitive to the VDS value. Therefore, soluble organics compositions may be accurately determined if the requisite data, including the VDS concentration of a specific wastewater, is accurately determined.

The fractionation of raw wastewater, PS and WAS into unbiodegradable and biodegradable fractions were considered to have been achieved. Batch tests were deemed to have reached biodegradation completion from a number of indicators sourced from PS and WAS biodegradability literature. Data deemed to characterise unbiodegradable organics was sourced from batch test contents at batch test termination. However, the accuracy of these fractionations were found to be inadequate to determine colloidal settled wastewater unbiodegradable and biodegradable fractions by difference. Particulate organics compositions results calculated with four different methods were variable. This variability was ascribed to data variability from test error. The determination of organics compositions was found to be highly sensitive to input data variation. Therefore, the indirect determination of particulate organics compositions requires highly accurate measured data. It is doubtful whether such accuracy can be achieved with the batch test method evaluated in this chapter. Therefore the unbiodegradable and biodegradable organics compositions for different wastewater streams could not be ascertained with any confidence with the anaerobic batch test method used. This method was therefore found to be unreliable for the determination of readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate organics compositions between unit operation links over a WWTP.

5.2. BATCH TEST TIMEFRAME AND SEQUENTIAL BATCH TEST PARAMETER ADJUSTMENTS

The batch test experimental study was based on a series of sequential experimentations whereby the planning of each new experiment was influenced by information gathered from the previous experiment. Thus, the process was iterative in nature and involved a series of related experiments. This approach resulted in a number of changes in controlled batch test configuration and procedures throughout the project. Batch test standing times were set according to previous experimental information.

The initial standing time for batch tests, BTG 1, was set at > 60 days. BTG 1 had a standing time of 69 days (at 22 °C). No batch tests in this group developed anaerobic processes as indicated by a lack of methane gas production and COD degradation. This was initially considered to be wholly due to procedural errors. Algal growth occurred in the WAS batch test of BTG 1. This rendered the results of this batch test un-useable. Subsequent batch tests were covered to prohibit UV light penetration and algal formation. No algal growth was observed in subsequent BTG's. There was a complete lack of biological process occurrence in the FS and PS batch tests of BTG 1. Subsequent batch tests were buffered and inoculated with anaerobic sludge seed. All subsequent batch tests shown biological process occurrence through methane production and/or COD removal.

Mahmoud et al. (2004) determined an end in anaerobic digestion processes for PS at ~ 60 days for batch tests incubated at 35 °C and ~ 75 days for batch tests incubated at 25 °C. Gosset and Belser (1982) used a very long batch test standing time of 128 days. BTG's 2 and 3 were set up simultaneously and incubated at 35 °C and 22 °C respectively for 62 days. The PS and WAS batch test residual COD concentrations were significantly lower in BTG 2 than in BTG 3 after 62 days standing time. PS residual COD as a percentage of total COD at was determined to be 46 % for BTG 2 and 60 % for BTG 3. WAS residual COD percentages were determined to be 76 % for BTG 2 and 92 % for BTG 3. Thus, a batch test standing time of ~ 60 days was not sufficient for biodegradation process completion for batch tests incubated at 22 °C. This is in accordance with the results of Mahmoud et al. (2004). It was unknown whether a 62 day standing time was adequate for batch tests incubated at 35 °C. Subsequent PS and WAS batch tests with much longer standing times (see below) had residual COD fractions ranging from 28 % - 31 % and 51 % - 69 % respectively. These percentages were lower than those determined for BTG 2 indicating that the standing time was possibly too short.

The FS batch tests of BTG's 2 and 3 had residual COD percentages of 72 % and 62 % respectively after 62 days standing time. It was hypothesized that the sulphate of the Alum flocculent (216 $mgSO_4/l$) may have generated sulphide which inhibited digestion processes in some way. The flocculent was changed from AlumSulphate to Iron(III)Chloride in BTG 6 and the batch test standing times were increased. The standing times for the PS and WAS batch tests for BTG's 4 (incubated at 35 °C) and 5 (incubated at 22 °C) were increased to 127 days. The FS batch tests for BTG's 4 and 5 were left to incubate until the termination of BTG 6, which resulted in a total standing time of 169 days. BTG 6 was incubated at 35 °C for 117 days. The residual FS COD to total percentages were determined to be 33.0 %, 33.4 % and 37.5 % for BTG's 4, 5 and 6 respectively. These percentages were much lower than the respective residual percentages determined for the FS batch tests from BTG's 2 and 3. This confirmed that a 62 day standing time and / or the use of AlumSulphate as a flocculant results in non-completion of anaerobic biodegradation processes.

From the results it was found that AD batch tests require heating, inoculation, buffering and darkness. Anaerobic digestion has a higher rate when incubated at 35 °C than at 22 °C and batch test standing times significantly higher than 60 days are required for complete substrate biodegradation. AlumSulphate as a flocculent seemingly retards AD biodegradation processes and Iron(III)Chloride is a preferred flocculent option.

5.3. BATCH TEST MASS BALANCES

Batch test mass balances were calculated to check the reliability of the measured data and the experimental procedure. Mass balances were calculated for COD, carbon, nitrogen and phosphorus. Refer to Appendix B.3. for a batch test mass balances summary for BTG's 2 - 6.

COD mass balances within the range 95 % to 100 % were achieved for 5 batch tests. Gas losses accounted for the lack of COD mass balances over the remaining 10 batch tests. Although the COD mass balance achievement was low (one third of batch tests), the achievement of a number of COD balances indicates that soluble and particulate COD measurement methods are reliable. It also indicates that the process may be viable if gas losses can be eliminated. Similar results and reasons pertain to the batch test carbon mass balances.

Mass balances for nitrogen within the range 95 % to 105 % were achieved for 11 batch tests. Although the remaining four batch tests scored outside this range (94 % and 109 %), the physical difference in mg/l was relatively small (< 30 mg/l). Similar results were obtained for the phosphorus mass balances. These results highlight a disadvantage in the batch test experimental procedure in that spurious measurements at batch test setup are undetectable at that stage because comparable measurements are only made at test termination. Duplicate measurements at batch test setup were performed - while this improves measurement precision, measurement accuracy cannot be determined until batch test mass balances are performed months later at test termination.

5.4. BATCH TEST TOTAL AND RESIDUAL DATA COMPARISONS

Total and residual batch test COD, Carbon (C), Organic Nitrogen (OrgN) and Volatile Suspended Solids (VSS) were documented and compared.

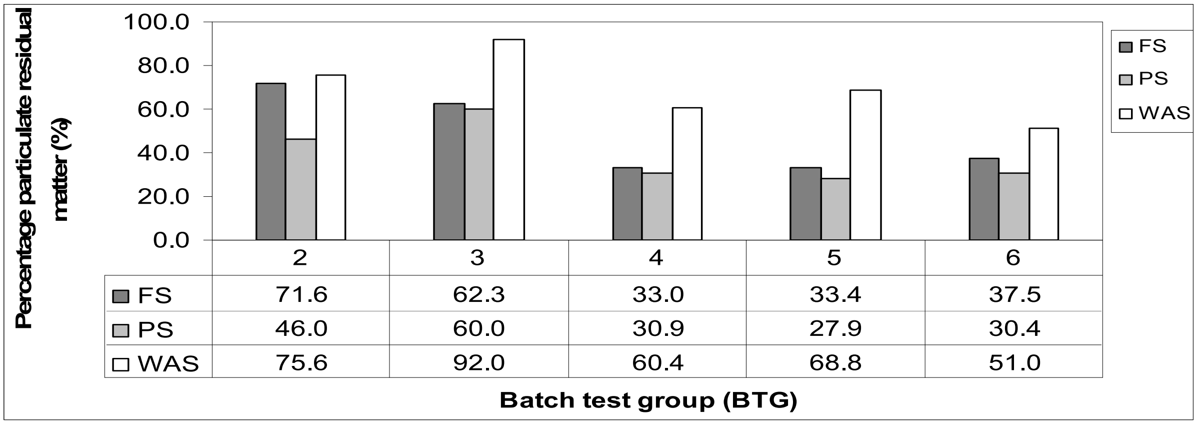
5.4.1. COD

Raw wastewater COD concentrations were much higher than the normally observed range (700 - 1000 mg/l) for wastewater from its particular source (Mitchell's Plain WWTP, Cape Town) and ranged from approximately 1150 to 2260 mg/l. This is probably due to an accumulation of particulate material at the bottom of storage containers from which the wastewater was tapped. This is deemed to be of little significance to the project since there is no known reason why high particulate content would affect the process outcome, i.e. the success of the experiment w.r.t. determination of total, unbiodegradable and biodegradable organics compositions.

The particulate COD data was variable (with the exception of BTG's 4 and 5, which were setup with wastewater from the same source and time). This is expected due to the long time elapses between batch test group setups. Concomitantly, residual particulate COD measured at batch test termination was highly variable. This result has been depicted in Fig. 5.1 below, which shows a comparison across batch test groups of total and residual particulate COD masses.

General discussion:

Notwithstanding the high variability in COD concentrations and masses, the remaining fraction of residual particulate COD at batch test termination was found to be strikingly similar for batch test groups 4, 5 and 6 (Refer to Fig. 4.5.4.1 (b)) for flocculated raw wastewater (FS) and primary sludge (PS) batch tests. The raw wastewater for batch tests 4 and 5 was derived from the same source at the same point in time and yielded particulate COD concentrations of approximately 1180 mg/l and 1210 mg/l with a difference of 30 mg/l between them. These concentrations are highly similar and a therefore expected similar residual FS batch test percentage results were obtained for BTG's 4 and 5 (33.0 % and 33.4 % respectively). Batch test group 4 was heated to 35 ºC, while BTG 5 was unheated at 22 ºC. If one accepts that the heating process increases digestion rates then the residual biodegradable fraction at a particulate time for heated and unheated batch tests would differ, unless no more biodegradable material remains in the batch tests. This indicates that both batch test groups may have reached bioprocess completion and therefore the residual particulate COD values may be accepted as being unbiodegradable. The residual particulate percentage of BTG 6 for the FS batch test was slightly higher at 37.5 %.



	2	3	4	5	6
■ FS	71.6	62.3	33.0	33.4	37.5
▨ PS	46.0	60.0	30.9	27.9	30.4
□ WAS	75.6	92.0	60.4	68.8	51.0

Fig.5.1: Batch test residual % particulate COD comparison across BTG's

BTG's 4, 5, and 6 showed similar residual particulate COD fractions for PS batch tests. BTG 5 had a slightly lower residual fraction than BTG 4 (approximately 28 % vs. 31 %), indicating either a lower unbiodegradable fraction in BTG 5 or that BTG 4 did not reach completion of digestion processes. The latter is unlikely since BTG 4 was heated and should thus have reached a state of completion before BTG 5. Thus, it must be accepted that the PS organic particulate material in BTG 5 had a lower unbiodegradable particulate COD fraction.

The residual particulate COD fraction of BTG 6 was strikingly similar to that of BTG 4 (30.4 % and 30.9 % respectively). The residual particulate COD fraction of BTG 2, at 46 %, was much higher than those obtained for BTG's 4, 5 and 6. This may indicate a higher fraction of particulate COD in BTG 2, or it may indicate that the digestion processes in BTG 2 did not reach completion. The standing time for BTG 2 was approximately half of that for BTG's 4,5 and 6. Though, this does not necessarily mean that a heated batch test standing time of 62 days is not enough to reach batch test completion, it does cast doubt on the use of the residual BTG 2 data as unbiodegradable data. However, no evidence to the contrary has been found as the accuracy of the data is unknown, thus the batch test residual data from BTG 2 has been considered unbiodegradable for the duration of this project. The relatively high residual COD fraction for BTG 3 (60 %) indicated that the batch test did not reach completion.

The residual WAS COD showed varied results. The residual WAS for BTG 3 was high at 92 %, indicating that the batch test did not reach completion. Thus, it was concluded that a standing time of 62 days for unheated batch tests is not long enough to ensure digestion process completion.

Comparison of results with literature data:

If it is accepted that the FS batch tests of BTG's 4, 5 and 6 reached substrate biodegradation completion, then the unbiodegradable particulate fractions ($f_{S'UP}$) of the raw wastewater used in these batch tests were calculated to be 0.31, 0.31 and 0.35 respectively. Typical South African raw wastewaters have $f_{S'UP}$ values around 0.15 (Wentzel et al 2006 cited in Wiechers 1984). The values determined in the BTG's are roughly twice this value. This may indicate a number of things, viz.(1) the batch test groups did not reach biodegradation completion or (2) the wastewater measured simply had higher unbiodegradable particulate COD concentrations than the South African standard. The long batch test standing times (169 days for BTG's 4 and 5 and 117 days for BTG 6) make it unlikely that the biodegradation processes did not reach completion. The similarity of the results also indicate that the processes were complete since the batch test parameters and setup times differed, viz. BTG's 4 and 5 were set up more than a month before BTG 6 and BTG's 4 and 6 were heated (35 °C) while BTG 5 was not (22 °C). Thus, it was accepted that the batch tests did reach biodegradation completion with higher unbiodegradable particulate COD values than the South African norm.

If it is accepted that the PS batch tests of BTG's 2, 4, 5 and 6 reached substrate biodegradation completion, then the unbiodegradable particulate fractions ($f_{PS'UP}$) of the primary sludge used in these batch tests were calculated to be 0.46, 0.31, 0.28 and 0.30 respectively. The $f_{PS'UP}$ values of BTG's 4, 5 and 6 correspond to the values determined by Sötemann et al. (2005) and Wentzel et al. (2006), which were 0.33 and 0.35 respectively. The $f_{PS'UP}$ value determined for BTG 2, however, was significantly different indicating once more that the PS batch test of this group did not reach substrate biodegradation completion.

If it is accepted that the WAS batch tests of BTG's 2, 4, 5 and 6 reached substrate biodegradation completion, then the unbiodegradable particulate fractions ($f_{AS'UP}$) of the waste activated sludge used in these batch tests were calculated to be 0.75, 0.59, 0.68 and 0.49 respectively. The $f_{AS'UP}$

values of BTG's 4 and 5 correspond to the value determined by Ekama et al. (2006 b), which was 0.63. This comparison may be made since the M.L.E. system used in both cases had the same sludge age (15 days).These values, however, significantly differ from each other. This is a surprising result since the same WAS was inserted into these batch tests. This may be an indication that the un-heated WAS batch test of BTG 5 did not reach biodegradation completion even after 127 days. This is unlikely and a more prudent explanation may pertain either to the accuracy of the results or to the acceptance that the result is correct and thus, that more unbiodegradable particulate COD was captured in BTG 5 at batch test setup. With no contrary information available the result was accepted as correct. The $f_{AS'UP}$ values determined for BTG's 2 and 6 were alternatively significantly higher and lower than the value determined by Ekama et al. (2006 b). Once more, the accuracy of the results were unknown and the results were used to calculate preliminary organics compositions for these batch tests.

5.4.2. Carbon (C)

The total and particulate residual carbon results for the primary sludge batch tests were variable. BTG 2 and 3 flocculated raw wastewater, as well as BTG 3 PS and WAS, residual carbon were not measured since these batch tests were not deemed to have reached completion.

The flocculated raw wastewater range of total organic carbon results for BTG's 4, 5 and 6 was 2.9 % (29.6 % to 32.5 %) indicating precise results. Conversely, the range for residual total organic carbon for the primary sludge batch tests was much higher at 11.9 % (31.9 % - 43.8 %). The imprecise nature of these results indicates high variability in primary sludge unbiodegradable fractions across different wastewaters. This is supported by the close results obtained for BTG's 4 and 5 (31.9 % and 33.6 % respectively), which contained PS from raw wastewater harvested from the same source at the same time.

The residual total and particulate results for WAS had a large range (18.8 %). This is unexpected since the WAS was harvested from the same system, albeit at different times. Most telling is the difference between the residual total (and similarly the particulate) fraction comparison between BTG's 4 and 5. The WAS for these groups was sourced from the same batch, thus the WAS total solids (TS) concentrations were identical (3248 mgTS/l) and the residual TS concentrations were very similar (2340 mg/l and 2050 mg/l respectively). From this it is expected that the residual carbon would be similar for the batch tests. However, the elemental analysis % carbon results differed greatly with residual % C results of 16.5 and 29.5 for BTG's 4 and 5 respectively. The reason for this large difference is unknown.

Table 5.1: Percentage total organic carbon residual fraction comparison across BTG's

Batch test contents	BTG 2	BTG 3	BTG 4	BTG 5	BTG 6
Flocculated raw wastewater	no data	no data	29.6%	31.8%	32.5%
Primary sludge	43.7%	no data	31.9%	33.6%	43.8%
Waste activated sludge	62.5%	no data	33.4%	52.2%	48.6%

Table 5.2: Percentage particulate carbon residual fraction comparison across BTG's

Batch test contents	BTG 2	BTG 3	BTG 4	BTG 5	BTG 6
Flocculate raw wastewater	no data	no data	30.4%	32.1%	35.1%
Primary sludge	44.2%	no data	31.9%	33.6%	44.2%
Waste activated sludge	62.2%	no data	33.0%	51.9%	48.3%

5.4.3. Organic nitrogen (OrgN)

The total and particulate residual organic nitrogen (orgN) results were variable. Surprisingly the total residual nitrogen results for BTG's 2 and 3 (which did not reach completion) for flocculated raw wastewater were in (or close to) the range of results for BTG's 4, 5 and 6 (10.3 % to 12.8 %) (Please refer to Table 4.5.3.3. (a) below). Similarly the particulate residual orgN results for BTG 2 (36.6 %) for flocculated raw wastewater is in the range of results for BTG 4, 5 and 6 (34.1 % - 39.3 %). Conversely, the particulate residual orgN of BTG 3 was found to be 55.5 %. This is a surprising result since it has been accepted that the degradation processes in BTG's 2 and 3 for flocculated raw wastewater did not reach completion and therefore one would expect the residual percentages to be higher (as for the COD) than those of the completed batch tests. In the absence of more information regarding the subject of biodegradability of organic nitrogen containing compounds in anaerobic batch tests, remains unexplained at this stage.

The total and particulate orgN results for the primary sludge batch tests were variable. BTG 3 had higher total and particulate percentages as expected. The range of total orgN results for BTG 2, 4, 5 and 6 was 8 % (47.5 % to 55.5 %). This has been considered to be a large range indicating variable, imprecise results. The particulate orgN results for BTG's 4,5 and 6 was similar to the particulate results. However, the particulate residual percentage for BTG's 2 and 6 (69.1 % and 59.8 % respectively) were relatively high compared to the total residual orgN results. This indicates variability in primary sludge unbiodegradable fraction for different wastewater batches. The WAS batch test results showed similar trends across BTG's

Table 5.3: Percentage total organic nitrogen residual fraction comparison across BTG's

Batch test contents	BTG 2	BTG 3	BTG 4	BTG 5	BTG 6
Flocculated raw wastewater	9.0%	11.5%	11.8%	12.8%	10.3%
Primary sludge	52.3%	63.5%	51.9%	55.5%	47.5%
Waste activated sludge	54.6%	61.8%	39.5%	54.5%	31.2%

Table 5.4: Percentage particulate organic nitrogen residual fraction comparison across BTG's

Batch test contents	BTG 2	BTG 3	BTG 4	BTG 5	BTG 6
Flocculated raw wastewater	36.6%	55.5%	39.3%	34.1%	27.6%
Primary sludge	69.1%	72.2%	54.7%	59.2%	59.8%
Waste activated sludge	55.0%	62.2%	40.6%	54.4%	31.9%

5.4.4. Volatile Suspended Solids (VSS)

The remaining fraction of residual VSS at FS batch test termination was found to be strikingly similar for batch test groups 4, 5 and 6 (Refer to Table 5.5) with a residual percentage range between 27.1 % and 32.1 %. The FS batch tests for BTG's 2 and 3 had higher residual VSS percentages, which were determined to be 49.1 % and 59.6 %. This is a further indication that these batch tests did not reach substrate biodegradation completion.

The PS batch test residual VSS for BTG's 4 and 6 were similar (44.5 % and 47.9 % respectively). The residual VSS for BTG 5 was significantly higher at 57.2 %. However, this VSS result was taken to represent the unbiodegradable fraction for organics composition calculations on the basis of assumption that a batch test standing time of 117 day would ensure PS substrate total biodegradation. The residual VSS for the PS batch test of BTG 2 was significantly higher than BTG's 4 - 6 (61.3 %) in accordance with the COD data.

The WAS residual VSS data for BTG's 4 - 6 were strikingly similar with a range between 54.9 % and 57.7 %. Conversely, the residual VSS data for BTG 2 was significantly higher at 66.6 %. This is in accordance with the COD data for this batch test.

Comparison of results with literature data:

If it is accepted that the FS batch tests of BTG's 4, 5 and 6 reached substrate biodegradation completion, then the unbiodegradable VSS fractions of the raw wastewater from these batch tests were calculated to be 0.27, 0.31 and 0.32 respectively. No comparison with literature data was made on the basis of VSS data. FS batch tests were assumed to have reached completion on the basis of COD data and long batch test standing times.

If it is accepted that the PS batch tests of BTG's 2, 4, 5 and 6 reached substrate biodegradation completion, then the unbiodegradable VSS fractions of the primary sludge used in these batch tests were calculated to be 0.61, 0.45, 0.57 and 0.48 respectively. The value for BTG 4 roughly corresponds to the value of a 0.60 PS biodegradability determined by Mahmoud et al. (2004) and Wentzel et al. (2006). The residual VSS values for the other BTG's were, however, significantly higher. Batch tests were assumed to have reached substrate biodegradation completion on the basis of COD data comparisons.

If it is accepted that the WAS batch tests of BTG's 2, 4, 5 and 6 reached substrate biodegradation completion, then the unbiodegradable VSS fractions of the waste activated sludge used in these batch tests were calculated to be 0.67, 0.58, 0.56 and 0.55 respectively. The values for BTG's 4, 5 and 6 correspond to the unbiodegradable VSS fraction of 0.57 calculated for the U.C.T. MLE system in Chapter 4. This comparison may be made because the sludge age of the M.L.E. system remained unchanged (at 15 days) during the experimentation time. The residual VSS fraction for the WAS batch test of BTG 2 was significantly higher, indicating once more that this batch test did not reach substrate biodegradation completion.

Table 5.5: Percentage volatile suspended solids residual fraction comparison across BTG's

Batch test contents	**BTG 2**	**BTG 3**	**BTG 4**	**BTG 5**	**BTG 6**
Flocculated raw wastewater	49.1%	51.6%	27.1%	30.8%	32.1%
Primary sludge	61.3%	50.7%	44.5%	57.2%	47.9%
Waste activated sludge	66.6%	55.0%	57.7%	56.2%	54.9%

5.5. METHOD SENSITIVITY ANALYSIS

Refer to Appendix G: SENSITIVITY ANALYSIS for complete results.

5.5.1. Particulate organics compositions

Method 1:

Compositions calculated with this method were sensitive to COD data input adjustments. A 10 % change in input COD data resulted in changes of carbon, oxygen and nitrogen composition values (x, z and a) by percentages as high as 23 % (z). Changes in x, z and a ranged between 16 % and 23 % from original values for all batch test groups.

Adjustment of nitrogen input data was not highly significant. The nitrogen composition value a was most affected with an average change of 9.25 % for all batch test groups.

Volatile solids input data adjustments of 10 % yielded increased values in organics composition composition values for most batch test groups. Percentage change in composition values ranged from 5 % to 15 % for all batch test groups. No significant differences in percentage change were observed across BTG's.

Elemental composition values were highly sensitive to a 10 % adjustment in input total solids (TS) data. The carbon composition value (x) showed percentage changes ranging from 18 % to 23 % across batch test groups. Percentage changes in composition value z ranged between 34 % and 39 %. Percentage changes in the composition value a were not highly significant with a range between 7 % and 12 %.

Elemental composition values were highly sensitive to a 10 % adjustment in input total solids the %C measured value. The carbon composition value (x) showed percentage changes ranging from 40 % to 57 % across batch test groups. Percentage changes in composition value z ranged between 15 % and 30 %. Percentage changes in the composition value a were significant with a range between 27 % and 43 %.

Method 2:

Method 2 showed relatively little sensitivity to adjustments in most of its input data. The highest sensitivity was shown to be due to COD input data adjustments. This influenced only the z value as other elemental composition values are calculated directly from elemental analysis percentage results. Percentage changes in z values ranged from 13 % to 21 % across batch tests. Changes in solids data also influence the z value across BTGs. The percentage change in z value ranged between 14 % and 24 %. Other composition value values were unaffected as there calculation relies on other measured values.

Method 3:

Method 3 showed high sensitivity to input VS and % carbon data adjustments. A 10 % adjustment of VS input data resulted in percentage changes in z ranging between 24 % and 30 % across batch test groups. Data was less sensitive to changes in the %C measurements with percentage changes in the composition value z ranging between 11 % and 16 %.

A sensitivity to % H measurements was also observed. A 10 % change in % hydrogen values resulted in roughly 10 % changes in x,z and a values when y was set equal to 7. A sensitivity to TS adjustment was only observed in BTG's 4 and 5 with a percentage increase of 11.5 % in the batch test values for both groups.

No sensitivity to a % adjustment in nitrogen content was observed.

Method 4:

Method 4 was found to be highly sensitive to much of its input data. A 10 % increase in input COD values yielded changes in the z value ranging between 33 % and 104 % across BTG's. Similar results were observed in 10 % adjustments in input TS and % carbon data. The percentage change in z values from TS adjustment ranged between 30 % and 93 % across BTG's. Adjustment of input % carbon values resulted in % change in z values ranging between 33 % and 84 %. There was no sensitivity to % nitrogen measurements.

5.5.2. Soluble organics compositions

Sensitivity to assumption of y = 7 and z = 2:

Analysis on the organics compositions determined based on the assumption that y/z = 7/2 was performed to evaluate the impact of this assumption on the final calculated results. An adjustment of + 10 % was made on the z value of all compositions and the resultant percentage change in x and a values were determined. A positive change of 13.33 % was determined for all x and a values with a positive adjustment of z by 10 %. Thus, the x and a value determinations are sensitive to changes in the z value. This value may therefore not be assumed. Measured data must be employed for the calculation of z.

Sensitivity to COD/VDS ratio:

COD/VDS data determined by Ubisi (1997) for the MLE system was employed to determine the sensitivity of organics compositions results to the COD/VDS ratio. The results indicated a < 10 % change in x, z and a values with a concomitant + 10 % change in the COD/VDS ratio. Therefore, the results are not sensitive to this ratio.

5.6. ORGANICS COMPOSITIONS

Organics compositions for particulate and soluble components of raw wastewater, primary sludge (PS) and waste activated sludge (WAS) were calculated after characterisation of these wastewaters in terms of COD, C, OrgN and VSS. Results from batch tests deemed to have reached completion in biodegradation processes were termed unbiodegradable and were used to characterise unbiodegradable COD, C, OrgN and VSS concentrations. The difference between total and unbiodegradable organic COD, C, OrgN and VSS concentrations were termed biodegradable and were used to calculate biodegradable organics compositions. The calculation method proposed by

Brink et al. (2007) (Method 1) was initially used to determine particulate organics compositions of the form $C_xH_yO_zN_a$ with this data. Three more methods (Methods 2, 3 and 4) for organics compositions calculation with different data sets were derived (Appendix H) and were used to investigate the accuracy of the results provided through the use of Method 1.

Organics compositions values x, y, z and a were compared across batch tests and methods used for calculation methods in the tables below. The x and a values were calculated in the same way for methods 2,3 and 4 and thus comparisons between the result of these methods and that of method 1 were made. The z values were calculated from different data sets and with different formulae for all four methods and thus all results were shown and compared. The y values were set equal to 7 in all cases (to enable comparison) and were thus not shown.

5.6.1. Particulate organics

Raw wastewater:

Measurements at FS batch test setup were made for BTG's 2, 3, 4, 5 and 6. The results for total raw wastewater relevant calculation variables and compositions for BTG's 2, 3, 4, 5 and 6 are shown in Table 5.6 below.

Table 5.6: Total particulate raw wastewater calculation variables

Data source:	**U.C.T. Laboratory Measurements**			**Elemental Analysis**		
BTG	**fcv**	**fc**	**fn**	**%C**	**%H**	**%N**
2	0.985	0.326	0.028	23.9	4.02	1.43
3	1.986	0.565	0.033	41.6	6.44	2.49
4	0.670	0.296	0.019	23.5	3.99	1.00
5	0.493	0.243	0.013	17.8	3.61	0.66
6	0.960	0.370	0.025	32.2	4.73	1.89

Table 5.7: Total particulate raw wastewater organics compositions determined subscript values

Composition Subscript:	**x**		**z**				**a**	
BTG	**Method 1**	**Methods 2,3,4**	**Method 1**	**Method 2**	**Method 3**	**Method 4**	**Method 1**	**Methods 2,3,4**
2	2.188	3.470	2.708	3.540	4.706	2.316	0.154	0.178
3	3.155	3.764	1.252	1.315	1.523	0.807	0.156	0.193
4	2.022	3.432	3.580	4.839	6.375	3.757	0.122	0.125
5	2.086	2.870	4.352	5.213	6.103	4.732	0.095	0.091
6	3.131	3.974	3.396	3.928	4.392	3.419	0.185	0.200

The FS batch tests of BTG's 2 and 3 were not deemed to have reached substrate biodegradation completion and thus no unbiodegradable data was obtained. The results for raw wastewater compositions for BTG's 4, 5 and 6 are shown in Tables 5.8 and 5.9 below.

Table 5.8: Unbiodegradable particulate raw wastewater calculation variables

Data source:	**U.C.T. Laboratory Measurements**			**Elemental Analysis**		
BTG	**fcv**	**Fc**	**Fn**	**%C**	**%H**	**%N**
4	0.871	0.301	0.027	18.2	2.94	0.86
5	0.567	0.253	0.019	17.1	2.66	0.80
6	1.215	0.405	0.034	28.7	4.69	1.58

Table 5.9: Unbiodegradable particulate raw wastewater organics compositions determined subscript values

Composition Subscript:	**x**		**z**				**a**	
BTG	**Method 1**	**Methods 2,3,4**	**Method 1**	**Method 2**	**Method 3**	**Method 4**	**Method 1**	**Methods 2,3,4**
4	2.010	3.608	2.925	4.088	5.716	2.672	0.157	0.146
5	2.044	3.746	3.964	5.649	7.707	4.484	0.131	0.150
6	2.821	3.569	2.493	2.899	3.347	2.356	0.202	0.168

Large discrepancies (> 10 %) between the x values calculated with method 1 and those calculated with the other methods was observed across BTG's for total and unbiodegradable organics. The use of method 1 to calculate the x value is sensitive to error in COD, VSS, and %C data. Methods 2,3 and 4 are insensitive to data changes and, assuming that the %C and TSS data are accurate, are thus a more reliable calculation method for the x value. This may be ascribed to the uncomplicated nature of the calculation (x = %C x TSS (g/l) / 12 (g/mol)) compared to the larger data requirement of method 1(%C, TSS, COD, VSS and OrgN), which increases the chance of data error inclusion in the final result.

Large discrepancies between the z value were observed across BTG's and methods in all cases. Results were highly variable. Methods 1, 2 and 4 used for the calculation of the z value are sensitive to COD error. Added to this method 1 is also sensitive to TSS and %C data error. Method 2 is sensitive to TSS and VSS error. Method 3 is sensitive to VSS, %C and %H error. Method for is sensitive to TSS and %C error. Thus, the z value is sensitive to the widest data base and this is reflected in the data. Further analysis was performed in an attempt to isolate erroneous data (section 5.7.). No final conclusions concerning the accuracy of any z values were made however. Thus, the accuracy of the results are unknown and the data could therefore not be validated.

Discrepancies between the a values calculated with method 1 and those calculated with the other methods was observed across BTG's in many cases. Only two cases, viz. the total organics a composition values of BTG's 4 and 5, provided results with good correlation (BTG 4: 0.122 vs. 0.125 and BTG5: 0.095 vs. 0.091). The use of method 1 to calculate the a value is sensitive to error in COD, VSS, TSS and %C data (Refer to section 5.5.). Methods 2,3 and 4 are insensitive to data changes and, assuming that the %N and TSS data are accurate, are thus a more reliable calculation method for the a value for the same reasons as for x above. However, the %N measurement is prone to error due to the fact that it represents a relatively small quantity and thus it may not be concluded that methods 2,3 and 4 provide more accurate results than method 1. Good nitrogen mass balances (within the 95 % - 105 % range) across batch tests are an indication that the nitrogen concentration measurements are more reliable than the elemental analysis %N measurements. Nitrogen concentration measurements and %N measurements were compared in section 5.7. The accuracy of the a values calculated have not been confirmed and these values are therefore not validated. No conclusions towards the best method to use for the calculation of the composition value a have been reached.

Biodegradable organics compositions were derived from total and unbiodegradable organics data (Appendix E). Therefore, similar trends were observed in these compositions. The failure to validate total and unbiodegradable organics compositions composition value values rendered the biodegradable organics compositions data un-validated.

Primary sludge compositions:

Measurements at PS batch test setup were made for BTG's 2, 3, 4, 5 and 6. The results for total PS compositions for BTG's 2, 3, 4, 5 and 6 are shown in Tables 5.10 and 5.11 below.

Table 5.10: Total particulate primary sludge calculation variables

Data source:	**U.C.T. Laboratory Measurements**			**Elemental Analysis**		
BTG	**fcv**	**fc**	**fn**	**%C**	**%H**	**%N**
2	2.248	0.700	0.061	43.9	6.17	2.17
3	2.086	0.566	0.033	46.6	6.71	2.00
4	1.503	0.546	0.030	46.1	3.38	1.21
5	1.381	0.463	0.027	38.9	5.68	1.23
6	1.766	0.520	0.028	46.0	6.72	1.97

Table 5.11: Total particulate primary sludge organics compositions determined subscript values

Composition Subscript:	**x**		**z**				**a**	
BTG	**Method 1**	**Methods 2,3,4**	**Method 1**	**Method 2**	**Method 3**	**Method 4**	**Method 1**	**Methods 2,3,4**
2	5.063	4.155	0.859	0.988	0.669	1.536	0.380	0.176
3	2.871	4.054	1.089	1.250	1.695	0.176	0.144	0.149
4	5.512	7.949	2.769	3.707	4.217	2.735	0.258	0.179
5	3.451	3.999	2.419	2.713	2.870	2.384	0.172	0.108
6	3.101	3.993	1.584	1.800	2.131	1.093	0.145	0.147

The PS batch tests of BTG 3 were not deemed to have reached substrate biodegradation completion and thus no unbiodegradable data was obtained. The results for PS compositions for BTG's 2, 4, 5 and 6 are shown in Tables 5.12 and 5.13 below.

Table 5.12: Unbiodegradable particulate primary sludge calculation variables

Data source:	**U.C.T. Laboratory Measurements**			**Elemental Analysis**		
BTG	**fcv**	**fc**	**fn**	**%C**	**%H**	**%N**
2	1.712	0.505	0.069	22.5	3.99	1.00
4	1.046	0.392	0.037	35.3	4.92	1.49
5	0.642	0.258	0.039	20.6	4.11	1.68
6	1.125	0.479	0.050	35.3	4.47	1.75

Table 5.13: Unbiodegradable particulate raw wastewater organics compositions determined subscript values

Composition Subscript:	**x**		**z**				**a**	
BTG	**Method 1**	**Methods 2,3,4**	**Method 1**	**Method 2**	**Method 3**	**Method 4**	**Method 1**	**Methods 2,3,4**
2	2.923	3.287	1.408	1.744	1.723	1.536	0.342	0.125
4	3.238	4.188	3.105	3.798	4.192	3.266	0.260	0.151
5	1.880	2.930	3.393	4.414	5.550	3.597	0.244	0.204
6	6.246	4.605	4.160	3.692	3.015	4.311	0.559	0.196

As for the raw wastewater compositions, large discrepancies (> 10 %) between the x values calculated with method 1 and those calculated with the other methods was observed across BTG's for total and unbiodegradable organics. Similarly, large discrepancies between the z value were observed across BTG's and methods in all cases. Discrepancies between the a values calculated with method 1 and those calculated with the other methods was observed across BTG's in all cases. Method sensitivities are as those discussed for the raw wastewater above. Results were highly variable. No final conclusions concerning the accuracy of any composition value values could be made.

Settled wastewater compositions

Settled wastewater organics compositions may be derived from raw wastewater and primary sludge organics data (Appendix E). The failure to validate raw wastewater and primary sludge organics compositions composition value values rendered the settled wastewater organics compositions data un-validated.

Waste activated sludge compositions

Measurements at WAS batch test setup were made for BTG's 2, 3, 4, 5 and 6. The results for total WAS compositions for BTG's 2, 3, 4, 5 and 6 are shown in Tables 5.14 and 5.15 below.

Table 5.14: Total particulate waste activated sludge calculation variables

Data source:	**U.C.T. Laboratory Measurements**			**Elemental Analysis**		
BTG	**fcv**	**fc**	**fn**	**%C**	**%H**	**%N**
2	1.457	0.508	0.085	43.2	5.98	7.15
3	1.275	0.463	0.063	41.3	6.00	5.67
4	1.468	0.516	0.073	35.9	5.23	4.14
5	1.468	0.516	0.079	35.9	5.23	4.14
6	1.643	0.506	0.087	44.0	6.48	7.23

Table 5.15: Total particulate waste activated sludge organics compositions determined subscript values

Composition Subscript:	**x**		**z**				**a**	
BTG	**Method 1**	**Methods 2,3,4**	**Method 1**	**Method 2**	**Method 3**	**Method 4**	**Method 1**	**Methods 2,3,4**
2	4.077	4.217	2.011	2.048	2.083	1.970	0.585	0.598
3	3.914	4.012	2.563	2.590	2.616	2.533	0.457	0.473
4	4.308	4.000	2.139	2.169	2.011	2.369	0.522	0.396
5	4.276	4.000	2.079	2.169	2.011	2.369	0.565	0.396
6	3.132	3.962	1.447	1.583	1.955	0.944	0.463	0.558

From Table 5.15 it may be observed that x, z and a composition value values correlate well in general across methods and BTG's. Good correlations across methods indicate trustworthy data. The WAS for all BTG's were sourced from the UCT MLE reactor with no change in reactor sludge age. Thus, the WAS organics compositions should be similar (with allowances for random error). As discussed in the raw waste water discussion section above, the calculation of x with methods 2,3 and 4 is considered to be less prone to error than calculation with method 1. Thus, the average measured value for x = 4.050 with a standard deviation of 0.1. The calculation of the z value with methods 2 and 3 are least sensitive to data error (refer to section 5.5.). An average z value and standard deviation for the results of these methods were calculated to be 2.13 and 0.32 respectively. An average value of a across BTG's and standard deviation were calculated to be 0.501 and 0.07 respectively. Thus, an average total WAS organics composition was calculated to be $C_{4.05}H_7O_{2.13}N_{0.5.}$ The x and a values differ significantly from the generally accepted WAS composition with x = 5 and a = 1. These values shown the smallest standard deviations and thus the highest precision. Conversely, the z value correlates more closely to the generally accepted WAS organics composition z = 2. The calculation results of this value shown a larger standard deviation and thus lower precision. As for the raw and PS compositions values, the accuracy of the values is unknown, but the determination of composition values across batch tests and methods indicates that the values are accurate.

The WAS batch test of BTG 3 were not deemed to have reached substrate biodegradation completion and thus no unbiodegradable data was obtained. The results for raw wastewater compositions for BTG's 2, 4, 5 and 6 are shown in Tables 5.16 and 5.17 below.

Table 5.16: Unbiodegradable particulate waste activated sludge calculation variables

Data source:	**U.C.T. Laboratory Measurements**			**Elemental Analysis**		
BTG	**fcv**	**fc**	**fn**	**%C**	**%H**	**%N**
2	1.648	0.474	0.070	32.3	3.90	3.80
4	1.527	0.295	0.051	16.5	4.76	1.22
5	1.790	0.477	0.078	29.5	4.51	2.81
6	1.502	0.446	0.060	23.5	4.57	1.88

Table 5.17: Unbiodegradable waste activated sludge organics compositions determined subscript values

Composition Subscript:	**x**		**z**				**a**	
BTG	**Method 1**	**Methods 2,3,4**	**Method 1**	**Method 2**	**Method 3**	**Method 4**	**Method 1**	**Methods 2,3,4**
2	2.599	4.832	1.434	1.903	3.153	-0.154	0.329	0.487
4	1.048	2.020	1.301	1.661	3.064	-0.480	0.156	0.128
5	2.280	3.821	1.158	1.532	2.436	-0.085	0.321	0.312
6	2.576	3.013	1.703	1.957	2.189	1.608	0.295	0.206

As for the raw wastewater and PS compositions, large discrepancies (> 10 %) between the x values calculated with method 1 and those calculated with the other methods was observed across BTG's for total and unbiodegradable organics.

Large discrepancies between the z values were observed across BTG's and methods in all cases. Some values were even negative, which is impossible if the data used for the calculations are accurate enough. It must be noted that the negative values occurred only in the results for method 4. This method is highly sensitive to COD, TSS and %C data error. COD errors adjust the calculated z values negatively by as much as 100 % (See section 5.5.). Thus, the occurrence of negative values are possible due to data inaccuracy. The COD test is generally accepted to be an accurate test and repeated COD measures during testing for this project indicated this. It must be noted that COD error may be within the range of generally accepted error, while the measurements are not necessarily accurate enough for organics compositions determinations with method 4. This is illustrated by the high sensitivity of method for to error in COD data. The large variation in z values rendered the determination of data accuracy impossible.

Discrepancies between the a values calculated with method 1 and those calculated with the other methods was observed across BTG's in all cases. Method sensitivities are as those discussed for the raw wastewater above. Results were highly variable. No final conclusions concerning the accuracy of any composition value values could be made.

5.6.2. Soluble organics compositions

The calculation of soluble organics compositions was based on a number of assumptions The first assumption was that raw wastewater, settled wastewater and PS have the same soluble organics (based on the assumption that no biodegradation processes occur during primary settling processes). The second assumption was that the soluble organics in the activated sludge system employed (U.C.T. MLE system) constitute the unbiodegradable soluble organics over the whole WWTP , viz.

in the raw wastewater, settled wastewater, PS and WAS streams. Therefore, WAS soluble total and unbiodegradable organics constitute the same organic compound.

Soluble organics compositions were initially calculated with theory based on an assumed ration of y/z = 7/2. Results are displayed in Appendix E. A sensitivity analysis was performed on the results to determine the effect of the assumption of y/z = 7/2 in section 5.5. The results indicated that the x and a subscripts are sensitive to changes in the z value with calculation based on this assumption. Therefore, the results and method are not validated.

The method of Brink et al. (2007), whereby organics compositions are calculated with volatile solids, COD, C and OrgN data was also investigated for soluble organics composition calculations. Volatile dissolved solids (VDS) were substituted for volatile suspended solids (VSS) used for the calculation of particulate organics compositions. VDS measurements were not performed during this project. Ubisi (1997) performed VDS measurements on the U.C.T. MLE system effluent (Appendix E). The measurements were variable, but conformed to a normal distribution. Variability was expected since different raw waste waters may contain varying unbiodegradable soluble organic components. The average COD/VDS ratio was calculated and substituted for the fcv value in the method of Brink et al. (2007). Organics compositions for the MLE effluent were calculated. A sensitivity analysis was performed on the results in section 5.5. to determine the sensitivity of the organics composition results to the COD/VDS ratio. The results indicated that the x, z and a values are insensitive to error in the COD/VDS ratio. This method may thus be employed to calculate soluble organics compositions if the VDS concentrations can be determined accurately enough. It is debatable whether this may be achieved with the method used by Ubisi (1997), whereby crucibles are employed for this determination.

5.7. MEASUREMENT AND PROCEDURAL ERROR

5.7.1. Measurement error

Discrepancies in organics compositions calculated from different data bases prompted an investigation into data discrepancies. %H and %N measurements were considered prone to error due to their small mass representation in elemental analysis measurements. TSS data pervaded the calculation of particulate organics compositions for all methods used and all results were sensitive to error in this data. Therefore %N, %H and TSS data were calculated from superfluous data and compared to measured data.

%N measurements

Particulate organics compositions calculations were not found to be sensitive to error in %N measurements. However, the accuracy of these measurements may indicate the accuracy of the %H measurements as they fall within the same range. The accuracy of the %N measurements also affect the organics compositions as calculated with methods 2, 3 and 4 and system nitrogen mass balances will not be achieved if the %N measurements do not correspond with the measured laboratory nitrogen data. The results of calculated vs. measured %N values are displayed in Table 5.18.

Table 5.18: Total %N calculated vs. measured values

	Raw wastewater		**PS**		**WAS**	
BTG	**%N measured**	**%N calculated**	**%N measured**	**%N calculated**	**%N measured**	**%N calculated**
2	1.43	2.03	2.17	3.84	7.14	5.84
3	2.49	2.39	2.00	2.72	5.67	4.95
4	1.00	1.65	1.21	2.51	4.14	4.97
5	0.66	0.95	1.23	2.26	4.14	5.41
6	1.89	2.22	1.97	2.50	7.23	5.32

The % discrepancies between measured and calculated %N values ranged from 0.1 - 0.65 % for raw wastewater, 0.53 - 1.67 % for PS and 0.72 - 1.9 % for WAS. The %N as calculated was based on laboratory measured (U.C.T.) data. The accuracy of this data was ascertained through good batch test mass balances (95 % - 105 %) for all BTG's. Therefore, the results indicate that percentage analysis measurements did contain error. The samples that were tested were particulate sludge. It is difficult to obtain completely representative samples from a material of this nature system mass balances should thus be based on laboratory measured concentrations rather than elemental analysis results.

%H measurements

Particulate organics compositions calculations are not sensitive to error in %H measurements. However, the accuracy of these measurements have a direct effect on final compositions representation due to the setting of y = 7, and the concomitant representation of the x, z and a values according to the y value. Thus, an error in the y value will result in a misrepresentation of the x, z and a values even though the data used for their calculation may be accurate. Therefore, the %H value as measured was compared to a %H value calculated from extra data (Appendix F). The results are displayed in Table 5.19.

Table 5.19: Total %H calculated vs. measured values

	Raw wastewater		**PS**		**WAS**	
BTG	**%H measured**	**%H calculated**	**%H measured**	**%H calculated**	**%H measured**	**%H calculated**
2	4.02	6.58	6.17	5.06	5.98	4.99
3	6.44	7.68	6.71	9.47	6.00	5.41
4	3.99	6.77	3.38	4.87	5.23	4.75
5	3.61	4.96	5.68	6.57	5.23	4.79
6	4.73	6.00	6.72	8.64	6.48	5.74

The % discrepancies between measured and calculated %H values ranged from 1.24 - 2.78 % for raw wastewater, 0.89 - 2.76 % for PS and 0.44 - 0.99 % for WAS. The %H as calculated was based on COD, %C, TSS, VSS and OrgN data. Thus, the calculated value may be erroneous. This exercise was not performed to ascertain the correct %H, but serves to illustrate discrepancies between U.C.T. laboratory data and elemental analysis data. The accuracy of the COD, %C, TSS and nitrogen data was ascertained through batch test mass balances for the FS, PS and WAS batch tests of BTG 2 and the WAS batch tests of BTG's 3 and 4. Assuming that the VSS measurements were accurate, the

%H measurement error was as high as 2.56 % for these batch tests. This is a significant discrepancy and is possibly due to procedural error whereby unrepresentative sludge samples were measured.

TSS measurements

Discrepancies between elemental analysis results and laboratory measured data can be clearly seen in a TSS calculation from laboratory and elemental analysis results and measured TSS data. The results are displayed in Table 5.20.

Table 5.20: Total TSS calculated vs. measured values

	Raw wastewater			**PS**			**WAS**		
BTG	**TSS meas. (g/l)**	**TSS calc. (g/l)**	**%(calc - meas.) / calc.**	**TSS meas. (g/l)**	**TSS calc. (g/l)**	**%(calc - meas.) / calc.**	**TSS meas. (g/l)**	**TSS calc. (g/l)**	**%(calc - meas.) / calc.**
2	1.50	1.30	15.6	8.01	8.45	-5.5	2.47	2.45	0.8
3	1.00	0.953	5.1	31.6	28.6	9.6	2.83	2.81	0.7
4	2.43	2.02	16.8	65.6	61.7	5.9	3.17	3.25	-2.4
5	3.78	3.37	11.0	53.0	51.1	3.7	3.17	3.25	-2.4
6	2.52	2.35	6.6	15.0	14.0	6.9	2.20	2.04	6.6

The % discrepancies between measured and calculated TSS values ranged from 5.1 - 16.8 % for raw wastewater, 3.7 - 9.6 % for PS and 0.7 - 6.6 % for WAS. Note that an adjustment of %H to calculated values renders the difference in measured and calculated TSS values 0 %. Thus the % differences between measured and calculated values below are an indication of the discrepancies between U.C.T. laboratory data and elemental analysis data. It also important to notice that the data discrepancies for the WAS values were the lowest and that the compositions calculated for the total WAS organics showed the highest precision across different methods of calculation.

5.7.2. Procedural error

Batch test configuration:

Gas leakage indicated that the batch test configuration was not adequate. Hoses and gas bags were gas impermeable. It is likely that gas leakage occurred in the connections between batch tests, hoses and gas bags. Gas leakage influenced COD and Carbon mass balances over batch test.

Batch test sludge preparation:

The use of AlumSulphate as a flocculent for the preparation of raw wastewater flocculated sludge seemingly inhibited AD biological digestion processes. Processes required a very long standing time (> 127 days) to reach complete substrate biodegradation. Iron (III) Chloride was employed as a flocculent in BTG 6. Complete substrate biodegradation was considered to have occurred at batch test termination after 117 days. Therefore, Iron (III) Chloride is a better option for flocculation of wastewater for the purpose of anaerobic digestion.

Batch test timeframe and estimation of stage of completion:

Estimation of completion of complete substrate biodegradation was mainly based on batch test standing time. Other indicators such as residual COD and VSS were also employed. The lack of literature on the determination of organics compositions of the form $C_xH_yO_zN_a$ has resulted in the use of such indicators. The possibility that batch tests deemed to have reached complete substrate biodegradation still contained biodegradable material cannot be overlooked. Such a procedural error would have a major impact on organics compositions calculations since the assumption that the residual material in the batch test is unbiodegradable would be incorrect.

Data collection procedures:

COD, Nitrogen, Phosphorus and Solids data were collected according to the guidelines set out in Standard Methods (1985). Samples were tested twice in all cases to ascertain the accuracy of the test results. Good COD batch test mass balances (95 % - 105 %) were achieved in 5 out of 15 batch tests. The cases where good mass balances were not achieved were ascribed to gas losses. Good nitrogen and phosphorus mass balances were achieved in all cases. This validates the nitrogen and phosphorus testing procedures.

Sludge at batch test setup and termination was harvested and dried for elemental analysis testing. Although batch test sludge was thoroughly mixed before sampling; unrepresentative samples may have been taken due to the non-homogenous nature of sludge. Good carbon balances over batch tests could have validated the elemental analysis results; however gas losses rendered this impossible in most cases. Therefore, sludge sampling was a possible source of data error.

Data capturing and analysis procedures:

Incorrect data capturing and/or analysis procedures were minimised by through data checking, hand calculation and batch test mass balances.

5.8. MAIN FINDINGS

The main findings of this investigation were as follows:

Batch test experimental procedure:

1. AD batch tests require darkness, inoculation, buffering and heating to decrease the incubation time period required for complete substrate biodegradation.
2. Very long AD incubation times are required (>> 60 days) for complete substrate biodegradation. This renders two disadvantages, viz. (1) data accuracy at batch test setup may only be determined with batch test mass balances at batch test termination and (2) lengthy experimental time requirements.
3. The use of AlumSulphate as a flocculent seemingly inhibits AD biodegradation processes. Iron(III)Chloride is a preferred option.
4. COD and carbon batch test mass balances (95 % - 105 %) were achieved for only 33 % of batch tests. Gas losses accounted for the inability to achieve mass balances for the remaining batch tests. The achievement of good mass balances for some batch tests validated the COD, carbon and gas collection as well as calculation procedures.

Particulate composition calculation methods:

1. The results determined with method 4 showed the greatest sensitivity to data error. A + 10 % change in COD data resulted in a change in the calculated z value of 33 % - 104 %. A + 10 % change in TSS and %C data resulted in a change in the calculated z value of > 30 % in all cases.
2. All methods were highly sensitive to error in COD data. Percentage increases in the z composition value due to a 10 % increase in COD data ranged from 13 % to 104 %. This indicates that COD error that is acceptable in normal wastewater testing and modelling applications may not be acceptable for the determination of organics compositions with the methods used in this investigation.
3. All methods were sensitive to error in TSS data. Percentage increases in the z composition value due to a 10 % increase in TSS data were > 10 % in most cases. It is difficult to accurate measure TSS to the degree required in normal wastewater laboratories due to the use of particulate material (may be unrepresentative) and the difficulty in accurately determining ISS mass accurately with the use of crucibles.
4. Method 1 was highly sensitive to error in %C measurements with a % change in x values > 40 % in all cases with a concomitant % change in %C data of + 10 %. It was also found to be sensitive to VSS data (> 10 % change in all cases).

Soluble composition calculation methods:

1. The initial assumption that a y/z = 7/2 ratio may be used in soluble organics compositions calculations was discredited. Sensitivity analyses showed that soluble organics composition values x and a calculated on the basis of this assumption were sensitive to change in the z value. Therefore, the z value needs to be accurately determined.
2. A COD/VDS ratio may be substituted for the fcv value used in method 1 for particulate organics compositions calculations and soluble organics compositions may thereby be calculated. The VDS value needs to be accurately determined. However, the calculation of x, z and a values with this method are not sensitive to the VDS value and it is possible that the required accuracy for its determination may be achieved in normal wastewater laboratories.

Organics compositions results:

1. The calculation of particulate organics compositions with four different methods yielded highly variable results for raw wastewater and PS total and unbiodegradable organics as well as for WAS unbiodegradable organics. This indicated that data accuracy was not high enough to yield valid particulate organics compositions results. The total WAS particulate organics compositions correlated well across methods and BTG's. The average WAS composition was determined to be $C_{4.05}H_7O_{2.13}N_{0.5}$. This differs from the standard WAS accepted composition of $C_5H_7O_2N_1$.
2. Soluble organics determined based on the assumption that y/z = 7/2 were not validated.

Batch test method validation:

The batch test method evaluation was based on the fulfilment of the research objectives, viz. the determination of (1) raw wastewater, PS and WAS unbiodegradable and biodegradable organic fractions, (2) settled wastewater colloidal unbiodegradable and biodegradable fractions and (3) organics compositions for raw wastewater, settled wastewater, PS and WAS. Thus, the validity of the batch test method was evaluated according to the fulfilment of the research objectives. The first objective was deemed to have been fulfilled on the basis of very long batch test incubation times and residual COD and VSS indicators sourced from literature. However, the inability to validate soluble and particulate organics compositions results has indicated that, although raw wastewater, PS and WAS unbiodegradable and biodegradable organic fractions could be determined with the batch test method, these fractions were not of the required accuracy to fulfil the second and third research objectives. Therefore, the batch test method designed in Chapter 4 and evaluated in Chapter 5, is not sufficiently accurate for the determination of readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate organics compositions at links between unit operations over a WWTP.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1. INTRODUCTION

The aims of this project comprised the investigation of current integrated plant wide WWTP modelling approaches and the design and evaluation of a batch test method to determine organic compound elemental compositions required in such models. The topic was chosen in response to a recent shift from effluent quality based WWTP modelling to integrated plant wide WWTP modelling.

Current WWTP unit operation sub-models are difficult to couple into plant wide models. This is mainly due to differences in type and number of state variables (or compounds) in different unit operation models. A general theme towards overcoming this problem of incompatible state variables is to express the organic compounds (state variables) in elemental composition form , viz. x, y, z, a, and b in $C_xH_yO_zN_aP_b$. The determination of organics compositions in this form requires elemental data, inter alia, carbon data, which is not commonly measured at WWTPs. Case studies used to elaborate on current modelling approaches link unit operation sub-models have used assumed composition data for the different organics. The experimental part of this project therefore comprised the design and evaluation of a simple batch test method for the determination of organics compositions at relevant links over a WWTP.

6.2. INTEGRATED WHOLE WWTP SIMULATION MODELS

A number of approaches towards the development of whole WWTP simulation models have been proposed. These include the continuity based interfacing method (CBIM) of Vanrolleghem et al. (2005) and Volcke et al. (2006); the 'supermodel' approach of Jones and Tákacs (2004) and Seco et al. (2004), both cited in Grau et al. (2007), and the transformation based approach of Grau et al. (2007), which is a combination of the CBIM and supermodel approaches. All three of these approaches leave the original unit operations sub-models unchanged and are aimed at circumventing the model interfacing difficulties caused by state variable incompatibilities. There is a fourth approach of Ekama et al (2006 a,b), Wentzel et al. (2006) and Sötemann et al. (2006) , which is similar to the three above in that it also uses compound elemental composition, but different because the problems of state variable incompatibility does not arise because it uses a different AD feed characterization structure one that is more aligned with that used in activated sludge models.

The CBIM approach of Vanrolleghem et al. (2005) and Volcke et al. (2006) is focussed on the creation of model interfaces between unit process sub-models. These model interfaces use a Petersen matrix to transform the compounds of the source model into the type and number of compounds in the destination model, leaving the individual sub-models unchanged. A disadvantage of this approach is that it leaves a large degree of freedom to the user regarding the definition of the transformation matrices used in this method. Volcke et al (2006) have proposed that such definitions are performed based on process knowledge and insight by the user of the method. As a consequence, this may result in different solutions to similar WWTP simulation problems solved by different users. Thus, although the activated sludge and anaerobic digestion models have been developed to provide a common framework and language to compare and transfer models, it diverts from this by allowing a large degree of choice to the user.

In contrast to the CBIM approach, the 'supermodel' approach of Jones and Tákacs (2004) and Seco et al. (2004) suggest that a plant wide WWTP model integrates all components of all the unit operations in a WWTP. Thus in some unit operation all there will be state variables (compounds) that are not required in a particular sub-model. This approach will therefore produce in very large WWTP models that are difficult to solve and require significant restructuring to add the additional components from the other sub-models. In each WWTP this may be different depending on the sub-models being linked. This is a major task not easily accomplished by inexperienced users (the majority) and current unit-operation sub-models such as Activated Sludge Model No 1 (ASM1) and Anaerobic Digestion Model No 1 (ADM1) are good representations of reality and thus careful consideration must be given towards changing them. The same applies to the transformation approach of Grau et al. (2007), except that it reduces the number of compounds (state variables) in the WWTP by transforming some of them. It is therefore a compromise approach between the CBIM and supermodel approaches.

The approach developed of Wentzel et a. (2006), Ekama et al. (2006 a,b) and Sötemann et al. (2006) is not for simulation models but steady state models - it is a simplification of the supermodel approach for steady state conditions. This allowed several assumptions to be made, inter alia, complete utilization of biodegradable organics in the AS system, which eliminated the need to transform the compounds of the AS system to those of the AD system. They took the view that if one is going to "invent" carbon fluxes at the AD to model the AD, one may as well create carbon fluxes at the WWTP influent and track the carbon throughout the WWTP including the AD. For this purpose Brink et al. (2007) developed bioprocess stoichiometry for all the WWTP bioprocesses such as organics removal by activated sludge under aerobic and anoxic conditions (for denitrification), nitrification and anoxic aerobic digestion of primary or waste activated sludges. This bioprocess stoichiometry, together with that developed for the AD model by Sötemann et al (2005) allows tracking of the C, H, O, N and COD around the WWTP and determine how much of these elements exit the various unit operations in gaseous, dissolved and solid forms (Brink et al., 2007). They suggested that plant wide WWTP simulation models should include such steady state models as simulation preprocessors to assist with unit operation and inter-connecting flow sizing and initial reactor concentration calculation before simulation. The stoichiometry developed is general and could be included in simulation models.

The C, H, O, N and COD mass balance bioprocess stoichiometry was linked to the existing COD mass balance steady state AS and AD models and applied to various linked unit operations making up different WWTP layouts, all under steady state conditions. To use this plant wide WWTP model structure, the C, H, O, N and COD composition of the different influent wastewater organic groups need to be known, i.e. the x, y, z, and a values in $C_xH_yO_zN_a$ defining the composition of the unbiodegradable particulate (UPO), unbiodegradable soluble organics (USO), biodegradable particulate organics (BPO) and biodegradable soluble organics (BSO), the last subdivided into fermentable biodegradable soluble organics (F-BSO) and volatile fatty acids (VFA) represented by acetic acid, the composition of which of course is known. Like Volcke et al. (2006), Brink et al. (2007) also assumed some composition values from previous experience with municipal wastewater and activated sludge systems.

A very important question that needed to be answered when linking AS and AD models, whether at steady state model level or dynamic simulation model level, is whether or not unbiodegradable organics from the influent and that endogenous generated, as defined by the "aerobic" activated sludge system, remain unbiodegradable in the AD. In all plant wide models developed, it was simply assumed that unbiodegradable organics in the AS system are also unbiodegradable in the AD. To check whether or not this assumption is valid (and also addressing various other questions such as the continuity of the inorganic suspended solids (ISS) around the WWTP), Wentzel et al. (2006), Ekama et al. (2006a,b) and Sötemann et al. (2006) undertook a plant wide modelling study using their own and literature data. They found that influent unbiodegradable organics and unbiodegradable organics generated by the biomass via the endogenous process appeared to remain unbiodegradable under anaerobic digestion conditions.

All the approaches above require the definition of the composition of the state-variables (compounds) in relative molar composition (the x, y, z, and a values in $C_xH_yO_zN_a$ as per Brink et al (2007) or elemental mass fractions (g element / g compound) as per Volcke et al. (2006). These two definitions can be shown to be linearly related. Case studies performed with the CBIM approach by Volcke et al. (2006) and Zaher et al. (2007) relied on assumed values for the determination of elemental mass fractions for organic compounds (readily biodegradable, slowly biodegradable, unbiodegradable soluble, unbiodegradable particulate, organisms and endogenous residue). Similarly, Brink et al. (2007) also assumed x, y, z and a values for the different wastewater organics and activated sludge biomass. No suggestions for experimental determination of the composition or the various organics was provided in the case studiers. The requirement of organic compound compositions in the suggested approaches towards integrated whole WWTP modelling has prompted the development and evaluation of a simple batch test method for such determinations.

6.3. EVALUATION OF A BATCH TEST METHOD FOR ORGANICS COMPOSITIONS DETERMINATION

Batch test experimental procedure:

- The experimental procedure was not completely designed at the outset of the project due to a lack of literature information to use as a design basis. Therefore the procedure was iterative in nature to enable procedural corrections based on experience.

- An initial batch test incubation period of > 60 days was considered sufficient based on literature produced by Mahmoud et al. (2004). Poor performance of batch tests with incubation times around 60 days resulted in the lengthening of incubation times to > 117 days. Flocculated raw wastewater sludge batch tests were allowed very long incubation times (169 days) due to a seeming interference of the flocculent (AlumSulphate) with the biodegradation processes. Iron(III)Chloride was used as a flocculent when this inhibition was discovered with preferable results. Disadvantages inherent in long incubation times include (1) difficulty in the determination of data accuracy at batch test setup since batch test mass balances are performed months later and (2) lengthy experimental time requirements.

- Gas losses accounted for an inability to obtain good COD and carbon batch test mass balances (95 % - 105 %) for the majority of batch tests. The batch test apparatus was thus considered to be faulty. The achievement of good mass balances for some batch tests validated the COD, carbon and gas collection as well as calculation procedures.

Particulate organics elemental composition calculation methods:

- Four different calculation methods that rely on different data sets were used to calculate particulate total and unbiodegradable organics compositions from measured data. These calculations were performed in an attempt to validate data and experimental procedure since, in the absence of data error, the methods should yield the same results for a specific wastewater sample. All results across batch test groups and wastewater types were significantly different. This indicated significant data error (see next point).

- Batch test mass balances were considered to be acceptable (95 % - 105 %) for a third of COD and C balances, and for all nitrogen (N) and phosphorus (P) balances. Gas losses accounted for the discrepancies in COD and C balances. Acceptable N and P mass balances indicated acceptable experimental error, including sample dilution error, for all tests. The test data was therefore initially accepted to be of acceptable accuracy from a normal modelling point of view. However, the large discrepancies in organics compositions results indicate that data accuracy falling within 95% - 105% mass balances may not be acceptable for the determination of organics compositions. Data sensitivity analyses gave support to this notion.

- The sensitivity of elemental compositions results to input data was analysed. All methods used for particulate organics elemental compositions calculations were found to be highly sensitive to error in COD data. Percentage increases in the oxygen subscript (z) due to a + 10 % increase in COD data ranged from 13 % to 104 %. Similarly a + 10 % increase in TSS data resulted in a > 10 % increase in the oxygen subscript (z) in most cases. Some methods were found to be more sensitive to certain data types than others, e.g. Method 1 was found to be highly sensitive to error in %C measurements with a % change in the carbon subscript (x) values > 40 % in all cases for a + 10 % change in %C data. Compositions results were insensitive to nitrogen data for all methods. It was therefore concluded that the determination of organics elemental compositions via indirect measurement and calculation methods are unlikely to yield accurate results due to the high sensitivities of the results to data error. Therefore, direct measurement of %C, %H, %O, %N and %P (% of dry solids mass) with elemental analysis is likely to yield results of higher accuracy. It was impossible to measure these components directly with the method investigated in this thesis due to the high dry mass requirements for oxygen measurement (> 10 g per sample). This requirement therefore renders the batch test method impractical for organics compound elemental compositions determinations.

Soluble composition calculation methods:

- The initial assumption that a hydrogen to oxygen subscript (y/z) = 7/2 ratio may be used in soluble organics compositions calculations was discredited. The assumption was initially made due to a lack of literature data availability and was proven to be baseless. Sensitivity analyses showed that soluble organics carbon and nitrogen subscripts (x and a respectively) calculated on the basis of this assumption were sensitive to change in the oxygen subscript (z) value. Therefore, the z value needs to be accurately determined for the accurate determination of the x and a subscripts and assumptions regarding the y/z ratio may not be made.

- Further analysis indicated that Method 1, used for the calculation of particulate organics compositions, may be modified and used for the determination of soluble organic compound elemental compositions. A soluble COD to Volatile Dissolved Solids (VDS) ratio (COD/VDS) may be substituted for the fcv value used in Method 1. Sensitivity analyses have indicated that the calculation of Carbon, Oxygen and Nitrogen subscript values (x, z and a respectively) are insensitive to change in VDS data. It is thus possible that the VDS value may be determined to the required accuracy in normal wastewater laboratories with the method described by Ubisi (1997). This requires further investigation.

Organics compositions results:

- The calculation of particulate organics compositions with four different methods yielded highly variable results for raw wastewater and PS total and unbiodegradable organics as well as for

WAS unbiodegradable organics. This indicated that data accuracy was not high enough to yield valid particulate organics compositions results.

- The total WAS particulate organics compositions correlated well across methods and BTG's. The average total WAS composition was determined to be $C_{4.05}H_7O_{2.13}N_{0.5}$. This differs from the standard WAS accepted composition of $C_5H_7O_2N_1$.

Batch test method validation:

- The batch test method evaluation was based on the fulfilment of the research objectives, viz. the determination of (1) raw wastewater, PS and WAS unbiodegradable and biodegradable organic fractions, (2) settled wastewater colloidal unbiodegradable and biodegradable fractions and (3) organics compositions for raw wastewater, settled wastewater, PS and WAS. The first objective was deemed to have been fulfilled on the basis of very long batch test incubation times and residual COD and VSS indicators sourced from literature. However, the inability to validate soluble and particulate organics compositions results has indicated that, although raw wastewater, PS and WAS unbiodegradable and biodegradable organic fractions could be determined with the batch test method, these fractions were not of the required accuracy to fulfil the second and third research objectives. Therefore, the batch test method designed in Chapter 4 and evaluated in Chapter 5, is not valid for the determination of readily biodegradable, slowly biodegradable, unbiodegradable soluble and unbiodegradable particulate organics compositions at links between unit operations over a WWTP.

6.4. RECOMMENDATIONS FOR FURTHER STUDY

The following recommendations are made:

1. The methanogenic batch test method evaluated in this project was considered to yield unreliable results. Different options for the determination of organic compound compositions over a WWTP include: (1) direct measurement of elemental mass fractions including oxygen and (2) the use of sulphidogenic AD batch tests.
    - The direct measurement of organic compound particulate elemental compositions can be used to avoid accumulative error in indirect measurement and calculations. Relatively large dry sample masses (> 10g) are required for this and long sludge age reactors may therefore be employed to produce large sample quantities. Direct particulate organics elemental %C, %H, %O, %N and %P measurements can be made on raw wastewater (flocculated), primary sludge and waste activated sludge (unbiodegradable organics compositions). Settled wastewater components may be calculated through mass balances over the primary settling tank.
    - The use of sulphidogenic AD batch tests may yield acceptable results because sewage biodegradable organics are carbon deficient for biological sulphate reduction in that they can donate more electrons than supply carbon for the alkalinity generated. In such systems, there is no H_2S and CO_2 gas generation so the C in the biodegradable organics utilized can be measured in the $H_2CO_3^*$ alkalinity generated.

2. It is possible that a different approach to this thesis may have been effected with the use of data reconciliation methods. The possibility exists that data reconciliation may have been used to produce results with higher accuracy from measured data. Measured data containing gross error may have been identified and eliminated and therefore the possibility remains that data sets with the necessary accuracy for organics compositions determinations may have been

determined.This may, therefore, have enabled the possibility of validating the batch test method evaluated in this thesis. It must be noted, however, that this would have increased the complexity of the compostions determination method and would therefore have negated the evaluation of a *simple* batch test method. Therefore, it is proposed that the data collected for this project be re-analysed with data reconciliation methodology, if a further attempt to validate the methanogenic batch test method is deemed to be of possible value.

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A-1 BATCH TEST TIME FRAME

Table A.1: Batch test timeframe

BTG	Contents	Setup date	Termination date	Incubation period (days)	Incubation temperature (°C)
1	Flocculated raw wastewater	20/08/2006	28/10/2006	69	22
	Primary sludge	20/08/2006	28/10/2006	69	22
	Waste activated sludge	20/08/2006	28/10/2006	69	22
2	Flocculated raw wastewater	13/11/2006	14/01/2007	62	35
	Primary sludge	13/11/2006	14/01/2007	62	35
	Waste activated sludge	13/11/2006	14/01/2007	62	35
3	Flocculated raw wastewater	13/11/2006	14/01/2007	62	22
	Primary sludge	13/11/2006	14/01/2007	62	22
	Waste activated sludge	13/11/2006	14/01/2007	62	22
4	Flocculated raw wastewater	21/01/2007	09/07/2007	169	35
	Primary sludge	21/01/2007	28/05/2007	127	35
	Waste activated sludge	21/01/2007	28/05/2007	127	35
5	Flocculated raw wastewater	21/01/2007	28/05/2007	169	35
	Primary sludge	21/01/2007	09/07/2007	127	35
	Waste activated sludge	21/01/2007	28/05/2007	127	35
6	Flocculated raw wastewater	14/03/2007	09/07/2007	117	35
	Primary sludge	14/03/2007	09/07/2007	117	35
	Waste activated sludge	14/03/2007	09/07/2007	117	35

A-2 INSTRUMENTATION

Table A.2: Measuring equipment

Equipment type	Unit of measurement
Graduated cylinders	
5	ml
10	ml
50	ml
100	ml
1000	ml
Volumetric flasks	
100	ml
200	ml
Pipettes	
5	ml
10	ml
20	ml
25	ml
50	ml
100	ml
Automatic pipettes	ml
Ritter drum type gas flow meter	ml
Scale	g
Thermometer	°C

Apparatus:

2 L Erlenmeyer flask

Afrox gas hose
Gas impermeable bag
Pipe clamps
Marine silicone gel
Heated water bath

B-1. BATCH TEST MASS BALANCES: THEORY

B1.1. Batch test COD,N, P and C masses at batch test setup

B1.1.1. Flocculated raw wastewater sludge (Flocculated sludge, FS) batch tests

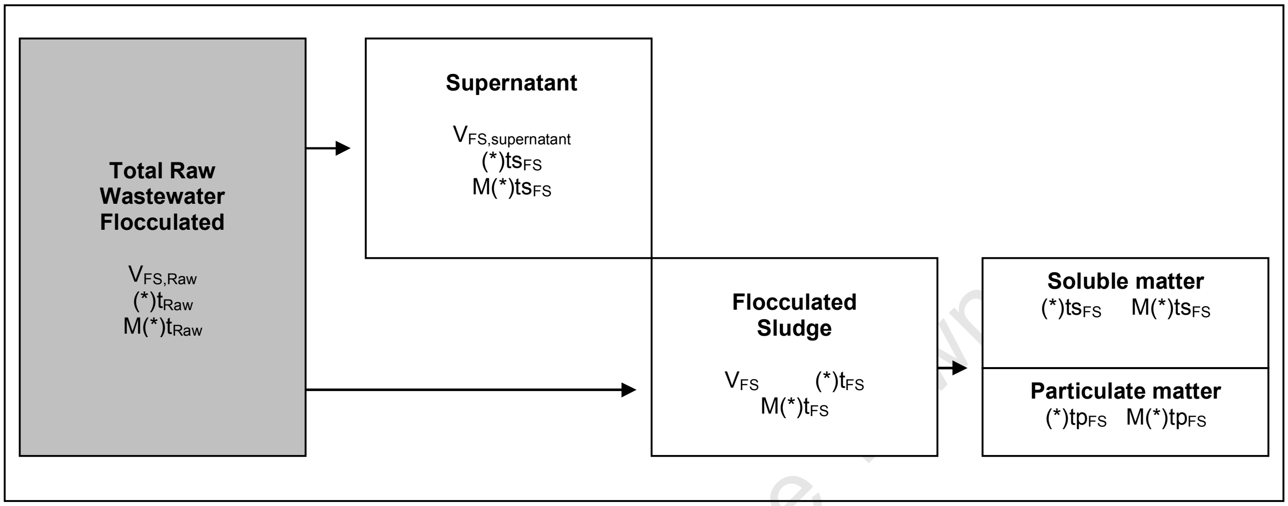


Fig. B1-1: Diagrammatic representation of flocculated raw wastewater batch test data sources at batch test setup

Table B1-1: Mass balances flocculated raw wastewater batch test COD, N and P calculations and sources

Variable	Term	Source
Volumes (L):		
1. Flocculated sludge raw wastewater volume	- $V_{FS,Raw}$	- Total raw wastewater volume flocculated (measured)
2. Flocculated sludge supernatant volume	- $V_{FS,supernatant}$	- Total volume of supernatant removed after raw wastewater flocculation (measured)
Concentrations (mg/l):		
1. Total raw wastewater COD, N of P concentration	- St_{Raw}, Nt_{Raw}, Pt_{Raw}	- Measured in raw wastewater
2. Dissolved raw wastewater COD, N or P concentration	- Sts_{Raw}, Nts_{Raw}, Pts_{Raw}	- Measured in flocculated sludge supernatant (FS supernatant) - 0.45 µm membrane filtered
Masses (mg): Total batch test COD, N or P mass	$MSt_{FS,BT}$, $MNt_{FS,BT}$, $MPt_{FS,BT}$	$M(*)t_{FS,BT} = (*)t_{Raw} \times V_{FS,Raw} - (*)ts_{Raw} \times V_{FS,supernatant}$

* Relevant parameter i.e. COD, N or P

Table B1-2: Mass balances flocculated raw wastewater batch test carbon calculations and sources

Variable	Term	Source
Volumes (L):		
1. Flocculated sludge volume	- V_{FS}	- Volume of sludge after removal of supernatant during flocculation
2. Flocculated sludge batch test final volume	- $V_{FS,BT}$	- Volume of sludge in batch test before sampling
Elemental analysis results: Percentage carbon per unit particulate compound (total solids) mass	$\%C_{FS,BT}$	Direct measurement in batch test particulate contents with elemental analysis
Concentrations (mg/l):		
1. Total batch test solids concentration	- $Xt_{FS,BT}$	- Direct measurement in batch test contents at setup
2. Dissolved raw wastewater and undiluted batch test DOC concentration	- Cts_{Raw}	- Measured in flocculated sludge supernatant (FS supernatant) - 0.45 µm membrane filtered
3. Diluted batch test dissolved organic carbon	- $Cts_{FS,BT}$	- $Cts_{FS,BT} = Cts_{Raw} \times V_{FS} / V_{FS,BT}$
Masses (mg):		
1. Total batch test solids mass	- $MXt_{FS,BT}$	- $MXt_{FS,BT} = Xt_{FS,BT} \times V_{FS,BT}$
2. Total batch test C mass	- $MCt_{FS,BT}$	- $MCt_{FS} = \%C_{FS,BT} / 100 \times MXt_{FS,BT} + Cts_{FS,BT} \times V_{FS,BT}$

B1.1.2. Primary sludge (PS) batch tests

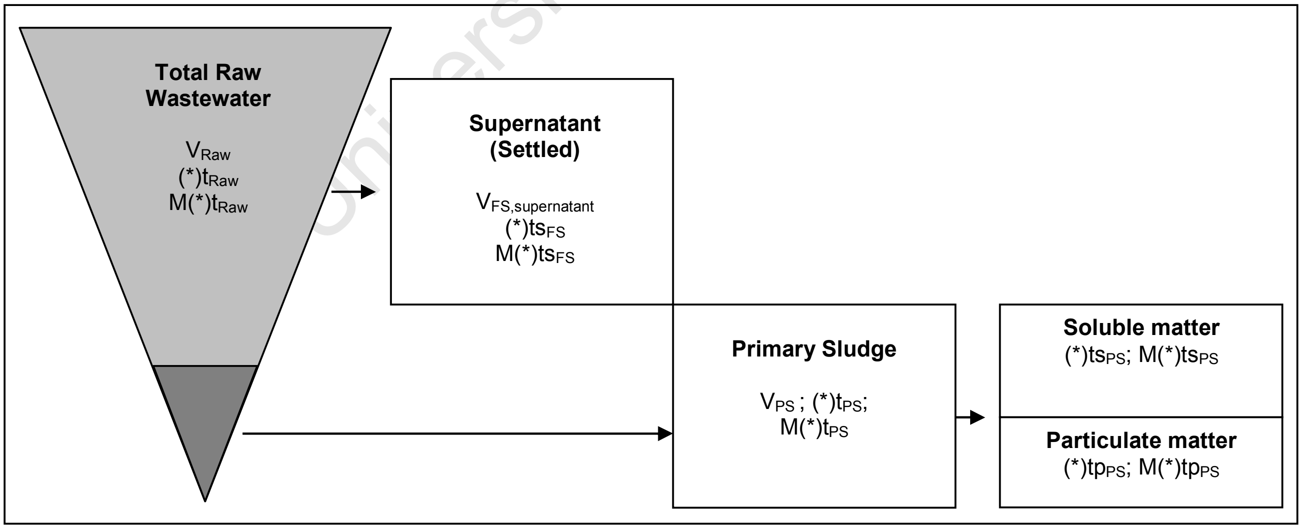


Fig. B1-2: Diagrammatic representation of primary sludge data sources at batch test setup

Table B1-3: Mass balances primary sludge COD, N and P calculations and sources

Variable	Term	Source
Volumes (L):		
1. Raw wastewater volume	- V_{Raw}	- Total raw wastewater volume settled (direct measurement)
2. Primary sludge volume	-V_{PS}	- Total primary sludge volume settled (direct measurement)
3. Settled wastewater volume	- $V_{Settled}$	- Total settled wastewater volume = V_{Raw} - V_{PS}
Concentrations (mg/l):		
1. Total raw wastewater COD, N or P	- St_{Raw}, Nt_{Raw}, Pt_{Raw}	- Direct measurement in raw wastewater with COD, TKN or TP test
2. Total settled wastewater COD, N or P	- $St_{Settled}$, $Nt_{Settled}$, $Pt_{Settled}$	- Direct measurement in settled wastewater with COD, TKN or TP test
3. Total primary sludge COD, N of P	- St_{PS}, Nt_{PS}, Pt_{PS}	- $(*)t_{PS} = [\ (*)t_{Raw} \times V_{Raw} - (*)t_{Settled} \times V_{Settled}\ ] / V_{PS}$
Masses (mg):		
Total batch test COD, N or P mass	$MSt_{PS,\ BT}$, $MNt_{PS,\ BT}$, $MPt_{PS,\ BT}$	$M(*)t_{PS,\ at\ setup} = (*)t_{PS} \times V_{PS}$

* Relevant parameter i.e. COD, N or P

Table B1-4: Mass balances primary sludge batch test carbon calculations and sources

Variable	Term	Source
Volumes (L):		
1. Primary sludge batch test final volume	- $V_{PS,BT}$	- Volume of sludge in batch test before sampling
2. Primary sludge undiluted volume	- V_{PS}	- Volume of sludge settled out from raw wastewater (direct measurement)
Elemental analysis results: Percentage carbon per unit particulate compound (total solids) mass	$\%C_{PS,BT}$	Direct measurement in batch test particulate contents with elemental analysis
Concentrations (mg/l):		
1. Total batch test solids concentration	- $Xt_{PS,BT}$	- Direct measurement in batch test contents at setup
2. Total primary sludge solids concentration	- Xt_{PS}	- $Xt_{PS} = Xt_{PS,BT} \times V_{PS,BT} / V_{PS}$
3. Dissolved C concentration	- Cts_{PS}	- Measured in flocculated sludge supernatant (FS supernatant) - 0.45 μm membrane filtered
Masses (mg):		
1. Total batch test solids mass	- MXt_{PS}	- $MXt_{PS} = Xt_{PS} \times V_{PS}$
2. Total batch test C mass	- $MCt_{PS,BT}$	$MCt_{PS} = \%C_{PS} / 100 \times MXt_{PS} + Cts_{PS,BT} \times V_{PS,BT}$

B1.1.3. Waste activated sludge (WAS) batch tests

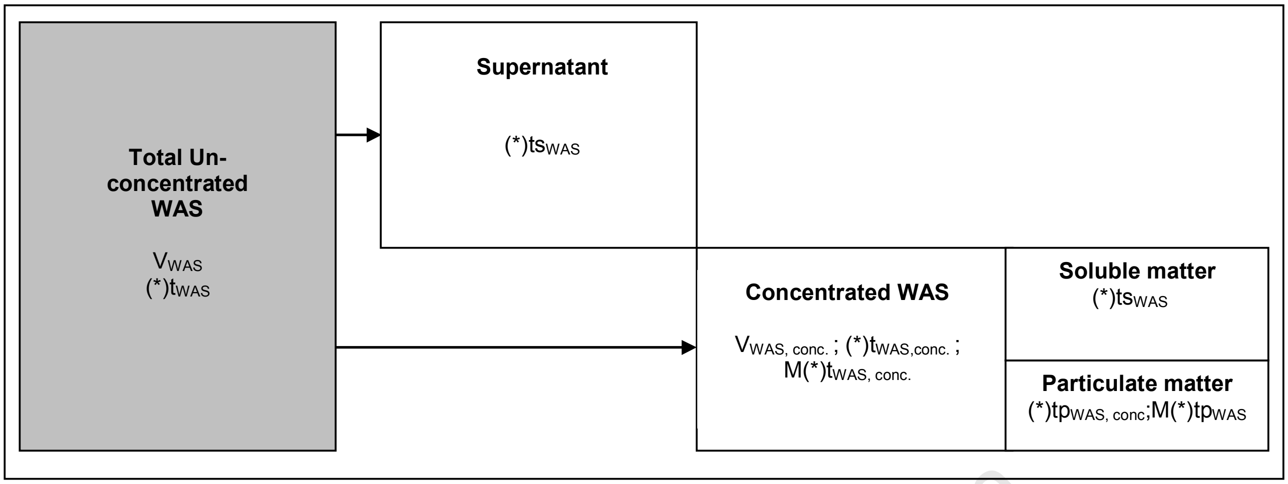


Fig. B1-3: Diagrammatic representation of WAS data sources at batch test setup

<u>Table B1-5:</u> Mass balances waste activated sludge batch tests COD, N and P calculations and sources

Variable	Term	Source
Volumes (L):		
1. Un-concentrated WAS	- V_{WAS}	- Total un-concentrated waste activated sludge volume (direct measurement)
2. Concentrated WAS	-$V_{WAS, conc.}$	- Total concentrated waste activated sludge volume (direct measurement)
Concentrations (mg/l):		
1. Total un-concentrated COD, N or P	- St_{WAS}, Nt_{WAS}, Pt_{WAS}	- Direct measurement in U.C.T. MLE system waste activated sludge with COD, TKN or TP test
2. Total soluble COD, N or P	- Sts_{WAS}, Nts_{WAS}, Pts_{WAS}	- Direct measurement in U.C.T. MLE system effluent with COD, TKN or TP test - 0.45 µm filtered samples
3. Total particulate COD, N or P	- Stp_{WAS}, Ntp_{WAS}, Ptp_{WAS}	- $(*)tp_{WAS} = (*)t_{WAS} - (*)ts_{WAS}$
4. Total concentrated waste activated sludge COD, N or P	- $St_{WAS, conc.}$, $Nt_{WAS, conc.}$, $Pt_{WAS, conc.}$	- $(*)t_{WAS, conc.} = (*)tp_{WAS} \times V_{WAS} / V_{WAS, conc.} + (*)ts_{WAS}$
Masses (mg):		
Total batch test COD, N or P mass	- $MSt_{WAS, BT}$, $MNt_{WAS, BT}$, $MPt_{WAS, BT}$	- $M(*)t_{WAS, BT} = (*)t_{WAS, conc.} \times V_{WAS, conc.}$

* Relevant parameter i.e. COD, N or P

Table B1-6: Mass balances waste activated sludge batch test carbon calculations and sources

Variable	Term	Source
Volumes (L): 1. WAS batch test final volume 2. WAS concentrated volume	- $V_{WAS,BT}$ - $V_{WAS,conc.}$	- Volume of sludge in batch test before sampling - Concentrated WAS volume after removal of supernatant (direct measurement)
Elemental analysis results: Percentage carbon per unit particulate compound (total solids) mass	$\%C_{WAS,BT}$	Direct measurement in batch test particulate contents with elemental analysis
Concentrations (mg/l): 1. Total batch test solids concentration 2. Undiluted dissolved C concentration 3. Diluted dissolved C concentration	- $Xt_{WAS,BT}$ - Cts_{WAS} - $Cts_{WAS,BT}$	- Direct measurement in batch test contents at setup - Measured in M.L.E. system effluent - 0.45 µm membrane filtered - $Cts_{WAS,BT} = Cts_{WAS} \times V_{WAS,conc.} / V_{WAS,BT}$
Masses (mg): 1. Total batch test solids mass 2. Total batch test C mass	- MXt_{WAS} - $MCt_{WAS,BT}$	- $MXt_{WAS} = Xt_{WAS} \times V_{WAS}$ - $MCt_{WAS} = \%C_{WAS} / 100 \times MXt_{WAS} + Cts_{WAS,BT} \times V_{WAS,BT}$

B1.2. Batch test COD,N, P and C masses at batch test termination

Data at batch test termination were edited in an identical fashion for all batch tests.

Table B1-7: Mass balances COD, N and P calculations and sources at batch test termination

Variable	Term	Source
Volumes (L): Diluted batch test volume	V_{BT}	Final batch test volume after addition of buffer and innoculant
Concentrations (mg/l): Total diluted batch test COD, N or P concentration at termination	St_{BT}, Nt_{BT}, Pt_{BT}	Direct measurement in batch test contents at batch test termination with COD, TKN or TP test
Masses (mg): Total batch test COD, N or P mass	$MSt_{BT.}$, MNt_{BT}, MPt_{BT}	$M(*)t_{BT} = (*)t_{BT} \times V_{BT}$

* Relevant parameter i.e. COD, N, or P

Table B1-8: Mass balances carbon calculations and sources at batch test termination

Variable	Term	Source
Volumes (L): Batch test final volume	V_{BT}	Volume of sludge in batch test after addition of buffer, distilled water and innoculant
Elemental analysis results: Percentage carbon per unit particulate compound (total solids) mass	$\%C_{BT}$	Direct measurement in batch test particulate contents with elemental analysis
Concentrations (mg/l): 1. Total batch test solids concentration 2. Dissolved batch test DOC concentration	- Xt_{BT} - Cts_{BT}	- Direct measurement with TSS, VSS, ISS test - Direct DOC measurement - 0.45 µm membrane filtered samples
Masses (mg): 1. Total batch test solids mass 2. Total batch test C mass	- MXt_{BT} - MCt_{BT}	- $MXt_{BT.} = Xt_{BT} \times V_{BT}$ - $MCt_{BT} = \%C_{BT} \times MXt_{BT} + Cts_{BT} \times V_{BT}$

Table B1-9: Mass balances gaseous COD and Carbon calculations and sources at batch test termination

Parameter	Term	Source
Volumes (L): 1. Volume of methane gas produced 2. Volume of carbon dioxide gas produced	- V_{CH4} - V_{CO2}	- Direct measurement with Ritter drum type gas flow meter - Direct measurement with Ritter drum type gas flow meter
Laboratory conditions: 1. Atmospheric pressure 2. Universal gas constant 3. Laboratory temperature	- P - R - T	- Assumed 1 atm. - 0.0821 atm.L/mol.K - 22 degC = 295.15 K
Masses (mole): Total gas produced	- n	- n = PV / RT
Masses (mg): 1. Total COD in methane gas 2. Total C in methane and CO2 gas	- MSm - $MC_{CH4;CO2}$	- $MSm = n_{CH4} \times 64$ gCOD/gmethane - $MC_{CH4,CO2} = (n_{CH4} + n_{CO2}) \times 12.01$ g C/mol

B2.1. CALCULATIONS: BTG 2

Note: See laboratory data - Appendix C.1.

B2.1.1. Flocculated raw wastewater (Flocculated Sludge, FS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	10.00
FS supernatant	VFS,Supern.	8.610
FS volume	VFS	1.390
Diluted batch test volume	VFS,BT	1.580

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	23.91

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1151	135	48.7	1266	n/a
Raw wastewater dissolved	(*)tsRaw	237	109	2.0	n/a	68.0
Diluted batch test total	(*)tFS,BT	n/a	n/a	n/a	n/a	n/a
Diluted batch test dissolved	(*)tsFS,BT	n/a	n/a	n/a	n/a	59.8

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	9468	410	469	12660	3122

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VFS,BT	1.580
Methane gas produced	VCH4	0.327
Carbon dioxide gas produced	VCO2	1.388

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	no data

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tFS,BT	5222	268	306.0	5792	no data
Dissolved batch test diluted	(*)tsFS,BT	n/a	n/a	n/a	n/a	no data

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	8250	424	484	9151	no data

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	864	n/a	n/a	n/a	162
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	687

B2.1.2. Primary Sludge (PS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Total settled raw wastewater	VPS,Raw	20.00
PS	VPS	0.980
Settled wastewater	VSettled	19.02
Total batch test diluted	VPS,BT	1.11

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	43.94

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1151	135	48.7	n/a	n/a
Settled wastewater total	(*)tSettled	583	120	40.9	n/a	n/a
PS total	(*)tPS	12157	434	200	8445	n/a
PS dissolved	(*)tsPS	n/a	n/a	n/a	n/a	68.0
Diluted batch total	(*)tPS,BT	n/a	n/a	n/a	7456	n/a
Diluted batch test dissolved	(*)tsPS,BT	n/a	n/a	n/a	n/a	60.0

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	11914	425	196	8276	3703

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VPS,BT	1.110
Methane gas produced	VCH4	2.041
Carbon dioxide gas produced	VCO2	1.195

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	22.48

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tPS,BT	5113	381	181	6447	n/a
Dissolved batch test diluted	(*)tsPS,BT	n/a	n/a	n/a	n/a	265

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	5675	423	201	7157	1903

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	5390	n/a	n/a	n/a	1011
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	592

B2.1.3. Waste Activated Sludge (WAS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Un-concentrated	VWAS	5.000
Concentrated	VWAS, conc.	1.600
Diluted batch test volume	VWAS,BT	1.730

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	43.22

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total un-concentrated	(*)tWAS	3068	183	103.4	2450	n/a
Total soluble	(*)tsWAS	32.6	6.2	32.3	n/a	8.3
Total particulate	(*)tpWAS	3036	177	71.1	n/a	n/a
Total concentrated	(*)tWAS, conc.	9519	560	254	n/a	8.3
Diluted batch test soluble	(*)tsWAS,BT	n/a	n/a	n/a	n/a	7.6

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	15230	896	407	12250	5308

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VWAS,BT	1.730
Methane gas produced	VCH4	1.257
Carbon dioxide gas produced	VCO2	1.298

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	32.30

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tWAS,BT	6787	543	228	5895	n/a
Dissolved batch test diluted	(*)tsWAS,BT	n/a	n/a	n/a	n/a	321

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	11741	940	395	10199	3850

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	3321	n/a	n/a	n/a	623
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	643

B2.2. CALCULATIONS: BTG 3

Note: See laboratory data - Appendix C.1.

B2.2.1. Flocculated raw wastewater (Flocculated Sludge, FS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	10.00
FS supernatant	VFS,Supern.	8.000
FS volume	VFS	2.000
Diluted batch test volume	VFS,BT	2.270

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	41.55

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1629	133	33.3	953	n/a
Raw wastewater dissolved	(*)tsRaw	236	110	0.8	n/a	55.9
Diluted batch test total	(*)tFS,BT	n/a	n/a	n/a	4198	n/a
Diluted batch test dissolved	(*)tsFS,BT	n/a	n/a	n/a	n/a	49.3

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	14402	449	327	9530	4072

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VFS,BT	2.27
Methane gas produced	VCH4	0.000
Carbon dioxide gas produced	VCO2	0.000

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	no data

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tFS,BT	4728	186	143.6	2988	no data
Dissolved batch test diluted	(*)tsFS,BT	n/a	n/a	n/a	n/a	no data

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	10733	423	326	6783	no data

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	0	n/a	n/a	n/a	0
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	0

B2.2.2. Primary Sludge (PS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Total settled raw wastewater	VPS,Raw	20.00
PS	VPS	0.485
Settled wastewater	VSettled	19.52
Total batch test diluted	VPS,BT	1.06

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	46.62

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1629	133	33.3	n/a	n/a
Settled wastewater total	(*)tSettled	444	114	28.2	n/a	n/a
PS total	(*)tPS	49326	888	238	28564	n/a
PS dissolved	(*)tsPS	n/a	n/a	n/a	n/a	55.9
Diluted batch total	(*)tPS,BT	n/a	n/a	n/a	13131	n/a
Diluted batch test dissolved	(*)tsPS,BT	n/a	n/a	n/a	n/a	25.7

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	23923	431	116	13853	6486

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VPS,BT	1.055
Methane gas produced	VCH4	1.181
Carbon dioxide gas produced	VCO2	1.344

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	no data

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tPS,BT	14659	402	112	8686	n/a
Dissolved batch test diluted	(*)tsPS,BT	n/a	n/a	n/a	n/a	no data

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	15465	424	118	9163	no data

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	3119	n/a	n/a	n/a	585
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	666

B2.2.3. Waste Activated Sludge (WAS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Un-concentrated	VWAS	5.000
Concentrated	VWAS, conc.	2.000
Diluted batch test volume	VWAS,BT	2.270

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	41.26

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total un-concentrated	(*)tWAS	3234	163	47.0	2812	n/a
Total soluble	(*)tsWAS	40.3	5.1	10.7	n/a	6.9
Total particulate	(*)tpWAS	3193	158	36.3	n/a	n/a
Total concentrated	(*)tWAS, conc.	8024	408	101	n/a	6.9
Diluted batch test soluble	(*)tsWAS,BT	n/a	n/a	n/a	n/a	6.1

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	16047	816	203	14060	5815

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VWAS,BT	2.27
Methane gas produced	VCH4	0.498
Carbon dioxide gas produced	VCO2	1.329

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	no data

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tWAS,BT	6606	361	90	6210	n/a
Dissolved batch test diluted	(*)tsWAS,BT	n/a	n/a	n/a	n/a	no data

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	14995	819	205	14097	no data

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	1314	n/a	n/a	n/a	246
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	658

B2.3. CALCULATIONS: BTG 4

Note: See laboratory data - Appendix C.1.

B2.3.1. Flocculated raw wastewater (Flocculated Sludge, FS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	6.000
FS supernatant	VFS,Supern.	4.000
FS volume	VFS	2.000
Diluted batch test volume	VFS,BT	2.120

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	23.47

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1360	119	101	2018	n/a
Raw wastewater dissolved	(*)tsRaw	179	86	0.0	n/a	35.0
Diluted batch test total	(*)tFS,BT	n/a	n/a	n/a	5711	n/a
Diluted batch test dissolved	(*)tsFS,BT	n/a	n/a	n/a	n/a	33.0

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	7444	371	606	12107	2911

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VFS,BT	2.120
Methane gas produced	VCH4	0.053
Carbon dioxide gas produced	VCO2	0.167

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	18.18

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tFS,BT	1408	179	272.4	2238	no data
Dissolved batch test diluted	(*)tsFS,BT	n/a	n/a	n/a	n/a	34

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	2984	378	577	4744	934

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	141	n/a	n/a	n/a	26
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	82

B2.3.2. Primary Sludge (PS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Total settled raw wastewater	VPS,Raw	10.00
PS	VPS	0.130
Settled wastewater	VSettled	9.870
Total batch test diluted	VPS,BT	0.903

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	46.05

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1360	119	101.0	n/a	n/a
Settled wastewater total	(*)tSettled	346	99	78.7	n/a	n/a
PS total	(*)tPS	78341	1637	1788	61722	n/a
PS dissolved	(*)tsPS	n/a	n/a	n/a	n/a	35.0
Diluted batch total	(*)tPS,BT	n/a	n/a	n/a	8886	n/a
Diluted batch test dissolved	(*)tsPS,BT	n/a	n/a	n/a	n/a	5.0

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	10184	213	232	8024	3700

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VPS,BT	0.903
Methane gas produced	VCH4	0.040
Carbon dioxide gas produced	VCO2	0.067

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	35.32

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tPS,BT	3604	258	237	3696	n/a
Dissolved batch test diluted	(*)tsPS,BT	n/a	n/a	n/a	n/a	214

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	3255	233	214	3337	1372

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	105	n/a	n/a	n/a	20
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	33

B2.3.3. Waste Activated Sludge (WAS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Un-concentrated	VWAS	2.290
Concentrated	VWAS, conc.	2.000
Diluted batch test volume	VWAS,BT	2.020

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	35.86

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total un-concentrated	(*)tWAS	3347	171	89.6	3248	n/a
Total soluble	(*)tsWAS	32.6	6.7	9.3	n/a	6.8
Total particulate	(*)tpWAS	3315	165	80.3	n/a	n/a
Total concentrated	(*)tWAS, conc.	3828	195	101	n/a	6.8
Diluted batch test soluble	(*)tsWAS,BT	n/a	n/a	n/a	n/a	6.7

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	7655	390	203	7438	2681

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VWAS,BT	2.02
Methane gas produced	VCH4	1.011
Carbon dioxide gas produced	VCO2	1.182

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	16.48

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tWAS,BT	2376	199	101	2648	n/a
Dissolved batch test diluted	(*)tsWAS,BT	n/a	n/a	n/a	n/a	28

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	4799	402	204	5349	939

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	2671	n/a	n/a	n/a	501
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	585

B2.4. CALCULATIONS: BTG 5

Note: See laboratory data - Appendix C.1.

B2.4.1. Flocculated raw wastewater (Flocculated Sludge, FS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	6.000
FS supernatant	VFS,Supern.	4.000
FS volume	VFS	2.000
Diluted batch test volume	VFS,BT	2.120

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	17.76

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1384	116	94.6	3365	n/a
Raw wastewater dissolved	(*)tsRaw	171	84	1.4	n/a	26.7
Diluted batch test total	(*)tFS,BT	n/a	n/a	n/a	9522	n/a
Diluted batch test dissolved	(*)tsFS,BT	n/a	n/a	n/a	n/a	25.2

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	7623	359	562	20188	3639

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VFS,BT	2.12
Methane gas produced	VCH4	0.000
Carbon dioxide gas produced	VCO2	0.031

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	17.08

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tFS,BT	1854	174	272.4	3182	no data
Dissolved batch test diluted	(*)tsFS,BT	n/a	n/a	n/a	n/a	136

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	3930	368	577	6745.8	1440

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	0	n/a	n/a	n/a	0
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	15

B2.4.2. Primary Sludge (PS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Total settled raw wastewater	VPS,Raw	10.00
PS	VPS	0.170
Settled wastewater	VSettled	9.83
Total batch test diluted	VPS,BT	0.79

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	38.93

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	1384	116	94.6	n/a	n/a
Settled wastewater total	(*)tSettled	379	96	81.6	n/a	n/a
PS total	(*)tPS	59542	1241	845	51100	n/a
PS dissolved	(*)tsPS	n/a	n/a	n/a	n/a	26.7
Diluted batch total	(*)tPS,BT	n/a	n/a	n/a	10996	n/a
Diluted batch test dissolved	(*)tsPS,BT	n/a	n/a	n/a	n/a	5.7

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	10122	211	144	8687	3386

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VPS,BT	0.790
Methane gas produced	VCH4	0.063
Carbon dioxide gas produced	VCO2	0.000

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	20.64

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tPS,BT	3789	264	190	6970	n/a
Dissolved batch test diluted	(*)tsPS,BT	n/a	n/a	n/a	n/a	219

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	2993	209	150	5506	1309

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	166	n/a	n/a	n/a	31
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	0

B2.4.3. Waste Activated Sludge (WAS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Un-concentrated	VWAS	2.290
Concentrated	VWAS, conc.	2.000
Diluted batch test volume	VWAS,BT	2.020

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	35.86

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total un-concentrated	(*)tWAS	3347	186	70.3	3248	n/a
Total soluble	(*)tsWAS	32.6	6.7	9.3	n/a	6.8
Total particulate	(*)tpWAS	3315	179	61.0	n/a	n/a
Total concentrated	(*)tWAS, conc.	3828	212	79	n/a	6.8
Diluted batch test soluble	(*)tsWAS,BT	n/a	n/a	n/a	n/a	6.7

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	7655	424	158	7438	2681

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VWAS,BT	2.02
Methane gas produced	VCH4	0.184
Carbon dioxide gas produced	VCO2	0.000

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	29.54

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tWAS,BT	2744	210	81	2321	n/a
Dissolved batch test diluted	(*)tsWAS,BT	n/a	n/a	n/a	n/a	14

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	5544	424	163	4689	1413

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	486	n/a	n/a	n/a	91
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	0

B2.5. CALCULATIONS: BTG 6

Note: See laboratory data - Appendix C.1.

B2.5.1. Flocculated raw wastewater (Flocculated Sludge, FS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	6.000
FS supernatant	VFS,Supern.	4.000
FS volume	VFS	2.000
Diluted batch test volume	VFS,BT	2.220

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	32.22

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	2262	143	58.1	2351	n/a
Raw wastewater dissolved	(*)tsRaw	298	91	2.3	n/a	76.0
Diluted batch test total	(*)tFS,BT	n/a	n/a	n/a	6353	n/a
Diluted batch test dissolved	(*)tsFS,BT	n/a	n/a	n/a	n/a	68.5

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	12381	494	339	14104	4696

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VFS,BT	2.22
Methane gas produced	VCH4	0.183
Carbon dioxide gas produced	VCO2	0.422

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CFS,BT	28.69

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tFS,BT	2554	210	145.4	2504	no data
Dissolved batch test diluted	(*)tsFS,BT	n/a	n/a	n/a	n/a	80

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tFS,BT	5671	466	323	5559	1772

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	484	n/a	n/a	n/a	91
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	209

B2.5.2. Primary Sludge (PS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Total settled raw wastewater	VPS,Raw	10.00
PS	VPS	0.640
Settled wastewater	VSettled	9.36
Total batch test diluted	VPS,BT	0.960

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	45.99

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Raw wastewater total	(*)tRaw	2262	143	58.1	n/a	n/a
Settled wastewater total	(*)tSettled	907	123	44.8	n/a	n/a
PS total	(*)tPS	22082	440	252	13943.617	n/a
PS dissolved	(*)tsPS	n/a	n/a	n/a	n/a	76.0
Diluted batch total	(*)tPS,BT	n/a	n/a	n/a	9296	n/a
Diluted batch test dissolved	(*)tsPS,BT	n/a	n/a	n/a	n/a	50.7

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	14133	281	162	8924	4153

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VPS,BT	0.960
Methane gas produced	VCH4	0.005
Carbon dioxide gas produced	VCO2	0.016

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CPS,BT	35.28

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tPS,BT	5191	302	180	5356	n/a
Dissolved batch test diluted	(*)tsPS,BT	n/a	n/a	n/a	n/a	47

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tPS,BT	4984	290	173	5142	1859

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	13	n/a	n/a	n/a	2
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	8

B2.5.3. Waste Activated Sludge (WAS) batch test

Data at batch test setup:

Volumes (L)

Parameter	Term	Value
Un-concentrated	VWAS	4.375
Concentrated	VWAS, conc.	2.000
Diluted batch test volume	VWAS,BT	2.220

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	44.01

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total un-concentrated	(*)tWAS	2964	159	46.6	2040	n/a
Total soluble	(*)tsWAS	50.4	4.1	0.0	n/a	5.3
Total particulate	(*)tpWAS	2913	155	46.6	n/a	n/a
Total concentrated	(*)tWAS, conc.	6423	343	102	n/a	5.3
Diluted batch test total	(*)tWAS,BT	n/a	n/a	n/a	4020	n/a
Diluted batch test soluble	(*)tsWAS,BT	n/a	n/a	n/a	n/a	4.7

Masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	12846	686	204	8924	3938

Data at batch test termination:

Volumes (L)

Parameter	Term	Value
Diluted batch test volume	VWAS,BT	2.22
Methane gas produced	VCH4	0.000
Carbon dioxide gas produced	VCO2	0.145

Elemental analysis results (% element / compound mass)

Parameter	Term	%C
Particulate carbon	%CWAS,BT	23.60

Concentrations (mg/l)

Parameter	Term	COD	N	P	TS	C
Total batch test diluted	(*)tWAS,BT	3090	308	98	3624	n/a
Dissolved batch test diluted	(*)tsWAS,BT	n/a	n/a	n/a	n/a	15

Particulate and soluble component masses (mg)

Parameter	Term	COD	N	P	TS	C
Total batch test	M(*)tWAS,BT	6860	684	217	8045	1931

Gaseous component masses (mg)

Parameter	Term	COD	N	P	TS	C
Methane gas	M(*)CH4	0	n/a	n/a	n/a	0
Carbon dioxide	M(*)CO2	n/a	n/a	n/a	n/a	72

B.3. SUMMARY

Table B3-1: COD batch test mass balances

		Batch test contents			
Parameter	**Unit**	**FS**	**PS**	**WAS**	**BTG**
Total mass at set up	mg	9468	11914	15230	**2**
COD in methane	mg	864	5390	3321	
Particulate and soluble mass at termination	mg	8250	5675	11741	
Balance	*%*	*96.26*	*92.88*	*98.90*	
Total mass at set up	mg	14402	23923	16047	**3**
COD in methane	mg	0	3119	1314	
Particulate and soluble mass at termination	mg	10733	15465	14995	
Balance	*%*	*74.52*	*77.68*	*101.63*	
Total mass at set up	mg	7444	10184	7655	**4**
COD in methane	mg	141	105	2671	
Particulate and soluble mass at termination	mg	2984	3255	4799	
Balance	*%*	*41.99*	*32.99*	*97.57*	
Total mass at set up	mg	7623	10122	7655	**5**
COD in methane	mg	0	166	486	
Particulate and soluble mass at termination	mg	3930	2993	5544	
Balance	*%*	*51.56*	*31.21*	*78.76*	
Total mass at set up	mg	12381	14133	12846	**6**
COD in methane	mg	484	13	0	
Particulate and soluble mass at termination	mg	5671	4984	6860	
Balance	*%*	*49.72*	*35.36*	*53.40*	

Table B3-2: Carbon batch test mass balances

		Batch test contents			
Parameter	**Unit**	**FS**	**PS**	**WAS**	**BTG**
Total mass at set up	mg	3122	3703	5308	**2**
C in methane	mg	162	1011	623	
C in carbon dioxide	mg	687	592	643	
Particulate and soluble mass at termination	mg	no data	1903	3850	
Balance	*%*	*27.21*	*94.66*	*96.37*	
Total mass at set up	mg	4072	6486	5815	**3**
C in methane	mg	0	585	246	
C in carbon dioxide	mg	0	666	658	
Particulate and soluble mass at termination	mg	no data	no data	no data	
Balance	*%*	*no data*	*19.28*	*15.56*	
Total mass at set up	mg	2911	3700	2681	**4**
C in methane	mg	26	20	501	
C in carbon dioxide	mg	82	33	585	
Particulate and soluble mass at termination	mg	934	1372	939	
Balance	*%*	*35.84*	*38.50*	*75.53*	
Total mass at set up	mg	3639	3386	2681	**5**
C in methane	mg	0	31	91	
C in carbon dioxide	mg	15	0	0	
Particulate and soluble mass at termination	mg	1440	1309	1413	
Balance	*%*	*40.00*	*39.58*	*56.09*	
Total mass at set up	mg	4696	4153	3938	**6**
C in methane	mg	91	2	0	
C in carbon dioxide	mg	209	8	72	
Particulate and soluble mass at termination	mg	1772	1859	1931	
Balance	*%*	*44.12*	*45.02*	*50.87*	

Table B3-3: Nitrogen batch test mass balances

		Batch test contents			
Parameter	**Unit**	**FS**	**PS**	**WAS**	**BTG**
Total mass at set up	mg	410	425	896	**2**
Total mass at termination	mg	424	423	940	
Balance	*%*	*103.51*	*99.38*	*104.90*	
Total mass at set up	mg	449	431	816	**3**
Total mass at termination	mg	423	424	819	
Balance	*%*	*94.28*	*98.44*	*100.34*	
Total mass at set up	mg	371	213	390	**4**
Total mass at termination	mg	378	233	402	
Balance	*%*	*101.92*	*109.27*	*103.01*	
Total mass at set up	mg	359	211	424	**5**
Total mass at termination	mg	368	209	424	
Balance	*%*	*102.61*	*98.88*	*99.94*	
Total mass at set up	mg	494	281	686	**6**
Total mass at termination	mg	466	290	684	
Balance	*%*	*94.39*	*103.16*	*99.74*	

Table B3-4: Phosphorus batch test mass balances

		Batch test contents			
Parameter	**Unit**	**FS**	**PS**	**WAS**	**BTG**
Total mass at set up	mg	469	196	407	**2**
Total mass at termination	mg	484	201	395	
Balance	*%*	*102.99*	*102.54*	*97.00*	
Total mass at set up	mg	327	116	203	**3**
Total mass at termination	mg	326	118	205	
Balance	*%*	*99.76*	*102.11*	*101.24*	
Total mass at set up	mg	606	232	203	**4**
Total mass at termination	mg	577	214	204	
Balance	*%*	*95.33*	*92.18*	*100.71*	
Total mass at set up	mg	562	144	158	**5**
Total mass at termination	mg	577	150	163	
Balance	*%*	*102.77*	*104.45*	*103.12*	
Total mass at set up	mg	339	162	204	**6**
Total mass at termination	mg	323	173	217	
Balance	*%*	*95.19*	*107.16*	*106.56*	

C1.1. LABORATORY DATA: BTG 2

C1.1.1. Operational data

1. Batch test retention time:	62	days			
2. Batch test temperature:	35	degC	±	0.5	degC

C1.1.2. Buffer calculations and usage

Formulae used:

1. NaHCO3 (mg/l) required = Alkalinity required (as mg/l CaCO3) x 84 / 50
2. Mass of NaHCO3 (mg) required estimate = concentration of NaHCO3 (mg/l) x batch test initial volume estimate (l)
3. NaHCO3 batch test concentration = actual mass of NaHCO3 (mg) used / batch test actual volume (l)

Assumptions

mg/l Alkalinity required (as CaCO3) = 2500-5500 mg/l

Batch test contents	Alkalinity range required - As mg/l CaCO3	Approx. alkalinity required (As mg/l CaCO3)	NaHCO3 (mg/l) required	Batch test initial volume estimate (l)	Mass NaHCO3 (g) estimated	Mass NaHCO3 (mg) used	Tested alkalinity (mg/l)	*Alkalinity within range ?*
PS	2500 - 5500	4500	7560	0.730	5.5188	5.3377	3365	*Yes*
FS	as above	4500	7560	1.110	8.3916	8.6501	3426	*Yes*
WAS	as above	4500	7560	1.350	10.2060	10.2356	3200	*Yes*

C1.1.3. Batch test volume measurements

Batch test contents	Total water volume (l)	Sludge initial volume (l)	Supernatant volume (l)	with distilled water addition (l)	Samples volume (l)	Buffer addition (l)	Innoculant (l)	Diluted batch test volume (l)	Final batch test volume (l)
PS	20.00	0.980	19.020	0.980	0.137	0.100	0.030	1.110	0.973
Samples taken								*yes*	
Measuring equipment	*1l grad. cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*10 ml pipette*	*calculated*	*calculated*
FS	10.000	1.390	8.610	1.450	0.145	0.100	0.030	1.580	1.435
Samples taken								*yes*	
Measuring equipment	*1l grad. cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*10 ml pipette*	*calculated*	*calculated*
WAS	5.000	1.600	3.400	1.600	0.140	0.100	0.030	1.730	1.590
Samples taken								*yes*	
Measuring equipment	*1l grad. cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*not measured*	*10 ml pipette*	*calculated*	*calculated*

C1.1.4. Test results at batch test setup

COD test results | Date: 14-Nov-06

FAS normality:		0.0510	Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24.5	24.6	24.55	0	
Raw	Unfiltered	10	50	10.5	10.4	10.45	1151	50 ml pipette
Settled	Unfiltered	10	50	17.1	17.7	17.4	583	50 ml pipette
WAS	Unfiltered	10	25	6.2	5.3	5.8	3068	25 ml pipette
Effluent	Filtered	10	50	24.2	24.1	24.15	32.6	50 ml pipette
FS supernatant	Unfiltered	10	50	21.7	21.7	21.7	233	50 ml pipette
FS supernatant	Filtered	10	50	21.3	22.0	21.65	237	50 ml pipette

General comments: WAS total sample unconcentrated

Sources of error: Dilution, incorrect titration readings

C1. 2

TKN test results

Date::
15-Nov-06

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
Raw	Unfiltered	10	50	48.2	48.3	48.3	135	50 ml pipette
Settled	Unfiltered	10	100	86.3	84.7	85.5	120	100 ml pipette
WAS	Unfiltered	10	50	65.5	65.5	65.5	183	50 ml pipette
Effluent	Filtered	10	100	4.7	4.2	4.5	6.2	100 ml pipette
FS supernatant	Unfiltered	10	100	78.4	78.1	78.3	110	100 ml pipette
FS supernatant	Filtered	10	100	78.0	78.2	78.1	109	100 ml pipette

General comments: WAS total sample unconcentrated

Sources of error: Dilution, incorrect titration readings

FSA test results

Date: 14-Nov-06

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
FS supernatant	Filtered	10	50	36.8	33.7	35.25	99	50 ml pipette
Effluent	Filtered	10	50	1.5	1.0	1.3	3.5	50 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings

Solids test results

Date: 14-Nov-06

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Measuring equipment
Raw	50	1.4118	58.3452	59.8203	58.3621	1266	928	338	50 ml pipette
WAS (unconcentrated)	50	0.0000	57.8868	58.0093	57.9051	2450	2084	366	50 ml pipette
PS	16	1.4990	58.5526	60.1709	58.5970	7456	4681	2775	50 ml cylinder
FS	25	1.5135	59.4217	61.0964	59.5465	6448	1456	4992	50 ml cylinder
WAS (From batch test)	20	1.5181	54.5517	56.1540	54.6236	4210	615	3595	50 ml cylinder

General: WAS and FS results from batch test are non-sensical (low VS), thus use un-concentrated WAS and Raw ww results

Sources of error: IS measurement error - small mass

Phosphate test results Raw

Date: 15-Nov-06

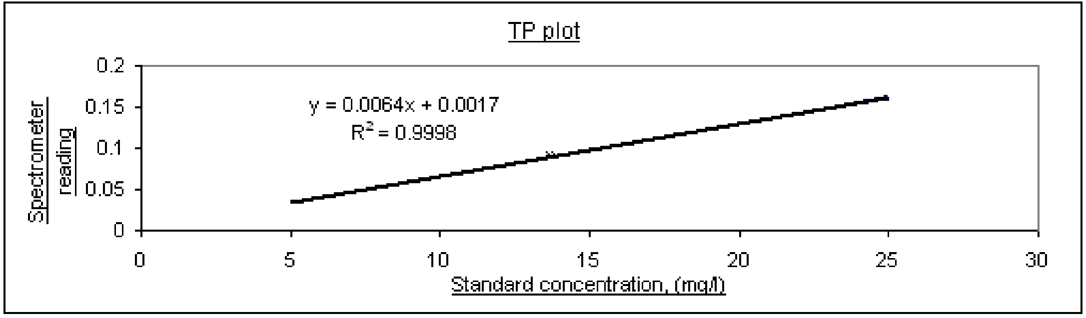
Total - phosphate (TP) test

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.034	n/a	n/a	n/a
Standard	10	0.066	n/a	n/a	n/a
Standard	15	0.098	n/a	n/a	n/a
Standard	20	0.129	n/a	n/a	n/a
Standard	25	0.163	n/a	n/a	n/a
Raw	9.7	0.064	20	48.7	20 ml pipette
Settled	8.2	0.054	20	40.9	20 ml pipette
WAS	20.7	0.134	20	103	20 ml pipette
Effluent	6.5	0.043	20	32.3	20 ml pipette
FS super.* - unfilt.	0.7	0.004	20	3.5	20 ml pipette
FS super.* - filt.	0.4	0.006	20	2.0	20 ml pipette

* FS supernatant - unfiltered or filtered

General comments:

Sources of error: Dilution, incorrect titration readings

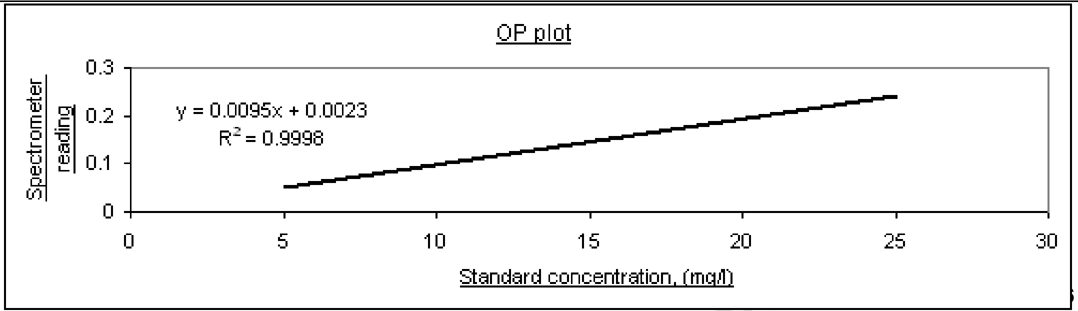


Ortho - phosphate (OP) test | Date: 15-Nov-06

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.051	n/a	n/a	n/a
Standard	10	0.096	n/a	n/a	n/a
Standard	15	0.144	n/a	n/a	n/a
Standard	20	0.193	n/a	n/a	n/a
Standard	25	0.240	n/a	n/a	n/a
FS supernatant	2.2	0.023	100	2.2	100 ml pipette
Effluent	14.2	0.137	100	14.2	100 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings



VFA tests

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	7.86	pH6.7:	6.73	pH5.9:	5.94	pH5.2:	5.24	pH4.3:	4.1
Ti:	21.7	V6.7:	2.965	V5.9:	7.76	V5.2:	10.39	V4.3:	11.59
Tf:	22.2	Alkalinity as CaCO3:	3426.1	mg/l ;		VFA:	171.7	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.07	pH6.7:	6.72	pH5.9:	5.93	pH5.2:	5.18	pH4.3:	4.34
Ti:	21.8	V6.7:	3.15	V5.9:	7.76	V5.2:	10.48	V4.3:	11.37
Tf:	22.5	Alkalinity as CaCO3:	3365.2	mg/l ;		VFA:	102.9	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.77	pH6.7:	6.72	pH5.9:	5.93	pH5.2:	5.24	pH4.3:	3.9
Ti:	18.8	V6.7:	3.25	V5.9:	7.475	V5.2:	9.65	V4.3:	10.475
Tf:	22.2	Alkalinity as CaCO3:	3199.6	mg/l ;		VFA:	0	mg/l as acetic acid	

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	43.94	6.17	2.17	52.28	68.0
FS	23.91	4.02	1.43	29.36	68.0
WAS	43.22	5.98	7.15	56.35	8.27

C1.1.5. Test results at batch test termination

Batch test contents appearance at batch test termination

Primary sludge batch test:

Dark brown / black granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

Flocculated raw wastewater batch test:

Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated

methane production.White substance coated sides of container - amount negligible.

Waste activated sludge batch test:

Dark brown / black granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

C1. 4

COD test results

FAS normality: 0.0509

Date: 16-Jan-07

				Titration Results				
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24.9	24.9	24.9	0	
PS	Unfiltered	10	5	19.4	19.1	19.25	5113	10 ml graduated cylinder
FS	Unfiltered	10	9	14.0	14.0	14.0	5222	10 ml graduated cylinder
WAS	Unfiltered	10	9	10.0	9.8	9.9	6787	10 ml graduated cylinder
PS	Filtered	10	20	24.0	23.8	23.9	204	10 ml pipette
FS	Filtered	10	20	23.9	23.8	23.85	214	10 ml pipette
WAS	Filtered	10	20	24.1	24.0	24.05	173	10 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings

TKN test results

Date: 16-Jan-07

H2SO4 normality: 0.001

				Titration Results				
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
PS	Unfiltered	10	5	13.6	13.6	13.6	381	10 ml graduated cylinder
FS	Unfiltered	10	6	11.5	11.5	11.5	268	10 ml graduated cylinder
WAS	Unfiltered	10	5	19.4	19.4	19.4	543	10 ml graduated cylinder
PS	Filtered	10	20	26.3	25.9	26.1	183	10 ml pipette
FS	Filtered	10	10	14.9	14.9	14.9	209	10 ml pipette
WAS	Filtered	10	20	37.1	37.7	37.4	262	10 ml pipette

General comments: FS filtered sample re-tested value

Sources of error: Dilution, incorrect titration readings

FSA test results

Date: 16-Jan-07

H2SO4 normality: 0.001

				Titration Results				
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
PS	Filtered	10	20	16.7	14.3	15.5	109	10 ml pipette
FS	Filtered	10	20	26.5	27.3	26.9	188	10 ml pipette
WAS	Filtered	10	20	33.9	29.7	31.8	223	10 ml pipette

General comments: variable titrations < 10% error - acceptable

Sources of error: Dilution, incorrect titration readings

Solids test results

Date: 15-Jan-07

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Volumetric measuring equipment
PS	40	1.4643	49.7452	51.4674	49.8884	6447	2867	3580	100 ml cylinder
FS	50	1.4595	24.0793	25.8284	24.2246	5792	2886	2906	100 ml cylinder
WAS	42	1.4381	28.4092	30.0949	28.4882	5895	4014	1881	100 ml cylinder

Sources of error: IS measurement error - small mass

Phosphate test results

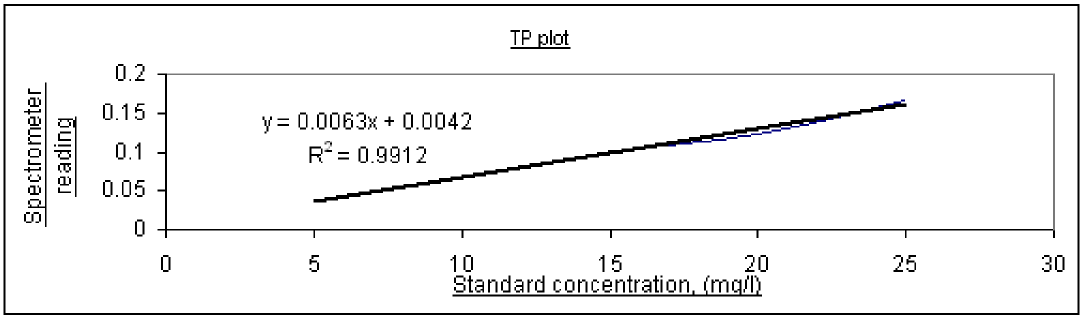
Total - phosphate (TP) test

Date: 15-Jan-07

Note: See plot next page

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.036	n/a	n/a	n/a
Standard		10	0.068	n/a	n/a	n/a
Standard		15	0.100	n/a	n/a	n/a
Standard		20	0.122	n/a	n/a	n/a
Standard		25	0.166	n/a	n/a	n/a
PS	Unfiltered	22.7	0.147	12.5	181	50 ml graduated cylinder
FS	Unfiltered	30.6	0.197	10	306	50 ml graduated cylinder
WAS	Unfiltered	22.8	0.148	10	228	50 ml graduated cylinder
PS	Filtered	7.3	0.05	20	36.3	20 ml pipette
FS	Filtered	9.3	0.063	20	46.7	20 ml pipette
WAS	Filtered	9.5	0.064	20	47.5	20 ml pipette

C1. 5



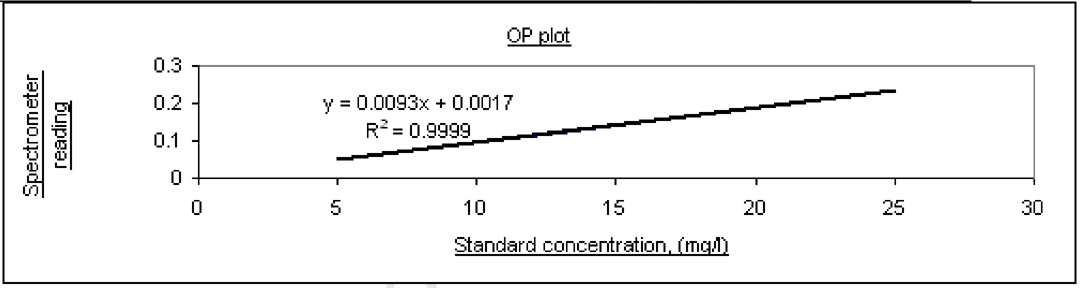
Ortho - phosphate (OP) test

Date: 15-Jan-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.049	n/a	n/a	n/a
Standard		10	0.094	n/a	n/a	n/a
Standard		15	0.142	n/a	n/a	n/a
Standard		20	0.189	n/a	n/a	n/a
Standard		25	0.235	n/a	n/a	n/a
PS	Filtered	6.6	0.063	20	33.0	20 ml pipette
FS	Filtered	0.6	0.007	20	2.8	20 ml pipette
WAS	Filtered	11.0	0.104	20	55.0	20 ml pipette

Comments:
WAS OP result higher than soluble TP result. Assume 0 mg/l WAS organic TP.

Sources of error: Dilution, incorrect titration readings



VFA tests

Date: 15-Jan-07

Note: All temperatures in degC and volumes in ml N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	8.45	pH6.7:	6.75	pH5.9:	5.93	pH5.2:	5.24	pH4.3:	4.27
Ti:	21.3	V6.7:	3.965	V5.9:	9.945	V5.2:	12.770	V4.3:	13.690
Tf:	22.1	Alkalinity as CaCO3:		4222.4	mg/l ;	VFA:	0	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.36	pH6.7:	6.74	pH5.9:	5.94	pH5.2:	5.22	pH4.3:	4.33
Ti:	21	V6.7:	3.785	V5.9:	9.145	V5.2:	11.82	V4.3:	12.62
Tf:	21.8	Alkalinity as CaCO3:		3888.7	mg/l ;	VFA:	4.4	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.38	pH6.7:	6.74	pH5.9:	5.95	pH5.2:	5.24	pH4.3:	4.22
Ti:	21.8	V6.7:	4.485	V5.9:	10.805	V5.2:	14.010	V4.3:	15.050
Tf:	21.8	Alkalinity as CaCO3:		4642.1	mg/l ;	VFA:	0	mg/l as acetic acid	

Gas results

Date: 16-Feb-07

Batch test contents	%CO2	%CH4	%N2	Adjusted %CO2	Adjusted %CH4	Total gas volume (l)	CO2 gas volume (l)	CH4 gas volume (l)
PS	35.202	60.12	4.678	36.9	63.1	3.236	1.195	2.041
FS	77.173	18.193	4.634	80.9	19.1	1.715	1.388	0.327
WAS	49.008	47.483	3.509	50.8	49.2	2.555	1.298	1.257

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	22.48	3.99	1.00	27.47	265
FS	no data	no data	no data	no data	no data
WAS	32.3	3.9	3.8	40.00	321

C1.2. LABORATORY DATA: BTG 3

C1.2.1. Operational data

1. Batch test retention time:	62	days			
2. Batch test temperature:	22	degC	±	0.5	degC

C1.2.2. Buffer calculations and usage

Formulae used:

1. NaHCO3 (mg/l) required = Alkalinity required (as mg/l CaCO3) x 84 / 50
2. Mass of NaHCO3 (mg) required = concentration of NaHCO3 (mg/l) x batch test initial volume estimate (l)
3. NaHCO3 batch test concentration = actual mass of NaHCO3 (mg) used / batch test actual volume (l)

Assumptions

mg/l Alkalinity required (as CaCO3) = 2500-5500 mg/l

Batch test contents	Alkalinity range required - As mg/lCaCO3	Approx. alkalinity required (As mg/l CaCO3)	NaHCO3 (mg/l) required	Batch test initial volume estimate (l)	Mass NaHCO3 (g) required	Mass NaHCO3 (mg) used	Tested alkalinity (mg/l)	within required range ?
PS	2500 - 5500	4500	7560	0.990	7.4844	7.453	3875	*Yes*
FS	as above	4500	7560	2.100	15.8760	15.9449	3915	*Yes*
WAS	as above	4500	7560	2.270	17.1612	16.0823	2996	*Yes*

C1.2.3. Batch test volume measurements

Batch test contents	Total water volume (l)	Sludge initial volume (l)	Super - natant volume (l)	with distilled water addition (l)	Samples volume (l)	Buffer addition (l)	Innoculant (l)	Diluted batch test volume (l)	Final batch test volume (l)
PS	20.00	0.485	19.515	0.785	0.083	0.250	0.020	1.055	0.972
Samples taken								*yes*	
Measuring equipment	*1l graduated cylinder*	*100 ml graduated cylinder*	*calculated*	*100 ml graduated cylinder*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
FS	10.000	2.000	8.000	2.000	0.171	0.250	0.020	2.270	2.099
Samples taken								*yes*	
Measuring equipment	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
WAS	5.000	2.000	3.000	2.000	0.156	0.250	0.020	2.270	2.114
Samples taken								*yes*	
Measuring equipement	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*not measured*	*20 ml pipette*	*calculated*	*calculated*

C1.2.4. Test results at batch test setup

COD test results — Date: 14-Nov-06

FAS normality: 0.0504

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24.5	24.6	24.55	0	
Raw	Unfiltered	10	25	14.7	14.2	14.45	1629	25 ml pipette
Settled	Unfiltered	10	50	19.3	18.8	19.1	444	50 ml pipette
WAS	Unfiltered	10	25	4.3	4.7	4.5	3234	25 ml pipette
Effluent	Filtered	10	100	23.6	23.5	23.55	40.3	100 ml pipette
FS supernatant	Unfiltered	10	50	21.7	21.3	21.5	246	50 ml pipette
FS supernatant	Filtered	10	100	19.0	18.4	18.7	236	100 ml pipette

General comments: WAS sample unconcentrated

Sources of error: Dilution, incorrect titration readings

Date: 14-Nov-06

C1. 7

TKN test results

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
Raw	Unfiltered	10	25	23.7	23.8	23.8	133	25 ml pipette
Settled	Unfiltered	10	50	42.0	39.6	40.8	114	50 ml pipette
WAS	Unfiltered	10	10	29.6	28.7	29.2	408	10 ml pipette
Effluent	Filtered	10	100	3.8	3.5	3.7	5.1	100 ml pipette
FS supernatant	Unfiltered	10	50	39.2	39.5	39.4	110	50 ml pipette
FS supernatant	Filtered	10	50	39.2	39.5	39.4	110	50 ml pipette

General comments: Concentrated WAS sample

Sources of error: Dilution, incorrect titration readings

FSA test results

Date: 14-Nov-06

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
FS supernatant	Filtered	10	50	36.9	33.6	35.25	99	50 ml pipette
Effluent	Filtered	10	100	2.1	1.5	1.8	2.5	100 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings

Solids test results

Date: 15-Nov-06

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Measuring equipment
Raw	25	1.4686	58.3484	59.8410	58.3599	960	500	460	25 ml pipette
WAS (unconcentrated)	50	0.0000	54.5521	54.6927	54.5675	2812	2504	308	50 ml pipette
PS	16	1.4512	58.5554	60.2167	58.5924	13131	10819	2312	50 ml cylinder
FS	61	1.4752	59.4355	61.1668	59.5031	4198	3090	1108	100 ml cyl.
WAS (From batch test)	50	0.0000	59.1580	59.4565	59.1914	5970	5302	668	50 ml cylinder

General:

Sources of error: IS measurement error - small mass

Phosphate test results

Date: 15-Nov-06

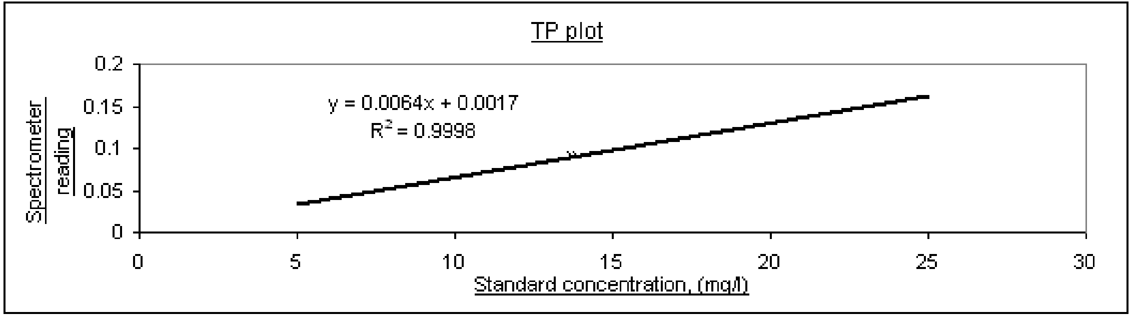
Total - phosphate (TP) test

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.034	n/a	n/a	n/a
Standard	10	0.066	n/a	n/a	n/a
Standard	15	0.098	n/a	n/a	n/a
Standard	20	0.129	n/a	n/a	n/a
Standard	25	0.163	n/a	n/a	n/a
Raw	8.3	0.055	25	33.3	25 ml pipette
Settled	14.1	0.092	50	28.2	50 ml pipette
WAS	23.5	0.152	50	47.0	50 ml pipette
Effluent	5.4	0.036	50	10.7	50 ml pipette
FS super.* - unfilt.	0.7	0.006	50	1.4	50 ml pipette
FS super.* - filt.	0.4	0.006	50	0.8	50 ml pipette

* FS supernatant - unfiltered or filtered

General comments:

Sources of error: Dilution, incorrect titration readings



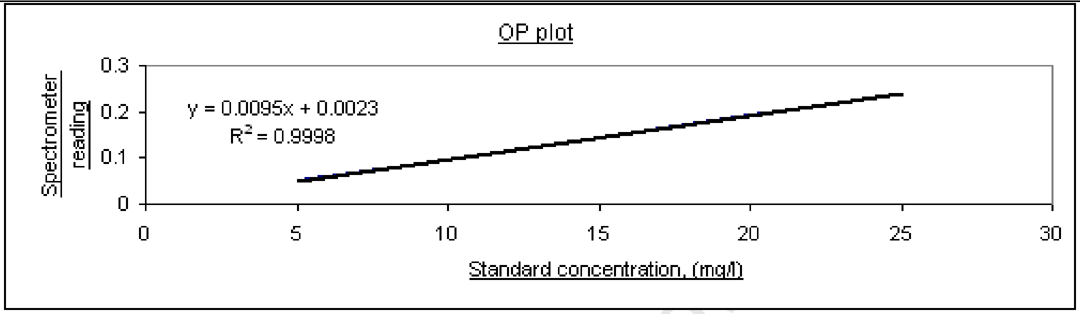
Ortho - phosphate (OP) test

Date: 15-Nov-06

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.051	n/a	n/a	n/a
Standard	10	0.096	n/a	n/a	n/a
Standard	15	0.144	n/a	n/a	n/a
Standard	20	0.193	n/a	n/a	n/a
Standard	25	0.240	n/a	n/a	n/a
FS supernatant	2.6	0.027	50	5.2	50 ml pipette
Effluent	20.1	0.193	100	20.1	100 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings



VFA tests

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	7.87	pH6.7:	6.73	pH5.9:	5.92	pH5.2:	5.24	pH4.3:	4.35
Ti:	21.9	V6.7:	3.120	V5.9:	8.675	V5.2:	11.775	V4.3:	12.87
Tf:	22.5	Alkalinity as CaCO3:		3915.3	mg/l ;	VFA:	80.7	mg/l as acetic acid	

Primary sludge batch:

pHi:	7.8	pH6.7:	6.73	pH5.9:	5.92	pH5.2:	5.23	pH4.3:	4.35
Ti:	22.7	V6.7:	3.12	V5.9:	8.675	V5.2:	11.585	V4.3:	12.87
Tf:	23.6	Alkalinity as CaCO3:		3874.8	mg/l ;	VFA:	150.4	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.03	pH6.7:	6.73	pH5.9:	5.92	pH5.2:	5.25	pH4.3:	4.22
Ti:	21.9	V6.7:	2.63	V5.9:	6.815	V5.2:	8.955	V4.3:	9.77
Tf:	22.5	Alkalinity as CaCO3:		2996.4	mg/l ;	VFA:	22.3	mg/l as acetic acid	

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	46.62	6.71	2.00	55.33	55.94
FS	41.55	6.44	2.49	50.48	55.94
WAS	41.26	6.00	5.67	52.93	6.88

C1.2.5. Test results at batch test termination

Batch test contents appearance at batch test termination

Primary sludge batch test:

Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated
methane production.

Flocculated raw wastewater batch test:

Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated
methane production.White substance coated sides of container - amount negligible.

Waste activated sludge batch test:

Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated
methane production.

C1. 9

COD test results

FAS normality: 0.0509

Date: 16-Jan-07

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24.9	24.9	24.9	0	
PS	Unfiltered	10	5	7.5	6.3	6.9	14659	10 ml graduated cylinder
FS	Unfiltered	10	9	14.3	14.6	14.5	4728	10 ml graduated cylinder
WAS	Unfiltered	10	9	10.2	10.4	10.3	6606	10 ml graduated cylinder
PS	Filtered	10	20	19.5	19.7	19.6	1079	20 ml pipette
FS	Filtered	10	20	22.6	22.9	22.75	438	20 ml pipette
WAS	Filtered	10	20	24.2	24.2	24.2	143	20 ml pipette

TKN test results

Date: 16-Jan-07

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
PS	Unfiltered	10	5	13.7	15.0	14.35	402	10 ml graduated cylinder
FS	Unfiltered	10	6.5	8.2	9.1	8.7	186	10 ml graduated cylinder
WAS	Unfiltered	10	6.5	16.9	16.6	16.8	361	10 ml graduated cylinder
PS	Filtered	10	20	21.0	20.1	20.6	144	10 ml pipette
FS	Filtered	10	20	18.9	18.4	18.65	131	10 ml pipette
WAS	Filtered	10	10	10.3	10.8	10.6	148	10 ml pipette

FSA test results

Date: 16-Jan-07

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
PS	Filtered	10	20	24.5	23.2	23.9	167	20 ml pipette
FS	Filtered	10	20	16.2	15.1	15.7	110	20 ml pipette
WAS	Filtered	10	20	21.2	21.7	21.5	150	20 ml pipette

Solids test results

Date: 15-Jan-07

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Volumetric measuring equipment
PS	70	1.5000	55.3944	57.5024	55.6185	8686	5484	3201	100 ml cylinder
FS	50	1.4996	58.0882	59.7372	58.1808	2988	1136	1852	100 ml cylinder
WAS	50	1.4502	48.0672	49.8279	48.2260	6210	3034	3176	100 ml cylinder

Sources of error: IS measurement error - small mass

Phosphate test

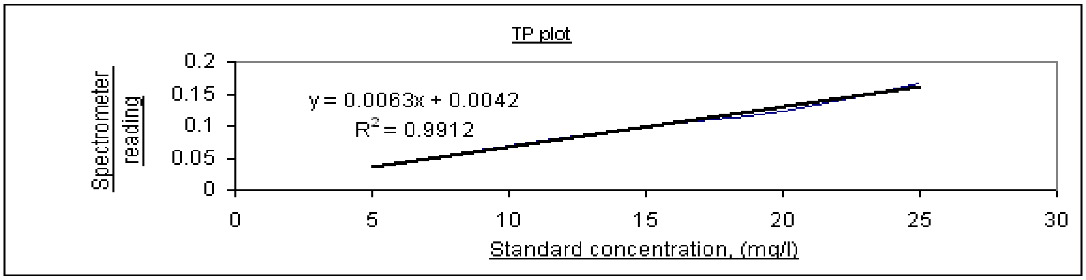
Total - phosphate (TP) test

Date: 15-Jan-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.036	n/a	n/a	n/a
Standard		10	0.068	n/a	n/a	n/a
Standard		15	0.100	n/a	n/a	n/a
Standard		20	0.122	n/a	n/a	n/a
Standard		25	0.166	n/a	n/a	n/a
PS	Unfiltered	7.3	0.050	6.5	112	50 ml graduated cylinder
FS	Unfiltered	9.3	0.063	6.5	144	50 ml graduated cylinder
WAS	Unfiltered	9.5	0.064	10.5	90.4	50 ml graduated cylinder
PS	Filtered	6.6	0.046	20	33.2	20 ml pipette
FS	Filtered	1.1	0.011	20	5.4	20 ml pipette
WAS	Filtered	10.6	0.071	20	53.0	20 ml pipette

Note: See plot next page

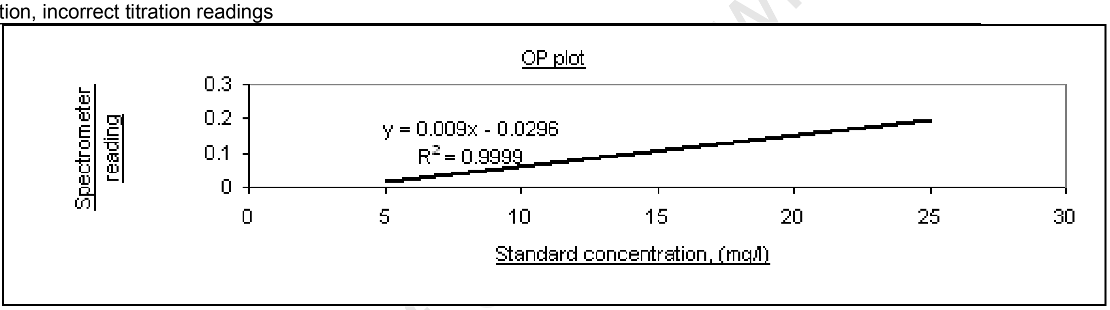
C1.10



Ortho - phosphate (OP) test Date: 15-Jan-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.016	n/a	n/a	n/a
Standard		10	0.061	n/a	n/a	n/a
Standard		15	0.105	n/a	n/a	n/a
Standard		20	0.151	n/a	n/a	n/a
Standard		25	0.197	n/a	n/a	n/a
PS	Filtered	11.0	0.069	50	21.9	50 ml pipette
FS	Filtered	5.1	0.016	50	10.1	50 ml pipette
WAS	Filtered	13.8	0.095	50	27.7	50 ml pipette

Sources of error: Dilution, incorrect titration readings



VFA tests

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	8.47	pH6.7:	6.75	pH5.9:	5.93	pH5.2:	5.25	pH4.3:	4.29
Ti:	22.7	V6.7:	4.320	V5.9:	10.700	V5.2:	13.755	V4.3:	14.990
Tf:	23.2	Alkalinity as CaCO3:		4545.4	mg/l ;	VFA:	160.4	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.46	pH6.7:	6.74	pH5.9:	5.94	pH5.2:	5.24	pH4.3:	4.29
Ti:	22.4	V6.7:	4.030	V5.9:	9.905	V5.2:	12.995	V4.3:	14.265
Tf:	22.9	Alkalinity as CaCO3:		4273.6	mg/l ;	VFA:	225.3	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.42	pH6.7:	6.74	pH5.9:	5.93	pH5.2:	5.24	pH4.3:	4.20
Ti:	22.9	V6.7:	4.700	V5.9:	11.315	V5.2:	14.510	V4.3:	15.650
Tf:	23.3	Alkalinity as CaCO3:		4762.7	mg/l ;	VFA:	37.6	mg/l as acetic acid	

Gas results Date: 16-Feb-07

Batch test contents	%CO2	%CH4	%N2	Adjusted %CO2	Adjusted %CH4	Total gas volume (l)	CO2 gas volume (l)	CH4 gas volume (l)
PS	45.386	39.883	14.732	53.2	46.8	2.525	1.344	1.181
FS	99.837	0	0.163	100.0	0.0	0.000	0.000	0.000
WAS	64.43	24.116	11.454	72.8	27.2	1.827	1.329	0.498

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	no data	no data	no data	no data	no data
FS	no data	no data	no data	no data	no data
WAS	no data	no data	no data	no data	no data

C1.3. LABORATORY DATA: BTG 4

C1.3.1. Operational data

1. Batch test retention time: 127 days (PS and WAS), 169 days (FS)
2. Batch test temperature: 35 degC ± 0.5 degC

C1.3.2. Buffer calculations and usage

Formulae used:

1. NaHCO3 (mg/l) required = Alkalinity required (as mg/l CaCO3) x 84 / 50
2. Mass of NaHCO3 (mg) required = concentration of NaHCO3 (mg/l) x batch test initial volume estimate (l)
3. NaHCO3 batch test concentration = actual mass of NaHCO3 (mg) used / batch test actual volume (l)

Assumptions

mg/l Alkalinity required (as CaCO3) = 2500-5500 mg/l

Batch test contents	Alkalinity range required - As mg/lCaCO3	Approx. alkalinity required (As mg/l CaCO3)	NaHCO3 (mg/l) required	Batch test initial volume estimate (l)	Mass NaHCO3 (g) required	Mass NaHCO3 (mg) used	Tested alkalinity (mg/l)
PS	2500 - 5500	4500	7560	1.003	7.5827	7.5015	4372
FS	as above	4500	7560	2.120	16.0272	15.500	3157
WAS	as above	4500	7560	2.020	15.2712	15.500	4283

C1.3.3. Batch test volume measurements

Batch test contents	Total water volume (l)	Sludge initial volume (l)	Supernatant volume (l)	with distilled water addition (l)	Samples volume (l)	Buffer addition (l)	Innoculant (l)	Diluted batch test volume (l)	Final batch test volume (l)
PS	10.00	0.130	9.870	0.783	0.105	0.100	0.020	0.903	0.798
Samples taken								*Yes*	
Measuring equipement	*1l graduated cylinder*	*100 ml graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
FS	6.000	2.000	4.000	2.000	0.196	0.100	0.020	2.120	2.120
Samples taken								*Yes*	
Measuring equipement	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
WAS	2.290	2.000	0.290	2.000	0.205	0.000	0.020	2.020	1.815
Samples taken								*Yes*	
Measuring equipement	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*not measured*	*20 ml pipette*	*calculated*	*calculated*

C1.3.4. Test results at batch test setup

COD test results

Date: 22-Jan-07

FAS normality: 0.0509

				Titration Results				
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	25.5	25.3	25.4	0	
Raw	Unfiltered	10	50	8.7	8.7	8.7	1360	50 ml pipette
Settled	Unfiltered	10	50	21.3	21.0	21.2	346	50 ml pipette
WAS	Unfiltered	10	10	15.7	16.3	16.0	3828	10 ml pipette
Effluent	Filtered	10	50	25.0	25.0	25	33	50 ml pipette
FS supernatant	Unfiltered	10	50	22.5	22.8	22.7	224	50 ml pipette
FS supernatant	Filtered	10	50	23.2	23.2	23.2	179	50 ml pipette

General comments: WAS total sample concentrated

Sources of error: Dilution, incorrect titration readings

Date: 22-Jan-07

C1.12

TKN test results

H2SO4 normality: 0.001

Date: 22-Jan-07

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
Raw	Unfiltered	10	20	17.0	17.0	17.0	119	20 ml pipette
Settled	Unfiltered	10	20	14.0	14.0	14.0	99	20 ml pipette
WAS	Unfiltered	10	50	61.2	61.2	61.2	171	50 ml pipette
Effluent	Filtered	10	50	2.4	2.4	2.4	6.7	50 ml pipette
FS supernatant	Unfiltered	10	50	30.8	30.8	30.8	86.2	50 ml pipette
FS supernatant	Filtered	10	50	30.6	30.6	30.6	85.7	50 ml pipette

General comments: WAS total sample unconcentrated

Sources of error: Dilution, incorrect titration readings

FSA test results

Date: 22-Jan-07

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
FS supernatant	Filtered	10	50	25.9	22.2	24.05	67	50 ml pipette
Effluent	Filtered	10	100	2.4	2.4	2.4	3.4	100 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings

Solids test results

Date: 22-Jan-07

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Measuring equipment
Raw	50	1.5001	24.0812	25.5234	24.0881	-1158	-1296	138	50 ml pipette
Settled	100	1.4229	32.0909	33.5405	32.0958	267	218	49	100 ml pipette
WAS (unconcentrated)	50	0.0000	22.4154	22.5778	22.4649	3248	2258	990	50 ml pipette
PS	35.0	1.4307	92.5056	94.2473	92.5545	8886	7489	1397	50 ml cyl.
FS	47	1.3000	55.4212	56.9896	55.4553	5711	4985	726	100 ml cyl.
WAS (From batch test)	51	1.4715	28.4090	29.9910	28.4344	2167	1669	498	100 ml cyl.

General: Use FS batch test results, use settled ww. and FS results to calculate PS.

Sources of error: IS measurement error - small mass

Phosphate test results

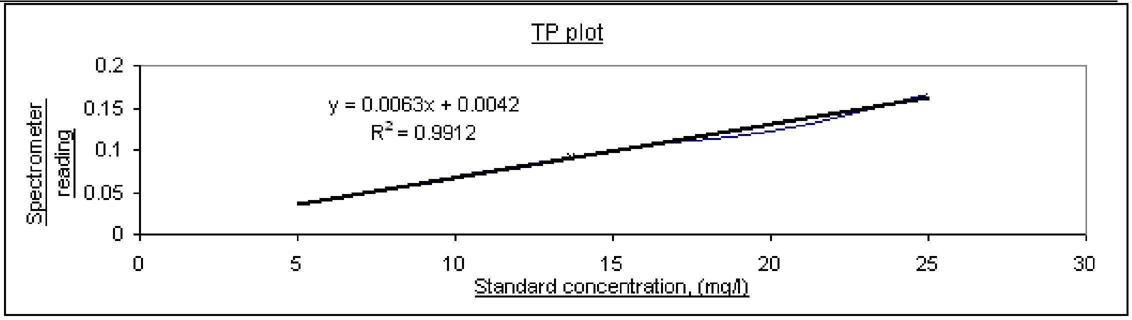
Date: 22-Jan-07

Total - phosphate (TP) test

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.036	n/a	n/a	n/a
Standard	10	0.068	n/a	n/a	n/a
Standard	15	0.100	n/a	n/a	n/a
Standard	20	0.122	n/a	n/a	n/a
Standard	25	0.166	n/a	n/a	n/a
Raw	5.0	0.036	5	101.0	5 ml pipette
Settled	3.9	0.029	5	78.7	5 ml pipette
WAS	4.6	0.033	5	89.6	5 ml pipette
Effluent	9.3	0.063	100	9.3	100 ml pipette
FS super.* - unfilt.	0.4	0.007	20	2.2	20 ml pipette
FS super.* - filt.	0.0	0.004	20	0.0	20 ml pipette

* FS supernatant - unfiltered or filtered

Sources of error: Dilution, incorrect titration readings



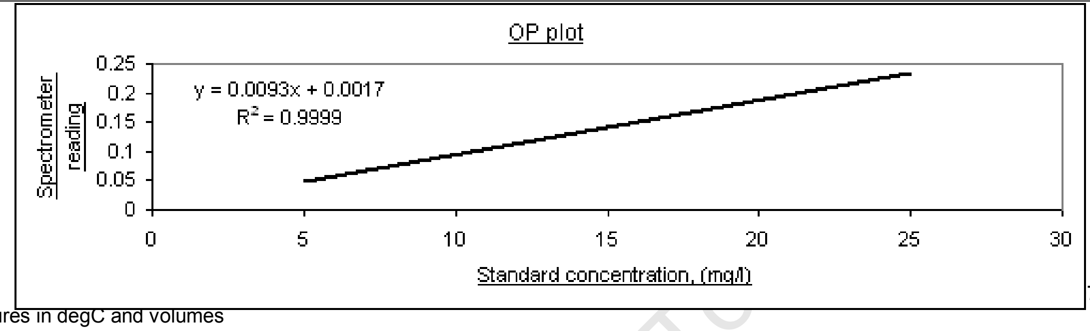
Ortho - phosphate (OP) test

Date: 22-Jan-07

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.049	n/a	n/a	n/a
Standard	10	0.094	n/a	n/a	n/a
Standard	15	0.142	n/a	n/a	n/a
Standard	20	0.189	n/a	n/a	n/a
Standard	25	0.235	n/a	n/a	n/a
FS supernatant	1.9	0.019	20	9.3	20 ml pipette
Effluent	1.5	0.016	50	3.1	50 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings



VFA tests

7

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	7.84	pH6.7:	6.72	pH5.9:	5.86	pH5.2:	5.24	pH4.3:	4.33
Ti:	24.2	V6.7:	2.805	V5.9:	7.58	V5.2:	9.495	V4.3:	10.33
Tf:	24.1	Alkalinity as CaCO3:		3156.7	mg/l ;	VFA:	75.9	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.23	pH6.7:	6.74	pH5.9:	5.93	pH5.2:	5.23	pH4.3:	4.26
Ti:	25.0	V6.7:	3.875	V5.9:	9.950	V5.2:	13.115	V4.3:	14.090
Tf:	25.9	Alkalinity as CaCO3:		4371.5	mg/l ;	VFA:	0	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.29	pH6.7:	6.74	pH5.9:	5.94	pH5.2:	5.24	pH4.3:	4.29
Ti:	23.1	V6.7:	3.835	V5.9:	9.705	V5.2:	12.810	V4.3:	13.775
Tf:	23.2	Alkalinity as CaCO3:		4283.4	mg/l ;	VFA:	0	mg/l as acetic acid	

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	46.05	3.38	1.21	50.64	35.0
FS	23.47	3.99	1.00	28.46	35.0
WAS	35.86	5.23	4.14	45.23	6.78

C1.3.5. Test results at batch test termination

Batch test contents appearance at batch test termination

Primary sludge batch test:
Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

Flocculated raw wastewater batch test:
Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production. White substance coated sides of container - amount negligible.

Waste activated sludge batch test:
Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

C1.14

COD test results

FAS normality:		0.0512	Titration Results				Date:	29-May-07
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24.0	24.2	24.1	0	
PS	Unfiltered	10	5.0	19.7	19.7	19.7	3604	10 ml grad. cylinder
FS	Unfiltered	10	6.0	22.2	21.9	22.1	1408	10 ml grad. cylinder
WAS	Unfiltered	10	5.0	21.2	21.2	21.2	2376	10 ml grad. cylinder
PS	Filtered	10	100	20.4	21.9	21.15	121	25 ml pipette
FS	Filtered	10	9.8	23.5	23.6	23.55	231	10 ml pipette
WAS	Filtered	10	100	21.2	21.1	21.15	121	25 ml pipette

General: FS terminated and measured 9 July 2007. N = 0.0515 , Blank Vave = 24.1 ml.

TKN test results

H2SO4 normality:		0.001	Titration Results				Date:	29-May-07
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
PS	Unfiltered	10	5.0	9.2	9.2	9.2	258	10 ml grad. cylinder
FS	Unfiltered	10	4.0	5.1	5.1	5.1	179	10 ml grad. cylinder
WAS	Unfiltered	10	4.5	6.4	6.4	6.4	199	10 ml grad. cylinder
PS	Filtered	10	10.5	10.1	10.2	10.2	135	10 ml grad. cylinder
FS	Filtered	10	10.0	10.1	10.1	10.1	141	10 ml grad. cylinder
WAS	Filtered	10	10.5	9.0	9.5	9.3	123	10 ml grad. cylinder

General comments: FS terminated and measured 9 July 2007.

Sources of error: Dilution, incorrect titration readings

FSA test results

H2SO4 normality:		0.001	Titration Results				Date:	29-May-07
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
PS	Filtered	10	10.5	5.7	5.5	5.6	75	10 ml graduated cylinder
FS	Filtered	10	10.5	7.0	7	7.0	93	10 ml graduated cylinder
WAS	Filtered	10	10.5	5.2	5.2	5.2	69	10 ml graduated cylinder

General comments: FS terminated and measured 9 July 2007.

Solids test results

								Date:	29-May-07
Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Volumetric measuring equipment
PS	47	1.3044	29.3529	30.8310	29.3700	3696	3332	364	50 ml cyl.
FS	45	1.4055	59.3768	60.8830	59.4167	2238	1351	887	50 ml cyl.
WAS	48	1.3626	30.7203	32.2100	30.7765	2648	1477	1171	50 ml cyl.

General comments: FS terminated and measured 9 July 2007.

Sources of error: IS measurement error - small mass

Phosphate test results

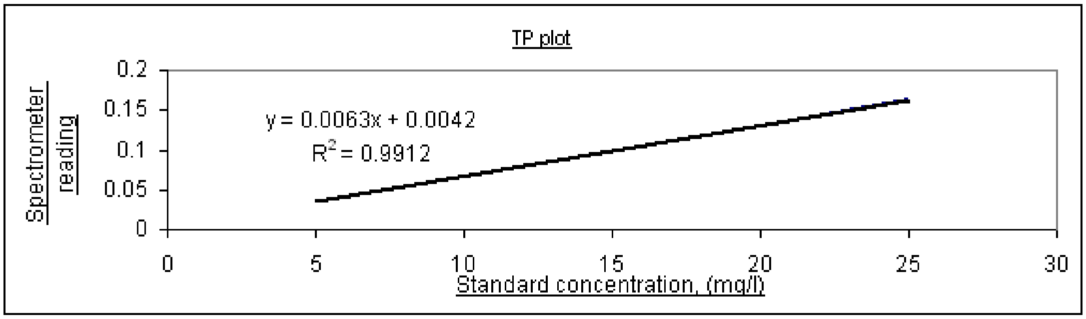
Total - phosphate (TP) test

Date: 29-May-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.035	n/a	n/a	n/a
Standard		10	0.066	n/a	n/a	n/a
Standard		15	0.098	n/a	n/a	n/a
Standard		20	0.131	n/a	n/a	n/a
Standard		25	0.164	n/a	n/a	n/a
PS	Unfiltered	9.5	0.064	4	237	5 ml graduated cylinder
FS	Unfiltered	13.6	0.090	5	272	5 ml graduated cylinder
WAS	Unfiltered	16.2	0.106	16	101.0	10 ml grad. cylinder
PS	Filtered	0.3	0.006	10	2.9	10 ml pipette
FS	Filtered	0.0	0.004	10	0.0	10 ml pipette
WAS	Filtered	2.5	0.02	10	25.1	10 ml pipette

Note: See plot next page

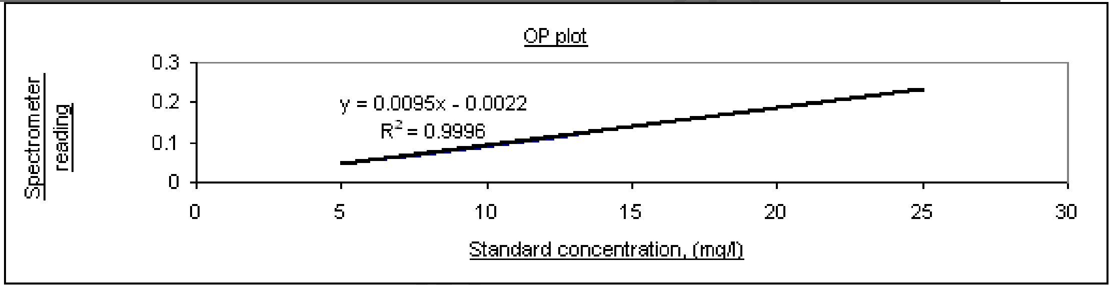
C1.15



Ortho - phosphate (OP) test Date: 29-May-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.047	n/a	n/a	n/a
Standard		10	0.091	n/a	n/a	n/a
Standard		15	0.139	n/a	n/a	n/a
Standard		20	0.187	n/a	n/a	n/a
Standard		25	0.236	n/a	n/a	n/a
PS	Filtered	0.3	0.001	10	3.4	10 ml pipette
FS	Filtered	0.4	0.002	10	4.4	10 ml pipette
WAS	Filtered	3.0	0.026	10	29.7	10 ml pipette

Sources of error: Dilution, incorrect titration readings



VFA tests

Note: All temperatures in degC and volumes in ml N = 0.062282 Date: 29-May-07

Flocculated raw wastewater sludge batch:

pHi:	8.39	pH6.7:	6.72	pH5.9:	5.9	pH5.2:	5.19	pH4.3:	4.35
Ti:	21.3	V6.7:	4.245	V5.9:	10.155	V5.2:	12.975	V4.3:	13.890
Tf:	21.5	Alkalinity as CaCO3:		4566.1	mg/l ;	VFA:	64.4	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.58	pH6.7:	6.68	pH5.9:	5.93	pH5.2:	5.23	pH4.3:	4.17
Ti:	21.2	V6.7:	4.755	V5.9:	10.275	V5.2:	13.04	V4.3:	14.145
Tf:	21.6	Alkalinity as CaCO3:		4660.1	mg/l ;	VFA:	156.3	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.41	pH6.7:	6.74	pH5.9:	5.92	pH5.2:	5.15	pH4.3:	4.30
Ti:	21.3	V6.7:	4.575	V5.9:	11.015	V5.2:	14.265	V4.3:	15.090
Tf:	21.5	Alkalinity as CaCO3:		4982.1	mg/l ;	VFA:	1.3	mg/l as acetic acid	

Gas results Date: 16-Feb-07

Batch test contents	%CO2	%CH4	%N2	Adjusted %CO2	Adjusted %CH4	Total gas volume (l)	CO2 gas volume (l)	CH4 gas volume (l)
PS	60.685	36.228	3.087	62.6	37.4	0.1068	0.067	0.040
FS	74.989	24.072	0.939	75.7	24.3	0.220	0.167	0.053
WAS	52.927	45.284	1.789	53.9	46.1	2.193	1.182	1.011

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	35.32	4.92	1.49	41.73	214
FS	18.18	2.94	0.86	21.98	33.9
WAS	16.48	4.76	1.22	22.46	28.3

C1.4. LABORATORY DATA: BTG 5

C1.4.1. Operational data

1. Batch test retention time: 127 days (PS and WAS), 169 days (FS)
2. Batch test temperature: 22 degC ± 0.5 degC

C1.4.2. Buffer calculations and usage

Formulae used:

1. NaHCO3 (mg/l) required = Alkalinity required (as mg/l CaCO3) x 84 / 50
2. Mass of NaHCO3 (mg) required = concentration of NaHCO3 (mg/l) x batch test initial volume estimate (l)
3. NaHCO3 batch test concentration = actual mass of NaHCO3 (mg) used / batch test actual volume (l)

Assumptions

mg/l Alkalinity required (as CaCO3) = 2500-5500 mg/l

Batch test contents	Alkalinity range required - As mg/lCaCO3	Approx. alkalinity required (As mg/l CaCO3)	NaHCO3 (mg/l) required	Batch test initial volume estimate (l)	Mass NaHCO3 (g) estimated	Mass NaHCO3 (mg) used	Tested alkalinity (mg/l)
PS	2500 - 5500	4500	7560	0.950	7.1820	7.1744	4356
FS	as above	4500	7560	1.950	14.7420	15.0030	4222
WAS	as above	4500	7560	1.950	14.7420	15.0030	4338

C1.4.3. Batch test volume measurements

Batch test contents	Total water volume (l)	Sludge initial volume (l)	Super - natant volume (l)	with distilled water addition (l)	Samples volume (l)	Buffer addition (l)	Innoculant (l)	Diluted batch test volume (l)	Final batch test volume (l)
PS	10.00	0.170	9.830	0.670	0.103	0.100	0.020	0.790	0.687
Samples taken								*Yes*	
Measuring equipment	*1l graduated cylinder*	*100 ml graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
FS	6.000	2.000	4.000	2.000	0.218	0.100	0.020	2.120	1.902
Samples taken								*Yes*	
Measuring equipment	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
WAS	2.290	2.000	0.290	2.000	0.203	0.000	0.020	2.020	1.817
Samples taken								*Yes*	
Measuring equipement	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*not measured*	*20 ml pipette*	*calculated*	*calculated*

C1.4.4. Test results at batch test setup

COD test results

Date: 22-Jan-07

FAS normality: 0.0509

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	25.5	25.3	25.4	0	
Raw	Unfiltered	10	50	8.4	8.4	8.4	1384	50 ml pipette
Settled	Unfiltered	10	50	20.7	20.8	20.8	379	50 ml pipette
WAS	Unfiltered	10	10	15.7	16.3	16.0	3828	10 ml pipette
Effluent	Filtered	10	50	25.0	25.0	25	33	50 ml pipette
FS supernatant	Unfiltered	10	50	23.3	22.9	23.1	187	50 ml pipette
FS supernatant	Filtered	10	50	23.3	23.3	23.3	171	50 ml pipette

General comments: WAS total sample concentrated

Sources of error: Dilution, incorrect titration readings

Date: 22-Jan-07

C1.17

TKN test results

H2SO4 normality: 0.001 — Titration Results — Date: 22-Jan-07

Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
Raw	Unfiltered	10	20	16.5	16.5	16.5	116	20 ml pipette
Settled	Unfiltered	10	50	34.3	34.3	34.3	96	50 ml pipette
WAS	Unfiltered	10	10	13.5	13.1	13.3	186	10 ml pipette
Effluent	Filtered	10	50	2.4	2.4	2.4	6.7	50 ml pipette
FS supernatant	Unfiltered	10	50	30.7	29.4	30.1	84.1	50 ml pipette
FS supernatant	Filtered	10	50	29.6	30.1	29.9	83.6	50 ml pipette

General comments: WAS total sample unconcentrated

Sources of error: Dilution, incorrect titration readings

FSA test results — Date: 22-Jan-07

H2SO4 normality: 0.001 — Titration Results

Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
FS supernatant	Filtered	10	50	25.9	22.2	24.05	67	50 ml pipette
Effluent	Filtered	10	100	2.4	2.4	2.4	3.4	100 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings

Solids test results — Date: 22-Jan-07

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Measuring equipment
Raw	50	1.4341	27.2804	28.7264	27.2709	238	428	-190	50 ml pipette
Settled	100	1.4229	32.0909	33.5405	32.0958	267	218	49	
WAS (unconcentrated)	50	0.0000	22.4154	22.5778	22.4649	3248	2258	990	50 ml pipette
PS	26.0	1.4490	90.2823	92.0172	90.3276	10996	9254	1742	50 ml cylinder
FS	49	1.4265	58.0040	59.8971	58.1296	9522	6959	2563	50 ml cylinder
WAS (From batch test)	46.5	1.4419	49.7424	51.3082	49.7782	2665	1895	770	50 ml cylinder

General:

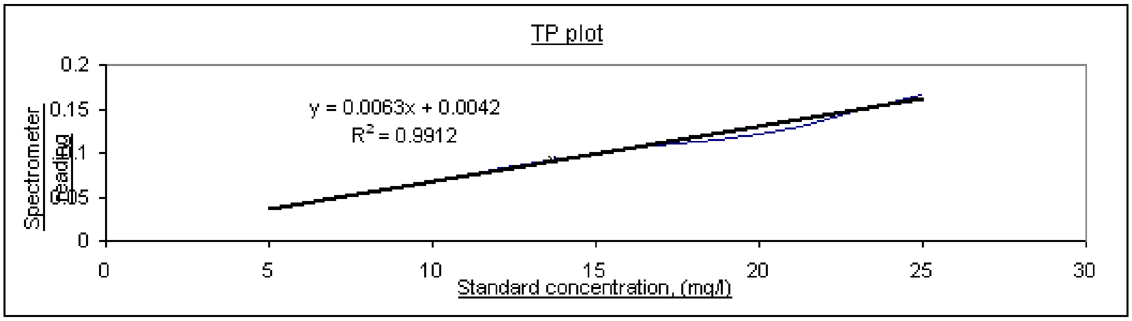
Sources of error: IS measurement error - small mass

Phosphate test results — Date: 22-Jan-07

Total - phosphate (TP) test

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.036	n/a	n/a	n/a
Standard	10	0.068	n/a	n/a	n/a
Standard	15	0.100	n/a	n/a	n/a
Standard	20	0.122	n/a	n/a	n/a
Standard	25	0.166	n/a	n/a	n/a
Raw	4.7	0.034	5	94.6	10 ml cylinder
Settled	4.6	0.033	5.6	81.6	10 ml cylinder
WAS	3.9	0.029	5.6	70.3	10 ml cylinder
Effluent	9.3	0.063	100	9.3	20 ml pipette
FS super.* - unfilt.	0.8	0.009	20	3.8	20 ml pipette
FS super.* - filt.	0.3	0.006	20	1.4	20 ml pipette

* FS supernatant - unfiltered or filtered



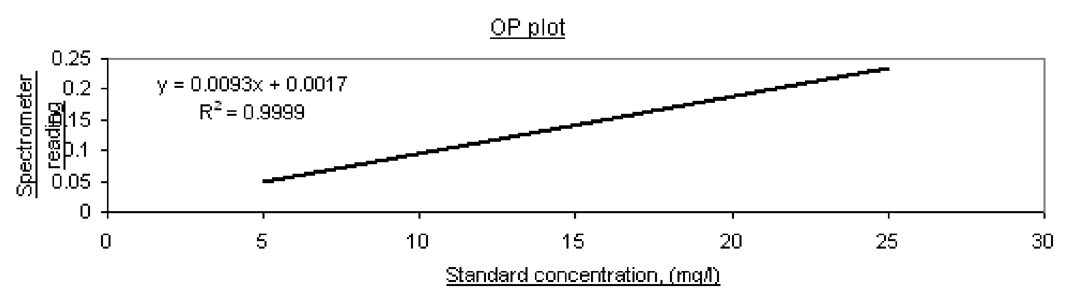
Ortho - phosphate (OP) test

Date: 22-Jan-07

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.049	n/a	n/a	n/a
Standard	10	0.094	n/a	n/a	n/a
Standard	15	0.142	n/a	n/a	n/a
Standard	20	0.189	n/a	n/a	n/a
Standard	25	0.235	n/a	n/a	n/a
FS supernatant	1.9	0.019	20	9.3	20 ml pipette
Effluent	1.5	0.016	50	3.1	50 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings



VFA tests

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	7.83	pH6.7:	6.74	pH5.9:	5.94	pH5.2:	5.23	pH4.3:	4.3
Ti:	23	V6.7:	3.435	V5.9:	9.42	V5.2:	12.53	V4.3:	13.7
Tf:	23.2	Alkalinity as CaCO3:		4222.4	mg/l ;	VFA:	87.2	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.3	pH6.7:	6.74	pH5.9:	5.94	pH5.2:	5.23	pH4.3:	4.25
Ti:	25.4	V6.7:	3.900	V5.9:	9.905	V5.2:	13.015	V4.3:	13.995
Tf:	25.3	Alkalinity as CaCO3:		4355.9	mg/l ;	VFA:	0	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.29	pH6.7:	6.72	pH5.9:	5.93	pH5.2:	5.24	pH4.3:	4.32
Ti:	23	V6.7:	4.07	V5.9:	9.96	V5.2:	13.040	V4.3:	14
Tf:	23.1	Alkalinity as CaCO3:		4337.9	mg/l ;	VFA:	0	mg/l as acetic acid	

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	38.93	5.68	1.23	45.84	26.7
FS	17.76	3.61	0.66	22.03	26.7
WAS	35.86	5.23	4.14	45.23	6.78

C1.4.5. Test results at batch test termination

Batch test contents appearance at batch test termination

Primary sludge batch test:
Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

Flocculated raw wastewater batch test:
Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.White substance coated sides of container - amount negligible.

Waste activated sludge batch test:
Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

COD test results

FAS normality: 0.0512 Titration Results Date: 29-May-07

Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24	24.2	24.1	0	
PS	Unfiltered	10	4	20.6	20.2	20.4	3789	10 ml grad. cylinder
FS	Unfiltered	10	6	21.4	21.4	21.4	1854	10 ml grad. cylinder
WAS	Unfiltered	10	5	20.7	20.8	20.8	2744	10 ml grad. cylinder
PS	Filtered	10	100	19.0	18.6	18.8	217	100 ml pipette
FS	Filtered	10	10	22.7	22.4	22.6	639	10 ml pipette
WAS	Filtered	10	100	20.0	19.9	20.0	170	100 ml pipette

General comments: FS terminated and measured 9 July 2007. N = 0.0515 , Blank Vave = 24.1 ml.

TKN test results

H2SO4 normality: 0.001 Titration Results Date: 29-May-07

Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
PS	Unfiltered	10	4	6.6	6.6	6.6	264	10 ml grad. cylinder
FS	Unfiltered	10	5	6.2	6.2	6.2	174	10 ml grad. cylinder
WAS	Unfiltered	10	5	7.5	7.5	7.5	210	10 ml grad. cylinder
PS	Filtered	10	9	7.5	7.5	7.5	117	auto. pipette
FS	Filtered	10	10	10.2	10.2	10.2	143	auto. pipette
WAS	Filtered	10	9	7.1	7.1	7.1	110	auto. pipette

General comments: FS terminated and measured 9 July 2007.

Sources of error: Dilution, incorrect titration readings

FSA test results

H2SO4 normality: 0.001 Titration Results Date: 29-May-07

Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
PS	Filtered	10	10	5.2	4.6	4.9	69	10 ml pipette
FS	Filtered	10	10	7.6	8.2	7.9	111	10 ml pipette
WAS	Filtered	10	10	7.3	6.7	7.0	98	10 ml pipette

General comments: FS terminated and measured 9 July 2007.

Sources of error: Dilution, incorrect titration readings

Solids test results Date: 29-May-07

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Volumetric measuring equipment
PS	46	1.3001	59.3790	60.9997	59.4563	6970	5289	1680	100 ml cylinder
FS	50	1.4005	53.4395	54.9991	53.4914	3182	2144	1038	100 ml cylinder
WAS	47	1.4831	62.1229	63.7151	62.1644	2321	1438	883	100 ml cylinder

General comments: FS terminated and measured 9 July 2007.

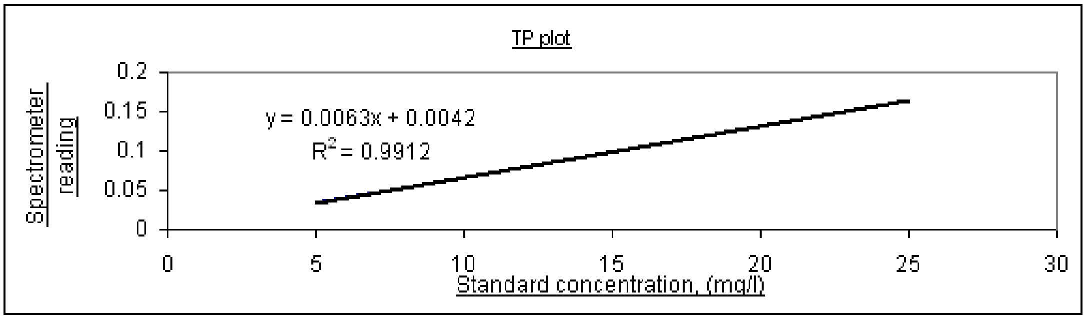
Sources of error: IS measurement error - small mass

Phosphate test results

Total - phosphate (TP) test Date: 29-May-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.035	n/a	n/a	n/a
Standard		10	0.066	n/a	n/a	n/a
Standard		15	0.098	n/a	n/a	n/a
Standard		20	0.131	n/a	n/a	n/a
Standard		25	0.164	n/a	n/a	n/a
PS	Unfiltered	9.5	0.064	5	190	5 ml graduated cylinder
FS	Unfiltered	13.6	0.090	5	272	5 ml graduated cylinder
WAS	Unfiltered	16.2	0.106	20	80.8	50 ml grad. cylinder
PS	Filtered	0.3	0.006	10	2.9	10 ml pipette
FS	Filtered	0.0	0.004	10	0.0	10 ml pipette
WAS	Filtered	2.5	0.02	10	25.1	10 ml pipette

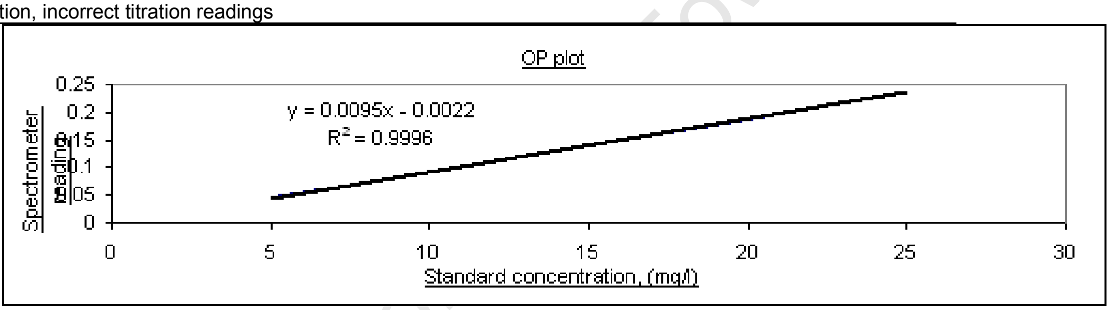
Note: See plot next page



Ortho -phosphate (OP) test Date: 29-May-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.047	n/a	n/a	n/a
Standard		10	0.091	n/a	n/a	n/a
Standard		15	0.139	n/a	n/a	n/a
Standard		20	0.187	n/a	n/a	n/a
Standard		25	0.236	n/a	n/a	n/a
PS	Filtered	0.3	0.001	10	3.4	10 ml pipette
FS	Filtered	0.4	0.002	10	4.4	10 ml pipette
WAS	Filtered	3.0	0.026	10	29.7	10 ml pipette

Sources of error: Dilution, incorrect titration readings



VFA tests Date: 07

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	8.4	pH6.7:	6.70	pH5.9:	5.90	pH5.2:	5.24	pH4.3:	4.33
Ti:	20.8	V6.7:	3.460	V5.9:	7.750	V5.2:	9.700	V4.3:	10.450
Tf:	21.3	Alkalinity as CaCO3:		3386.5	mg/l ;	VFA:	59.4	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.58	pH6.7:	6.68	pH5.9:	5.93	pH5.2:	5.08	pH4.3:	4.27
Ti:	21.3	V6.7:	4.425	V5.9:	9.755	V5.2:	13.320	V4.3:	14.100
Tf:	21.6	Alkalinity as CaCO3:		4576.6	mg/l ;	VFA:	0	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.69	pH6.7:	6.71	pH5.9:	5.94	pH5.2:	5.22	pH4.3:	4.22
Ti:	21.7	V6.7:	4.535	V5.9:	10.38	V5.2:	13.970	V4.3:	15.260
Tf:	21.8	Alkalinity as CaCO3:		4947.5	mg/l ;	VFA:	85.7	mg/l as acetic acid	

Gas results Date: 16-Feb-07

Batch test contents	%CO2	%CH4	%N2	Adjusted %CO2	Adjusted %CH4	Total gas volume (l)	CO2 gas volume (l)	CH4 gas volume (l)
PS	0	0	100	0.0	0.0	0.063	0.000	0.063
FS	97.726	0	2.274	100.0	0.0	0.031	0.031	0.000
WAS	0	0	100	0.0	0.0	0.184	0.000	0.184

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	20.64	4.11	1.68	26.43	218.6
FS	17.08	2.66	0.80	20.54	135.8
WAS	29.54	4.51	2.81	36.86	13.6

C1.5. LABORATORY DATA: BTG 6

C1.5.1. Operational data

1. Batch test retention time: 117 days
2. Batch test temperature: 35 degC ± 0.5 degC

C1.5.2. Buffer calculations and usage

Formulae used:

1. NaHCO3 (mg/l) required = Alkalinity required (as mg/l CaCO3) x 84 / 50
2. Mass of NaHCO3 (mg) required = concentration of NaHCO3 (mg/l) x batch test initial volume estimate (l)
3. NaHCO3 batch test concentration = actual mass of NaHCO3 (mg) used / batch test actual volume (l)

Assumptions

mg/l Alkalinity required (as CaCO3) = 2500-5500 mg/l

Batch test contents	Alkalinity range required - As mg/lCaCO3	Approx. alkalinity required (As mg/l CaCO3)	NaHCO3 (mg/l) required	Batch test initial volume estimate (l)	Mass NaHCO3 (g) required	Mass NaHCO3 (mg) used	Tested alkalinity (mg/l)
PS	2500 - 5500	4500	7560	0.817	6.1765	6.2046	4334
FS	as above	4500	7560	1.950	14.7420	14.754	3998
WAS	as above	4500	7560	1.957	14.7949	14.773	4215

C1.5.3. Batch test volume measurements

Batch test contents	Total water volume (l)	Sludge initial volume (l)	Supernatant volume (l)	with distilled water addition (l)	Samples volume (l)	Buffer addition (l)	Innoculant (l)	Diluted batch test volume (l)	Final batch test volume (l)
PS	10.00	0.640	9.360	0.840	0.133	0.100	0.020	0.960	0.827
Samples taken								*Yes*	
Measuring equipment	*1l graduated cylinder*	*100 ml graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
FS	6.000	2.000	4.000	2.000	0.160	0.200	0.020	2.220	2.060
Samples taken								*Yes*	
Measuring equipment	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*100 ml volumetric flask*	*20 ml pipette*	*calculated*	*calculated*
WAS	4.375	2.000	2.375	2.000	0.153	0.200	0.020	2.220	2.067
Samples taken								*Yes*	
Measuring equipment	*1l graduated cylinder*	*1l graduated cylinder*	*calculated*	*calculated*	*see tests*	*not measured*	*20 ml pipette*	*calculated*	*calculated*

C1.5.4. Test results at batch test setup

COD test results Date: 15-Mar-07

FAS normality: 0.0504

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24.4	24.8	24.6	0	
Raw	Unfiltered	10	18	14.4	14.6	14.5	2262	10 ml cylinder tested pipette
Settled	Unfiltered	10	20	20.1	20.1	20.1	907	10 ml cylinder tested pipette
WAS	Unfiltered	10	20	10.0	9.8	9.9	2964	10 ml cylinder tested pipette
Effluent	Filtered	10	100	23.0	23.7	23.35	50.4	100 ml pipette
FS supernatant	Unfiltered	10	100	16.6	16.6	16.6	323	100 ml pipette
FS supernatant	Filtered	10	100	17.1	17.3	17.2	298	100 ml pipette

General comments: WAS total sample unconcentrated

Sources of error: Dilution, incorrect titration readings

TKN test results

H2SO4 normality: 0.001

Date: 15-Mar-07

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
Raw	Unfiltered	10	20	20.4	20.4	20.4	143	20 ml pipette
Settled	Unfiltered	10	20	17.5	17.5	17.5	123	20 ml pipette
WAS	Unfiltered	10	20	22.7	22.7	22.7	159	20 ml pipette
Effluent	Filtered	10	100	2.9	2.9	2.9	4.1	100 ml pipette
FS supernatant	Unfiltered	10	25	16.8	16.8	16.8	94.1	25 ml pipette
FS supernatant	Filtered	10	25	16.1	16.3	16.2	90.7	25 ml pipette

General comments: WAS total sample unconcentrated

Sources of error: Dilution, incorrect titration readings

FSA test results

Date: 15-Mar-07

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
FS supernatant	Filtered	10	25	14.8	14.5	14.65	82	25 ml pipette
Effluent	Filtered	10	100	2.6	2.8	2.7	3.8	100 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings

Solids test results

Date: 15-Mar-07

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Measuring equipment
Raw	93	1.4580	58.5623	60.0935	58.5856	787	537	251	100 ml cyl.
WAS (unconcentrated)	50	0.0000	59.3689	59.4578	59.3799	1778	1558	220	50 ml pipette
PS	47	1.3600	60.1083	61.9052	60.1587	9296	8223	1072	50 ml cylinder
FS	49	1.3000	28.4057	30.0170	28.4461	6353	5529	824	50 ml cylinder
WAS (From batch test)	50	0.0000	22.4468	22.6478	22.4731	4020	3494	526	50 ml cylinder

General:

Sources of error: IS measurement error - small mass

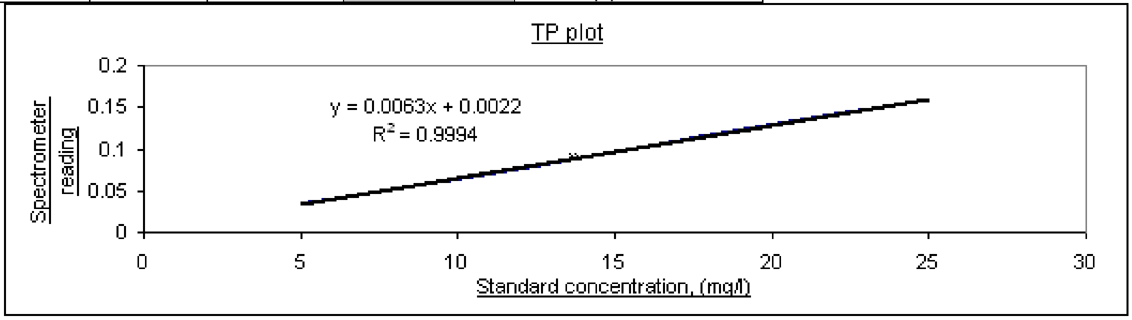
Phosphate test results

Date: 15-Mar-07

Total - phosphate (TP) test

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.035	n/a	n/a	n/a
Standard	10	0.064	n/a	n/a	n/a
Standard	15	0.096	n/a	n/a	n/a
Standard	20	0.130	n/a	n/a	n/a
Standard	25	0.160	n/a	n/a	n/a
Raw	15.7	0.101	27.0	58.1	Cylinder tested auto. pipette
Settled	8.1	0.053	18.0	44.8	Cylinder tested auto. pipette
WAS	8.4	0.055	18.0	46.6	Cylinder tested auto. pipette
Effluent	0.0	0.002	25.0	0.0	25 ml pipette
FS super.* - unfilt.	3.0	0.021	25.0	11.9	25 ml pipette
FS super.* - filt.	2.3	0.017	100.0	2.3	100 ml pipette

* FS supernatant - unfiltered or filtered

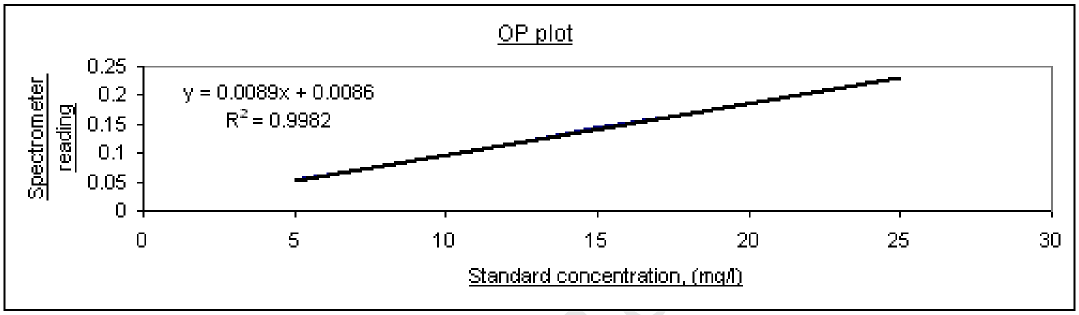


Ortho - phosphate (OP) test Date: 15-Mar-07

Wastewater type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard	5	0.054	n/a	n/a	n/a
Standard	10	0.094	n/a	n/a	n/a
Standard	15	0.146	n/a	n/a	n/a
Standard	20	0.184	n/a	n/a	n/a
Standard	25	0.231	n/a	n/a	n/a
FS supernatant	2.1	0.027	25	8.3	25 ml pipette
Effluent	-0.9	0.001	25	-3.4	25 ml pipette

General comments:

Sources of error: Dilution, incorrect titration readings



VFA tests Date: 15-Mar-07

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	7.95	pH6.7:	6.75	pH5.9:	5.95	pH5.2:	5.24	pH4.3:	4.36
Ti:	19.5	V6.7:	3.27	V5.9:	8.85	V5.2:	11.97	V4.3:	13.08
Tf:	20.1	Alkalinity as CaCO3:		3997.9	mg/l ;	VFA:	93.7	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.08	pH6.7:	6.73	pH5.9:	5.94	pH5.2:	5.23	pH4.3:	4.29
Ti:	19.3	V6.7:	3.670	V5.9:	9.625	V5.2:	12.965	V4.3:	14.190
Tf:	20	Alkalinity as CaCO3:		4333.8	mg/l ;	VFA:	114.5	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.23	pH6.7:	6.75	pH5.9:	5.94	pH5.2:	5.23	pH4.3:	4.23
Ti:	19.0	V6.7:	3.705	V5.9:	5.595	V5.2:	12.595	V4.3:	13.535
Tf:	19.9	Alkalinity as CaCO3:		4215.1	mg/l ;	VFA:	0	mg/l as acetic acid	

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	45.99	6.72	1.97	54.68	76
FS	32.22	4.73	1.89	38.84	76
WAS	44.01	6.48	7.23	57.72	5.26

C1.5.5. Test results at batch test termination

Batch test contents appearance at batch test termination

Primary sludge batch test:

Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

Flocculated raw wastewater batch test:

Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.White substance coated sides of container - amount negligible.

Waste activated sludge batch test:

Dark brown granulated sludge mass apparent at bottom of container. Supernatant clear. Smell upon opening indicated methane production.

COD test results Date: 09-Jul-07

FAS normality: 0.0515

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	COD (mg/l)	Volumetric measuring equipment for dilutions
Blank	-	10	-	24.0	24.2	24.1	0	
PS	Unfiltered	10	5.0	17.4	18.2	17.8	5191	10 ml grad. cylinder
FS	Unfiltered	10	5.0	21.0	21.0	21.0	2554	10 ml grad. cylinder
WAS	Unfiltered	10	5.0	20.7	20.0	20.35	3090	10 ml grad. cylinder
PS	Filtered	10	9.8	22.2	22.4	22.3	757	10 ml grad. cylinder
FS	Filtered	10	9.8	23.1	23.2	23.15	399	10 ml grad. cylinder
WAS	Filtered	10	9.8	23.6	23.6	23.6	210	10 ml grad. cylinder

General comments:

Sources of error: Dilution, incorrect titration readings

TKN test results Date: 08-Jul-07

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	TKN (mg/l)	Volumetric measuring equipment for dilutions
PS	Unfiltered	10	5.0	10.8	10.8	10.8	302	10 ml grad. cylinder
FS	Unfiltered	10	5.0	7.5	7.5	7.5	210	10 ml grad. cylinder
WAS	Unfiltered	10	5.0	11.0	11.0	11.0	308	10 ml grad. cylinder
PS	Filtered	10	9.8	7.4	7.3	7.4	105	10 ml grad. cylinder
FS	Filtered	10	9.8	10.5	10.5	10.5	150	10 ml grad. cylinder
WAS	Filtered	10	9.8	13.5	13.6	13.6	194	10 ml grad. cylinder

General comments: FS terminated and measured 9 July 2007.

Sources of error: Dilution, incorrect titration readings

FSA test results Date: 08-Jul-07

H2SO4 normality: 0.001

			Titration Results					
Wastewater type	Sample type	Sample Volume, V (ml)	Dilution: ml in 100 ml	Volume a titrated, V (ml)	Volume b titrated, V (ml)	Average Vol. titrated, V (ml)	FSA (mg/l)	Volumetric measuring equipment for dilutions
PS	FIltered	10	9.8	7.7	7.7	7.7	110	10 ml grad. cylinder
FS	FIltered	10	9.8	8.5	8.2	8.4	119	11 ml grad. cylinder
WAS	FIltered	10	9.8	9.4	10.4	9.9	141	12 ml grad. cylinder

Sources of error: Dilution, incorrect titration readings

Solids test results Date: 08-Jul-07

Wastewater type	Sample vol. (ml)	Filter paper mass (g)	Crucible mass (g)	Mass after drying (g)	Mass after incineration (g)	TS (mg/l)	VS (mg/l)	IS (mg/l)	Volumetric measuring equipment
PS	48	1.4295	58.1201	59.8067	58.1880	5356	3942	1415	100 ml cyl
FS	49	1.4330	59.1588	60.7145	59.1946	2504	1773	731	100 ml cyl
WAS	46	1.3643	39.3199	40.8509	39.3984	3624	1917	1707	100 ml cyl

Sources of error: IS measurement error - small mass

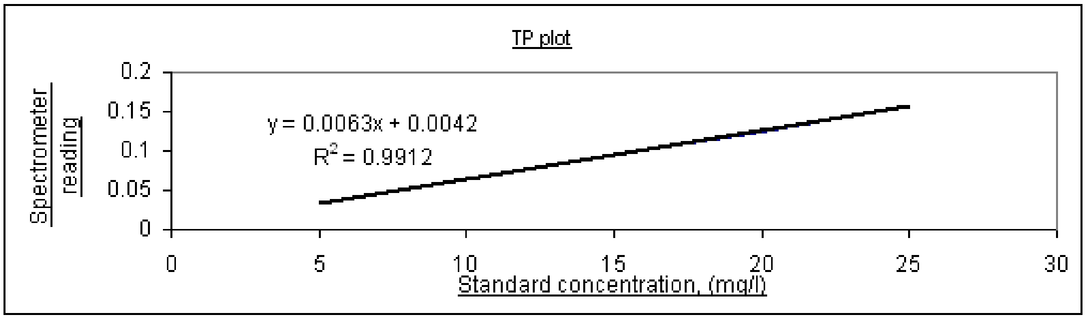
Phosphate test results

Total - phosphate (TP) test Date: 08-Jul-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.034	n/a	n/a	n/a
Standard		10	0.064	n/a	n/a	n/a
Standard		15	0.095	n/a	n/a	n/a
Standard		20	0.125	n/a	n/a	n/a
Standard		25	0.157	n/a	n/a	n/a
PS	Unfiltered	9.0	0.061	5.0	180	5 ml graduated cylinder
FS	Unfiltered	7.3	0.050	5.0	145	5 ml graduated cylinder
WAS	Unfiltered	4.9	0.035	5.0	97.8	5 ml graduated cylinder
PS	Filtered	1.6	0.014	9.8	15.9	10 ml pipette
FS	Filtered	0.0	0.004	9.8	0.0	10 ml pipette
WAS	Filtered	2.8	0.022	9.8	28.8	10 ml pipette

Note: See plot next page

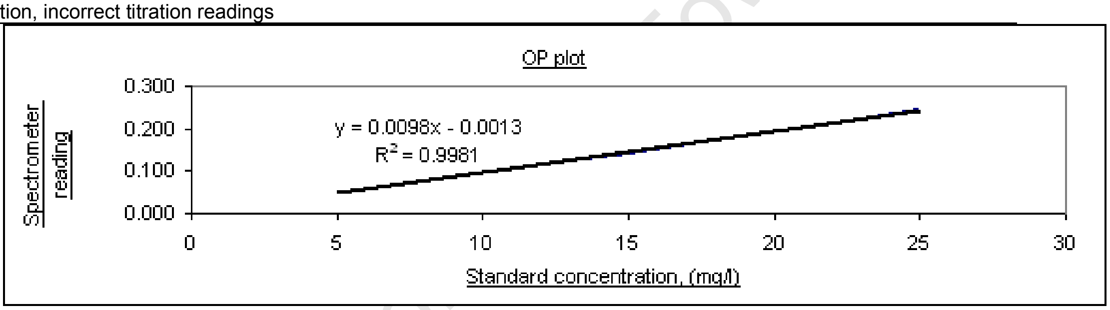
C1.25



Ortho - phosphate (OP) test Date: 08-Jul-07

Wastewater type	Sample Type	Diluted Conc. (mg/l)	Spectro - meter reading	Dilution: ml in 100 ml	Final conc. (mg/l)	Volumetric measuring equipment for dilutions
Standard		5	0.050	n/a	n/a	n/a
Standard		10	0.097	n/a	n/a	n/a
Standard		15	0.141	n/a	n/a	n/a
Standard		20	0.192	n/a	n/a	n/a
Standard		25	0.247	n/a	n/a	n/a
PS	Filtered	3.2	0.03	9.8	32.6	10 ml grad. cylinder
FS	Filtered	0.9	0.008	9.8	9.7	10 ml grad. cylinder
WAS	Filtered	3.5	0.033	9.8	35.7	10 ml grad. cylinder

Sources of error: Dilution, incorrect titration readings



VFA tests Date: 08-Jul-07

Note: All temperatures in degC and volumes in ml

N = 0.062282

Flocculated raw wastewater sludge batch:

pHi:	8.39	pH6.7:	6.72	pH5.9:	5.9	pH5.2:	5.19	pH4.3:	4.35
Ti:	21.3	V6.7:	4.245	V5.9:	12.975	V5.2:	12.975	V4.3:	13.890
Tf:	21.5	Alkalinity as CaCO3:		4566.1	mg/l ;	VFA:	64.4	mg/l as acetic acid	

Primary sludge batch:

pHi:	8.58	pH6.7:	6.68	pH5.9:	5.93	pH5.2:	5.23	pH4.3:	4.17
Ti:	21.2	V6.7:	4.755	V5.9:	12.275	V5.2:	13.04	V4.3:	14.145
Tf:	21.6	Alkalinity as CaCO3:		4660.1	mg/l ;	VFA:	156.3	mg/l as acetic acid	

Waste activated sludge batch:

pHi:	8.41	pH6.7:	6.74	pH5.9:	5.92	pH5.2:	5.15	pH4.3:	4.30
Ti:	21.3	V6.7:	4.575	V5.9:	11.015	V5.2:	14.265	V4.3:	15.090
Tf:	21.5	Alkalinity as CaCO3:		4982.1	mg/l ;	VFA:	1.3	mg/l as acetic acid	

Gas results Date: 16-Feb-07

Batch test contents	%CO2	%CH4	%N2	Adjusted %CO2	Adjusted %CH4	Total gas volume (l)	CO2 gas volume (l)	CH4 gas volume (l)
PS	76.242	23.758	0.000	76.2	23.8	0.021	0.016	0.005
FS	66.461	28.92	4.619	69.7	30.3	0.605	0.422	0.183
WAS	99.596	0	0.404	100.0	0.0	0.145	0.145	0.000

Elemental analysis results

Wastewater type	% Carbon	% Hydrogen	%Nitrogen	Total %	DOC (mg/l)
PS	35.28	4.47	1.75	41.50	46.9
FS	28.69	4.69	1.58	34.96	79.9
WAS	23.6	4.57	1.88	30.05	14.75

C-2 DATA EDITING: THEORY

Table.C2-1: Raw wastewater COD, N and P concentrations (mg/l) calculations and sources

Concentration	Term	Source
Total	$(*)t_{Raw}$	Direct measurement in raw wastewater with COD, TKN or TP test
Organic biodegradable	$(*)b_{Raw}$	$(*)bs_{Raw} + (*)bp_{Raw}$
Organic unbiodegradable	$(*)u_{Raw}$	$(*)us_{Raw} + (*)up_{Raw}$
Total soluble	$(*)ts_{Raw}$	Direct measurement in settled wastewater - 0.45 µm membrane filtered sample
Total particulate	$(*)tp_{Raw}$	$(*)t_{Raw} - (*)ts_{Raw}$
Organic biodegrable soluble	$(*)obs_{Raw}$	$(*)ts_{Raw} - (*)us_{Raw}$ (- measured inorganic N or P where applicable)
Biodegradable particulate	$(*)obp_{Raw}$	$(*)tp_{Raw} - (*)oup_{Raw}$
Unbiodegradable soluble	$(*)ous_{Raw}$	Direct measurement in UCT MLE system effluent. **Assumption:** Unbiodegradable soluble organics in activated sludge treatment remains unbiodegradable during anaerobic treatment .
Ubiodegrable particulate	$(*)oup_{Raw}$	From batch test data at termination: 1. $(*)tp_{FS,\ at\ termination} = (*)t_{FS,\ at\ termination} - (*)ts_{FS,\ at\ termination}$ Where: a) $(*)t_{FS,\ at\ termination}$ = total COD, N or P b) $(*)ts_{FS,\ at\ termination}$ = soluble COD, N or P The compounds above are directly measured in the batch test contents at termination. 2. $(*)oup_{Raw} = (*)tp_{FS,\ at\ termination} \times V_{FS,\ BT} / V_{Raw}$ Where: a) $V_{FS,BT}$ denotes the diluted flocculated sludge volume after addition of buffer and innoculant at batch test setup. b) $V_{FS,\ Raw}$ denotes the total volume of raw wastewater flocculated at batch test setup.

* Relevant parameter i.e. COD, N, or P

Table C2-2: Settled wastewater COD, N and P concentrations (mg/l) calculations and sources

Concentration	Term	Source
Total	$(*)t_{Settled}$	Direct measurement in settled wastewater with COD, TKN or TP test
Organic biodegradable	$(*)ob_{Settled}$	$(*)bs_{Settled} + (*)bp_{Settled}$
Organic unbiodegradable	$(*)ou_{Settled}$	$(*)us_{Settled} + (*)up_{Settled}$
Total soluble	$(*)ts_{Settled}$	Direct measurement in settled wastewater - 0.45 μm membrane filtered sample
Total particulate	$(*)tp_{Settled}$	$(*)t_{Settled} - (*)ts_{Settled}$
Organic biodegrable soluble	$(*)obs_{Settled}$	$(*)ts_{Settled} - (*)us_{Settled}$ (- measured inorganic N or P where applicable)
Biodegradable particulate	$(*)obp_{Settled}$	$(*)tp_{Raw} - (*)oup_{Raw}$
Unbiodegradable soluble	$(*)ous_{Settled}$	Direct measurement in UCT MLE system effluent. **Assumption:** Unbiodegradable soluble organics in activated sludge treatment remains unbiodegradable in anaerobic treatment .
Ubiodegrable particulate	$(*)oup_{Settled}$	From raw wastewater and primary sludge data: $(*)oup_{Settled} = [\ (*)oup_{Raw} \times V_{Raw} - (*)oup_{PS} \times V_{PS}\ ] / V_{Settled}$ Where: a) $(*)oup_{Raw}$ = Raw wastewater unbiodegradable particulate COD, N or P concentrations b) $(*)oup_{PS,\ at\ termination}$ = Primary sludge unbiodegradable particulate COD, N or P concentrations c) V_{Raw} denotes the total raw wastewater volume settled to produce primary sludge (measured) d) V_{PS} denotes the volume of settled primary sludge (measured) e) $V_{Settled}$ denotes the volume of settled wastewater = $V_{Raw} - V_{Settled}$

* Relevant parameter i.e. COD, N, or P

Table C2-3: Primary sludge COD, N and P concentrations (mg/l) calculations and sources

Concentration	Term	Source
Total	$(*)t_{PS}$	From raw wastewater and settled wastewater data: $(*)t_{PS} = [(*)t_{Raw} \times V_{Raw} - (*)t_{Settled} \times V_{Settled}] / V_{PS}$ Where: a) $(*)t_{Raw}$ = Raw wastewater total COD, N or P concentrations (direct measurement) b) $(*)t_{Settled}$ = Settled wastewater total COD, N or P concentrations (direct measurement) c) V_{Raw} denotes the total raw wastewater volume settled to produce primary sludge (direct measurement) d) V_{PS} denotes the volume of settled primary sludge (direct measurement) e) $V_{Settled}$ denotes the volume of settled wastewater = $V_{Raw} - V_{Settled}$
Organic biodegradable	$(*)ob_{PS}$	$(*)bs_{PS} + (*)bp_{PS}$
Organic unbiodegradable	$(*)ou_{Settled}$	$(*)us_{PS} + (*)up_{PS}$
Total soluble	$(*)ts_{PS}$	Direct measurement in settled wastewater - 0.45 μm membrane filtered sample
Total particulate	$(*)tp_{PS}$	$(*)t_{PS} - (*)ts_{PS}$
Organic biodegrable soluble	$(*)obs_{PS}$	$(*)ts_{PS} - (*)us_{PS}$ (- measured inorganic N or P where applicable)
Biodegradable particulate	$(*)obp_{Settled}$	$(*)tp_{PS} - (*)oup_{PS}$
Unbiodegradable soluble	$(*)ous_{PS}$	Direct measurement in UCT MLE system effluent. **Assumption:** Unbiodegradable soluble organics in activated sludge treatment remains unbiodegradable in anaerobic treatment .
Ubiodegrable particulate	$(*)oup_{PS}$	From batch test data at termination: 1. $(*)tp_{PS,\ at\ termination} = (*)t_{PS,\ at\ termination} - (*)ts_{PS,\ at\ termination}$ Where: a) $(*)t_{PS,\ at\ termination}$ = total COD, N or P b) $(*)ts_{PS,\ at\ termination}$ = soluble COD, N or P The compounds above are directly measured in the batch test contents at termination. 2. $(*)oup_{PS} = (*)tp_{PS,\ at\ termination} \times V_{PS,\ BT} / V_{PS}$ Where: a) $V_{PS.,BTI}$ denotes the diluted primary sludge volume after addition of buffer and innoculant at batch test setup. b) V_{PS} denotes the total volume of primary sludge

* Relevant parameter i.e. COD, N or P

Table C2-4: Waste activated sludge COD, N and P concentrations (mg/l) calculations and sources

Concentration	**Term**	**Source**
Total	$(*)t_{WAS}$	Direct measurement in un-concentrated WAS from U.C.T. MLE system with COD, TKN and TP tests
Organic biodegradable	$(*)ob_{WAS}$	$(*)bs_{WAS} + (*)bp_{WAS}$
Organic unbiodegradable	$(*)ou_{WAS}$	$(*)us_{WAS} + (*)up_{WAS}$
Total soluble	$(*)ts_{WAS}$	Direct measurement in U.C.T. MLE system effluent wastewater - 0.45 μm membrane filtered sample
Total particulate	$(*)tp_{WAS}$	$(*)t_{WAS} - (*)ts_{WAS}$
Organic biodegrable soluble	$(*)obs_{WAS}$	$(*)ts_{WAS} - (*)us_{WAS}$ (- measured inorganic N or P where applicable)
Biodegradable particulate	$(*)obp_{WAS}$	$(*)tp_{WAS} - (*)oup_{WAS}$
Unbiodegradable soluble	$(*)ous_{WAS}$	Direct measurement in UCT MLE system effluent. **Assumption:** Unbiodegradable soluble organics in activated sludge treatment remains unbiodegradable in anaerobic treatment.
Ubiodegrable particulate	$(*)oup_{WAS}$	From batch test data at termination: 1. $(*)tp_{\text{WAS, at termination}} = (*)t_{\text{WAS, at termination}} - (*)ts_{\text{WAS, at termination}}$ Where: a) $(*)t_{\text{WAS, at termination}}$ = total COD, N or P b) $(*)ts_{\text{WAS, at termination}}$ = soluble COD, N or P The compounds above are directly measured in the batch test contents at termination. 2. $(*)oup_{WAS} = (*)tp_{\text{WAS, at termination}} \times V_{\text{WAS, BTI}} / V_{WAS}$ Where: a) $V_{\text{WAS, BT}}$ denotes the diluted (previously concentrated) waste activated sludge volume after addition of buffer and innoculant at batch test setup. b) V_{WAS} denotes the total unconcentrated volume of WAS

* Relevant parameter i.e. COD, N or P

Table C2-5: Carbon (C) concentrations (mg/l) calculations and sources

The carbon parameters were calculated in an identical fashion for raw wastewater, primary sludge and waste activated sludge. Settled wastewater parameters were calculated by performing primary settling tank mass balances.

Concentration	Term	Source
Total	Ct	Cts + Ctp
Organic biodegradable	Cb	Cbs + Cbp
Organic unbiodegradable	Cu	Cus + Cup
Total soluble	Cts	Direct DOC measurement in U.C.T. MLE system effluent (WAS) or flocculated raw wastewater supernatant (raw, settled wastewater and primary sludge) - 0.45 µm membrane filtered sample
Total particulate	Ctp	%C x Xt
Organic biodegrable soluble	Cbs	Cts - Cus
Biodegradable particulate	Cbp	Ctp - Cup
Unbiodegradable soluble	Cus	Direct DOC measurement in UCT MLE system effluent. **Assumption:** Unbiodegradable soluble organics in activated sludge treatment remains unbiodegradable in anaerobic treatment.
Ubiodegrable particulate	Cup	From batch test data at termination: 1. $Ctp_{\text{at termination}} = \%C_{\text{at termination}} \times Xt_{BT}$ Where: a) $\%C_{\text{at termination}}$ is the percentage particulate carbon measured (elemental analysis). b) Xt_{BT} is the total solids (TS) concentration directly measured in the batch test contents at termination. 2. $Ctp = Ctp_{\text{at termination}} \times V_{BT} / V$ Where: a) V_{BT} denotes the diluted batch test volume after addition of buffer, distilled water and innoculant at batch test setup. b) V denotes the initial un-concentrated sludge or wastewater volume

C3.1. CALCULATIONS: BTG 2

C3.1.1. Raw wastewater

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	10.00
Diluted batch test volume	VFS,BT	1.580
Total volume settled out for PS	VPS,Raw	20.000

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tRaw	1151	135	371	1266	928	98.7
Organic biodegradable	(*)obRaw	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable	(*)ouRaw	no data	no data	no data	n/a	n/a	n/a
Total soluble	(*)tsRaw	237	109	68.0	n/a	n/a	98.7
Total particulate	(*)tpRaw	914	25.8	302.7	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsRaw	204	7.9	59.7	n/a	n/a	n/a
Biodegradable particulate	(*)obpRaw	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousRaw	32.6	2.7	8.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupRaw	no data	no data	no data	n/a	n/a	n/a

C3.1.2. Settled wastewater

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	20.00
Total settled ww. in PS supernatant	VSettled	19.02
Total PS	VPS	0.980

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tSettled	583	120	195.1	896	703	98.7
Organic biodegradable	(*)obSettled	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable	(*)ouSettled	no data	no data	no data	n/a	n/a	n/a
Total soluble	(*)tsSettled	237	109	68.0	n/a	n/a	98.7
Total particulate	(*)tpSettled	347	10.4	127	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsSettled	204	7.9	59.7	n/a	n/a	n/a
Biodegradable particulate	(*)obpSettled	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousSettled	32.6	2.7	8.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupSettled	no data	no data	no data	n/a	n/a	n/a

C3.1.3. Primary sludge (PS)

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	20.00
Total settled ww. in PS supernatant	VSettled	19.02
Total PS	VPS	0.980
Diluted batch test volume	VPS,BT	1.110

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tPS	12157	434	3779	8445	5302	98.7
Organic biodegradable	(*)obPS	6564	108	2129	n/a	2054	n/a
Organic unbiodegradable	(*)ouPS	5593	227	1650	n/a	3248	n/a
Total soluble	(*)tsPS	237	109	68.0	n/a	n/a	98.7
Total particulate	(*)tpPS	11921	325	3711	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsPS	204	7.9	59.7	n/a	n/a	n/a
Biodegradable particulate	(*)obpPS	6360	100	2069	n/a	2054	n/a
Organic unbiodegradable soluble	(*)ousPS	32.6	2.7	8.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupPS	5560	224	1642	n/a	3248	n/a

C3.1.4. Waste activated sludge (WAS)

Volumes (L)

Parameter	Term	Value
Total WAS	VWAS	5.000
Diluted batch test volume	VWAS,BT	1.730

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tWAS	3068	183	1067	2450	2084	3.5
Organic biodegradable	(*)obWAS	747	79.8	400	n/a	695	n/a
Organic unbiodegradable	(*)ouWAS	2321	100.1	667	n/a	1389	n/a
Total soluble	(*)tsWAS	32.6	6.2	8.3	n/a	n/a	n/a
Total particulate	(*)tpWAS	3036	177	1059	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsWAS	0.0	0.0	0.0	n/a	n/a	n/a
Biodegradable particulate	(*)obpWAS	747	79.8	400	n/a	695	n/a
Organic unbiodegradable soluble	(*)ousWAS	32.6	2.7	8.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupWAS	2288	97.4	659	n/a	1389	n/a

C3.2. CALCULATIONS: BTG 3

C3.2.1. Raw wastewater

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	10.00
Diluted batch test volume	VFS,BT	2.270
Total volume settled out for PS	VPS,Raw	20.000

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tRaw	1629	133	452	953	701	98.7
Organic biodegradable	(*)obRaw	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable	(*)ouRaw	no data	no data	no data	n/a	n/a	n/a
Total soluble	(*)tsRaw	236	110	55.9	n/a	n/a	98.7
Total particulate	(*)tpRaw	1393	22.8	396	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsRaw	196	8.9	49.1	n/a	n/a	n/a
Biodegradable particulate	(*)obpRaw	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousRaw	40.3	2.6	6.9	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupRaw	no data	no data	no data	n/a	n/a	n/a

C3.2.2. Settled wastewater

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	20.00
Total settled ww. in PS supernatant	VSettled	19.52
Total PS	VPS	0.485

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tSettled	444	114	131	267	134.0	98.7
Organic biodegradable	(*)obSettled	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable	(*)ouSettled	no data	no data	no data	n/a	n/a	n/a
Total soluble	(*)tsSettled	236	110	55.9	n/a	n/a	98.7
Total particulate	(*)tpSettled	208	4.1	75	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsSettled	196	8.9	49.1	n/a	n/a	n/a
Biodegradable particulate	(*)obpSettled	no data	no data	no data	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousSettled	40.3	2.6	6.9	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupSettled	no data	no data	no data	n/a	n/a	n/a

C3.2.3. Primary sludge (PS)

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	20.00
Total settled ww. in PS supernatant	VSettled	19.52
Total PS	VPS	0.485
Diluted batch test volume	VPS,BT	1.055

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tPS	49326	888	13372	28564	23534	98.7
Organic biodegradable	(*)obPS	no data	no data	no data	n/a	no data	n/a
Organic unbiodegradable	(*)ouPS	no data	no data	no data	n/a	no data	n/a
Total soluble	(*)tsPS	236	110	55.9	n/a	n/a	98.7
Total particulate	(*)tpPS	49090	778	13316	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsPS	196	8.9	49.1	n/a	n/a	n/a
Biodegradable particulate	(*)obpPS	no data	no data	no data	n/a	no data	n/a
Organic unbiodegradable soluble	(*)ousPS	40.3	2.6	6.9	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupPS	no data	no data	no data	n/a	no data	n/a

C3.2.4. Waste activated sludge (WAS)

Volumes (L)

Parameter	Term	Value
Total WAS	VWAS	5.000
Diluted batch test volume	VWAS,BT	2.270

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tWAS	3234	163	1167	2812	2504	2.5
Organic biodegradable	(*)obWAS	no data	no data	no data	n/a	no data	n/a
Organic unbiodegradable	(*)ouWAS	no data	no data	no data	n/a	no data	n/a
Total soluble	(*)tsWAS	40.3	5.1	6.9	n/a	n/a	n/a
Total particulate	(*)tpWAS	3193	158	1160	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsWAS	0.0	0.0	0.0	n/a	n/a	n/a
Biodegradable particulate	(*)obpWAS	no data	no data	no data	n/a	no data	n/a
Organic unbiodegradable soluble	(*)ousWAS	40.3	2.6	6.9	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupWAS	no data	no data	no data	n/a	no data	n/a

C3.3. CALCULATIONS: BTG 4

C3.3.1. Raw wastewater

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	6.000
Diluted batch test volume	VFS,BT	2.120
Total volume settled out for PS	VPS,Raw	10.00

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tRaw	1360	119	509	2018	1761	67.3
Organic biodegradable	(*)obRaw	912	35.2	358.1	n/a	1284	n/a
Organic unbiodegradable	(*)ouRaw	448	16.5	150.5	n/a	477	n/a
Total soluble	(*)tsRaw	179	85.7	35.0	n/a	n/a	67.3
Total particulate	(*)tpRaw	1181	33.3	474	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsRaw	147	15.0	28.2	n/a	n/a	n/a
Biodegradable particulate	(*)obpRaw	765	20.2	329.8	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousRaw	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupRaw	416	13.1	143.7	n/a	477	n/a

C3.3.2. Settled wastewater

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	10.00
Total settled ww. in PS supernatant	VSettled	9.87
Total PS	VPS	0.130

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tSettled	346	99	140.5	1231	1099.5	67.3
Organic biodegradable	(*)obSettled	211	26	107	n/a	921	n/a
Organic unbiodegradable	(*)ouSettled	135	5.5	33	n/a	179	n/a
Total soluble	(*)tsSettled	179	86	35.0	n/a	n/a	67.3
Total particulate	(*)tpSettled	167	13.3	105	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsSettled	147	15.0	28.2	n/a	n/a	n/a
Biodegradable particulate	(*)obpSettled	65	11	79.2	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousSettled	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupSettled	102	2	26	n/a	179	n/a

C3.3.3. Primary sludge (PS)

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	10.00
Total settled ww. in PS supernatant	VSettled	9.87
Total PS	VPS	0.130
Diluted batch test volume	VPS,BT	0.903

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tPS	78341	1637	28458	61722	52017	67.3
Organic biodegradable	(*)obPS	54110	717	19384	n/a	28873	n/a
Organic unbiodegradable	(*)ouPS	24231	853	9074	n/a	23144	n/a
Total soluble	(*)tsPS	179	86	35.0	n/a	n/a	67.3
Total particulate	(*)tpPS	78161	1552	28423	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsPS	147	15.0	28.2	n/a	n/a	n/a
Biodegradable particulate	(*)obpPS	53963	702	19356	n/a	28873	n/a
Organic unbiodegradable soluble	(*)ousPS	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupPS	24198	849	9067	n/a	23144	n/a

C3.3.4. Waste activated sludge (WAS)

Volumes (L)

Parameter	Term	Value
Total WAS	VWAS	2.290
Diluted batch test volume	VWAS,BT	2.020

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tWAS	3347	171	1172	3248	2258	3.4
Organic biodegradable	(*)obWAS	1326	97.8	780	n/a	955	n/a
Organic unbiodegradable	(*)ouWAS	2022	70.2	392	n/a	1303	n/a
Total soluble	(*)tsWAS	32.6	6.7	6.8	n/a	n/a	n/a
Total particulate	(*)tpWAS	3315	165	1165	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsWAS	0.0	0.0	0.0	n/a	n/a	n/a
Biodegradable particulate	(*)obpWAS	1326	97.8	780	n/a	955	n/a
Organic unbiodegradable soluble	(*)ousWAS	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupWAS	1989	66.8	385	n/a	1303	n/a

C3.4 CALCULATIONS: BTG 5

C3.4.1. Raw wastewater

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	6.00
Diluted batch test volume	VFS,BT	2.120
Total volume settled out for PS	VPS,Raw	10.000

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tRaw	1384	116	624	3365	2459	67.3
Organic biodegradable	(*)obRaw	922	33.9	425	n/a	1701	n/a
Organic unbiodegradable	(*)ouRaw	462	14.2	199	n/a	758	n/a
Total soluble	(*)tsRaw	171	83.6	26.7	n/a	n/a	67.3
Total particulate	(*)tpRaw	1213	31.9	598	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsRaw	138	12.9	19.9	n/a	n/a	n/a
Biodegradable particulate	(*)obpRaw	784	21	405.5	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousRaw	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupRaw	429	10.9	192	n/a	758	n/a

C3.4.2. Settled wastewater

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	10.00
Total settled ww. in PS supernatant	VSettled	9.83
Total PS	VPS	0.170

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tSettled	379	96.0	290.6	2539	1758	67.3
Organic biodegradable	(*)obSettled	196	26.1	204.0	n/a	1412	n/a
Organic unbiodegradable	(*)ouSettled	182	2.6	86.5	n/a	345.6	n/a
Total soluble	(*)tsSettled	171	83.6	26.7	n/a	n/a	67.3
Total particulate	(*)tpSettled	208	12.5	263.9	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsSettled	138	12.9	19.9	n/a	n/a	n/a
Biodegradable particulate	(*)obpSettled	58	13.2	184.1	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousSettled	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupSettled	150	-0.8	79.7	n/a	345.6	n/a

C3.4.3. Primary sludge (PS)

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	10.00
Total settled ww. in PS supernatant	VSettled	9.83
Total PS	VPS	0.170
Diluted batch test volume	VPS,BT	0.790

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tPS	59542	1241	19920	51100	43003	67.3
Organic biodegradable	(*)obPS	42912	485	13228	n/a	18424	n/a
Organic unbiodegradable	(*)ouPS	16631	688	6692	n/a	24579	n/a
Total soluble	(*)tsPS	171	84	26.7	n/a	n/a	67.3
Total particulate	(*)tpPS	59371	1157	19893	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsPS	138	12.9	19.9	n/a	n/a	n/a
Biodegradable particulate	(*)obpPS	42773	472	13208	n/a	18424	n/a
Organic unbiodegradable soluble	(*)ousPS	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupPS	16598	685	6685	n/a	24579	n/a

C3.4.4. Waste activated sludge (WAS)

Volumes (L)

Parameter	Term	Value
Total WAS	VWAS	2.290
Diluted batch test volume	VWAS,BT	2.020

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tWAS	3347	186	1172	3248	2258	3.4
Organic biodegradable	(*)obWAS	1044	91.7	560	n/a	989	n/a
Organic unbiodegradable	(*)ouWAS	2303	91.2	612	n/a	1269	n/a
Total soluble	(*)tsWAS	32.6	6.7	6.8	n/a	n/a	n/a
Total particulate	(*)tpWAS	3315	179	1165	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsWAS	0.0	0.0	0.0	n/a	n/a	n/a
Biodegradable particulate	(*)obpWAS	1044	91.7	560	n/a	989	n/a
Organic unbiodegradable soluble	(*)ousWAS	32.6	3.4	6.8	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupWAS	2271	87.8	605	n/a	1269	n/a

C3.5. CALCULATIONS: BTG 6

C3.5.1. Raw wastewater

Volumes (L)

Parameter	Term	Value
FS total raw wastewater	VFS,Raw	6.00
Diluted batch test volume	VFS,BT	2.220
Total volume settled out for PS	VPS,Raw	10.000

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tRaw	2262	143	833	2351	2046	82.0
Organic biodegradable	(*)obRaw	1415	38.3	562	n/a	1389	n/a
Organic unbiodegradable	(*)ouRaw	848	22.5	271	n/a	656	n/a
Total soluble	(*)tsRaw	298	90.7	76.0	n/a	n/a	82.0
Total particulate	(*)tpRaw	1964	52.1	757	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsRaw	248	8.4	70.7	n/a	n/a	n/a
Biodegradable particulate	(*)obpRaw	1167	29.9	492	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousRaw	50.4	0.3	5.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupRaw	797	22.2	266	n/a	656	n/a

C3.5.2. Settled wastewater

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	10.00
Total settled ww. in PS supernatant	VSettled	9.36
Total PS	VPS	0.640

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tSettled	907	123	446.7	1558	1342	82.0
Organic biodegradable	(*)obSettled	460	36.7	351.2	n/a	1045.2	n/a
Organic unbiodegradable	(*)ouSettled	447	3.8	95.4	n/a	296.8	n/a
Total soluble	(*)tsSettled	298	90.7	76.0	n/a	n/a	82.0
Total particulate	(*)tpSettled	609	31.8	371	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsSettled	248	8.4	70.7	n/a	n/a	n/a
Biodegradable particulate	(*)obpSettled	212	28.3	281	n/a	n/a	n/a
Organic unbiodegradable soluble	(*)ousSettled	50.4	0.3	5.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupSettled	397	3.5	90.2	n/a	296.8	n/a

C3.5.3. Primary sludge (PS)

Volumes (L)

Parameter	Term	Value
Total raw ww. settled out for PS	VRaw	10.00
Total settled ww. in PS supernatant	VSettled	9.36
Total PS	VPS	0.640
Diluted batch test volume	VPS,BT	0.960

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tPS	22082	440	6489	13944	12335	82.0
Organic biodegradable	(*)obPS	15380	61	3649	n/a	6423	n/a
Organic unbiodegradable	(*)ouPS	6702	296	2840	n/a	5912	n/a
Total soluble	(*)tsPS	298	91	76.0	n/a	n/a	82.0
Total particulate	(*)tpPS	21784	349	6413	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsPS	248	8.4	70.7	n/a	n/a	n/a
Biodegradable particulate	(*)obpPS	15132	53	3578	n/a	6423	n/a
Organic unbiodegradable soluble	(*)ousPS	50.4	0.3	5.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupPS	6652	296	2835	n/a	5912	n/a

C3.5.4. Waste activated sludge (WAS)

Volumes (L)

Parameter	Term	Value
Total WAS	VWAS	4.375
Diluted batch test volume	VWAS,BT	2.220

Concentrations (mg/l)

Parameter	Term	COD	N	C	TS	VS	FSA
Total	(*)tWAS	2964	159	903	2040	1773	3.8
Organic biodegradable	(*)obWAS	1452	96.8	464	n/a	800	n/a
Organic unbiodegradable	(*)ouWAS	1512	58.3	439	n/a	973	n/a
Total soluble	(*)tsWAS	50.4	4.1	5.3	n/a	n/a	n/a
Total particulate	(*)tpWAS	2913	155	898	n/a	n/a	n/a
Organic biodegradable soluble	(*)obsWAS	0.0	0.0	0.0	n/a	n/a	n/a
Biodegradable particulate	(*)obpWAS	1452	96.8	464	n/a	800	n/a
Organic unbiodegradable soluble	(*)ousWAS	50.4	0.3	5.3	n/a	n/a	n/a
Unbiodegradable particulate	(*)oupWAS	1461	58.1	434	n/a	973	n/a

C.4. SUMMARY

Table C4-1: Wastewater volumes (L)

		Batch Test Group				
Wastewater type	**term**	**2**	**3**	**4**	**5**	**6**
Raw	VRAW	20.000	20.000	10.000	10.000	10.000
Settled	VSETT.	19.020	19.515	9.870	9.830	9.360
Primary Sludge	VPS	0.980	0.485	0.130	0.170	0.640
Waste Activated Sludge	VWAS	5.000	5.000	2.290	2.290	4.375

Table C4-2: COD concentrations (mg/l)

		Batch Test Group				
Wastewater type	**term**	**2**	**3**	**4**	**5**	**6**
Total	StRaw	1151	1629	1360	1384	2262
Organic biodegradable	SbRaw	no data	no data	912	922	1415
Organic unbiodegradable	SuRaw	no data	no data	448	462	848
Total soluble	StsRaw	237	236	179	171	298
Total particulate	StpRaw	914	1393	1181	1213	1964
Organic biodegradable soluble	SbsRaw	204	196	147	138	248
Biodegradable particulate	SbpRaw	no data	no data	765	784	1167
Organic unbiodegradable soluble	SusRaw	32.6	40.3	32.6	32.6	50.4
Unbiodegradable particulate	SupRaw	no data	no data	416	429	797
Settled wastewater						
Total	StSettled	583	444	346	379	907
Organic biodegradable	SbSettled	no data	no data	211	196	460
Organic unbiodegradable	SuSettled	no data	no data	135	182	447
Total soluble	StsSettled	237	236	179	171	298
Total particulate	StpSettled	347	208	167	208	609
Organic biodegradable soluble	SbsSettled	204	196	147	138	248
Biodegradable particulate	SbpSettled	no data	no data	65	58	212
Organic unbiodegradable soluble	SusSettled	32.6	40.3	32.6	32.6	50.4
Unbiodegradable particulate	SupSettled	no data	no data	102	150	397
Primary sludge (PS)						
Total	StPS	12157	49326	78341	59542	22082
Organic biodegradable	SbPS	6564	no data	54110	42912	15380
Organic unbiodegradable	SuPS	5593	no data	24231	16631	6702
Total soluble	StsPS	237	236	179	171	298
Total particulate	StpPS	11921	49090	78161	59371	21784
Organic biodegradable soluble	SbsPS	204	196	147	138	248
Biodegradable particulate	SbpPS	6360	no data	53963	42773	15132
Organic unbiodegradable soluble	SusPS	32.6	40.3	32.6	32.6	50.4
Unbiodegradable particulate	SupPS	5560	no data	24198	16598	6652
Waste activated sludge (WAS)						
Total	StWAS	3068	3234	3347	3347	2964
Organic biodegradable	SbWAS	747	no data	1326	1044	1452
Organic unbiodegradable	SuWAS	2321	no data	2022	2303	1512
Total soluble	StsWAS	32.6	40.3	32.6	32.6	50.4
Total particulate	StpWAS	3036	3193	3315	3315	2913
Organic biodegradable soluble	SbsWAS	0	0	0	0	0
Biodegradable particulate	SbpWAS	747	no data	1326	1044	1452
Organic unbiodegradable soluble	SusWAS	32.6	40.3	32.6	32.6	50.4
Unbiodegradable particulate	SupWAS	2288	no data	1989	2271	1461

Table C4-3: Nitrogen (N) concentrations (mg/l)

		Batch Test Group				
Wastewater type	**term**	**2**	**3**	**4**	**5**	**6**
Raw wastewater						
Total	NtRaw	135	133	119	116	143
Organic biodegradable	NobRaw	no data	no data	35.2	34	38.3
Organic unbiodegradable	NouRaw	no data	no data	16.5	14.2	22.5
Total soluble	NtsRaw	109	110	85.7	83.6	90.7
Total particulate	NtpRaw	25.8	22.8	33.3	31.9	52.1
Organic biodegradable soluble	NobsRaw	7.9	8.9	15.0	12.9	8.4
Biodegradable particulate	NobpRaw	no data	no data	20.2	21	29.9
Organic unbiodegradable soluble	NousRaw	2.7	2.6	3.4	3.4	0.3
Unbiodegradable particulate	NoupRaw	no data	no data	13.1	10.9	22.2
Settled wastewater						
Total	NtSettled	120	114	99.0	96.0	123
Organic biodegradable	NobSettled	no data	no data	26.2	26.1	36.7
Organic unbiodegradable	NouSettled	no data	no data	5.5	2.6	3.8
Total soluble	NtsSettled	109	110	85.7	83.6	90.7
Total particulate	NtpSettled	10.4	4.1	13.3	12.5	31.8
Organic biodegradable soluble	NobsSettled	7.9	8.9	15.0	12.9	8.4
Biodegradable particulate	NobpSettled	no data	no data	11.2	13.2	28.3
Organic unbiodegradable soluble	NousSettled	2.7	2.6	3.4	3.4	0.3
Unbiodegradable particulate	NoupSettled	no data	no data	2.1	-0.8	3.5
Primary sludge (PS)						
Total	NtPS	434	888	1637	1241	440
Organic biodegradable	NobPS	108	no data	717	485	61.3
Organic unbiodegradable	NouPS	227	no data	853	688	296
Total soluble	NtsPS	109	110	86	84	90.7
Total particulate	NtpPS	325	778	1552	1157	349
Organic biodegradable soluble	NobsPS	7.9	8.9	15.0	12.9	8.4
Biodegradable particulate	NobpPS	100	no data	702	472	53
Organic unbiodegradable soluble	NousPS	2.7	2.6	3.4	3.4	0.3
Unbiodegradable particulate	NoupPS	224	no data	849	685	296
Waste activated sludge (WAS)						
Total	NtWAS	183	163	171	186	159
Organic biodegradable	NobWAS	79.8	no data	98	91.7	96.8
Organic unbiodegradable	NouWAS	100.1	no data	70.2	91.2	58.3
Total soluble	NtsWAS	6.2	5.1	6.7	6.7	4.1
Total particulate	NtpWAS	177	158	165	179	155
Organic biodegradable soluble	NobsWAS	0.0	0.0	0.0	0.0	0.0
Biodegradable particulate	NobpWAS	79.8	no data	97.8	91.7	96.8
Organic unbiodegradable soluble	NousWAS	2.7	2.6	3.4	3.4	0.3
Unbiodegradable particulate	NoupWAS	97.4	no data	66.8	87.8	58.1

Table C4-4: Carbon (C) concentrations (mg/l)

		Batch Test Group				
Wastewater type	**term**	**2**	**3**	**4**	**5**	**6**
Raw wastewater						
Total	CtRaw	371	452	509	624	833
Organic biodegradable	CbRaw	no data	no data	358	425.4	562
Organic unbiodegradable	CuRaw	no data	no data	151	199	271
Total soluble	CtsRaw	68.0	55.9	35.0	26.7	76.0
Total particulate	CtpRaw	303	396	474	598	757
Organic biodegradable soluble	CbsRaw	59.7	49.1	28.2	19.9	70.7
Biodegradable particulate	CbpRaw	no data	no data	330	406	492
Organic unbiodegradable soluble	CusRaw	8.3	6.9	6.8	6.8	5.3
Unbiodegradable particulate	CupRaw	no data	no data	144	192	266
Settled wastewater						
Total	CtSettled	195	131	140	291	447
Organic biodegradable	CbSettled	no data	no data	107	204	351
Organic unbiodegradable	CuSettled	no data	no data	33.0	86.5	95.4
Total soluble	CtsSettled	68.0	55.9	35.0	26.7	76.0
Total particulate	CtpSettled	127.1	74.9	105.4	263.9	370.7
Organic biodegradable soluble	CbsSettled	59.7	49.1	28.2	19.9	70.7
Biodegradable particulate	CbpSettled	no data	no data	79	184	281
Organic unbiodegradable soluble	CusSettled	8.3	6.9	6.8	6.8	5.3
Unbiodegradable particulate	CupSettled	no data	no data	26.2	79.7	90.2
Primary sludge (PS)						
Total	CtPS	3779	13372	28458	19920	6489
Organic biodegradable	CbPS	2129	no data	19384	13228	3649
Organic unbiodegradable	CuPS	1650	no data	9074	6692	2840
Total soluble	CtsPS	68.0	55.9	35.0	26.7	76.0
Total particulate	CtpPS	3711	13316	28423	19893	6413
Organic biodegradable soluble	CbsPS	59.7	49.1	28.2	19.9	70.7
Biodegradable particulate	CbpPS	2069	no data	19356	13208	3578
Organic unbiodegradable soluble	CusPS	8.3	6.9	6.8	6.8	5.3
Unbiodegradable particulate	CupPS	1642	no data	9067	6685	2835
Waste activated sludge (WAS)						
Total	CtWAS	1067	1167	1172	1172	903
Organic biodegradable	CbWAS	400	no data	780	560	464
Organic unbiodegradable	CuWAS	667	no data	392	612	439
Total soluble	CtsWAS	8.3	6.9	6.8	6.8	5.3
Total particulate	CtpWAS	1059	1160	1165	1165	898
Organic biodegradable soluble	CbsWAS	0.0	0.0	0.0	0.0	0.0
Biodegradable particulate	CbpWAS	400	no data	780	560	464
Organic unbiodegradable soluble	CusWAS	8.3	6.9	6.8	6.8	5.3
Unbiodegradable particulate	CupWAS	659	no data	385	605	434

Table C4-5: Solids concentrations (mg/l)

		Batch Test Group				
Wastewater type	**term**	**2**	**3**	**4**	**5**	**6**
Raw wastewater						
Total	XtRaw	1266	953	2018	3365	2351
VS:	XvRaw	928	701	1761	2459	2046
Biodegradable	XvbRaw	n/a	n/a	1284	1701	1389
Unbiodegradable	XvuRaw	n/a	n/a	477	758	656
IS	XiRaw	338	252	256	906	305
Settled wastewater						
Total	XtSettled	896	267	1231	2539	1558
VS:	XvSettled	703	134.0	1099	1758	1342
Biodegradable	XvbSettled	n/a	n/a	921	1412	1045
Unbiodegradable	XvuSettled	n/a	n/a	179	346	297
IS	XiSettled	193	133	132	781	216
Primary sludge (PS)						
Total	XtPS	8445	28564	61722	51100	13944
VS:	XvPS	5302	23534	52017	43003	12335
Biodegradable	XvbPS	2054	no data	28873	18424	6423
Unbiodegradable	XvuPS	3248	no data	23144	24579	5912
IS	XiPS	3143	5030	9705	8097	1609
Waste activated sludge (WAS)						
Total	XtWAS	2450	2812	3248	3248	2040
VS:	XvWAS	2084	2504	2258	2258	1773
Biodegradable	XvbWAS	695	no data	955	989	800
Unbiodegradable	XvuWAS	1389	no data	1303	1269	973
IS	XiWAS	366	308	990	990	267

Table C4-6: Elemental analysis results (% element per TS mass)

		Batch Test Group				
Batch test contents	**term**	**2**	**3**	**4**	**5**	**6**
FS						
Carbon	%C					
at batch test setup	%Cat setup	23.9	41.6	23.5	17.8	32.2
at batch test termination	%Cat term.	no data	no data	18.2	17.1	28.7
Hydrogen	%H					
at batch test setup	%Hat setup	4.02	6.44	3.99	3.61	4.73
at batch test termination	%Hat term.	no data	no data	2.94	2.66	4.69
Nitrogen	%N					
at batch test setup	%Nat setup	1.43	2.49	1.00	0.66	1.89
at batch test termination	%Nat term.	no data	no data	0.860	0.800	1.580
PS						
Carbon	%C					
at batch test setup	%Cat setup	43.9	46.6	46.1	38.9	46.0
at batch test termination	%Cat term.	22.5	no data	35.3	20.6	35.3
Hydrogen	%H					
at batch test setup	%Hat setup	6.17	6.71	3.38	5.68	6.72
at batch test termination	%Hat term.	3.99	no data	4.92	4.11	4.47
Nitrogen	%N					
at batch test setup	%Nat setup	2.17	2.00	1.21	1.23	1.97
at batch test termination	%Nat term.	1.00	no data	1.49	1.68	1.75
WAS						
Carbon	%C					
at batch test setup	%Cat setup	43.2	41.3	35.9	35.9	44.0
at batch test termination	%Cat term.	32.3	no data	16.5	29.5	23.6
Hydrogen	%H					
at batch test setup	%Hat setup	5.98	6.00	5.23	5.23	6.48
at batch test termination	%Hat term.	3.90	no data	4.76	4.51	4.57
Nitrogen	%N					
at batch test setup	%Nat setup	7.15	5.67	4.14	4.14	7.23
at batch test termination	%Nat term.	3.80	no data	1.22	2.81	1.88

E1.1. PARTICULATE ORGANICS COMPOSITIONS: BTG 2

E1.1.1. Method 1: Calculation with U.C.T. laboratory measured data and %C

Wastewater type	fcv	fc	fn	x	y	z	a
Raw							
Total	0.98	0.326	0.028	2.118	7.000	2.708	0.154
Unbiodegradable	no data	no data	no data	no data	no data	no data	no data
Biodegradable	no data	no data	no data	no data	no data	no data	no data
Settled							
Total	0.49	0.181	0.015	1.129	7.000	3.329	0.079
Unbiodegradable	no data	no data	no data	no data	no data	no data	no data
Biodegradable	no data	no data	no data	no data	no data	no data	no data
Primary sludge							
Total	2.25	0.700	0.061	5.063	7.000	0.859	0.380
Unbiodegradable	1.71	0.505	0.069	2.923	7.000	1.408	0.342
Biodegradable	3.10	1.007	0.049	12.08	7.000	-0.942	0.502
Waste activated sludge							
Total	1.457	0.508	0.085	4.077	7.000	2.011	0.585
Unbiodegradable	1.65	0.474	0.070	2.599	7.000	1.434	0.329
Biodegradable	1.08	0.576	0.115	64.77	7.000	25.697	11.076

E1.1.2. Method 2: Calculation with elemental analysis and VS / COD correlation

Elemental analysis results

Wastewater type	% Element		
Raw	%C	%H	%N
Total	23.910	4.020	1.430
Residual	no data	no data	no data
Primary sludge			
Total	43.940	6.170	2.170
Residual	22.480	3.990	1.000
Waste activated sludge			
Total	43.220	5.980	7.150
Residual	32.300	3.900	3.800

PST volumes (l)

Raw	20.00
Settled	19.020
PS	0.980

Element molar masses (g/mol)

C	H	N
12.01	1.00	14.01

Relevant data

Wastewater type	Sp (g/l)	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Np (g/l)
Raw	-	-	-	-	-	-
Total	0.914	0.928	1.266	0.303	0.051	0.018
Residual	-	-	-	-	-	-
Biodegraded	-	-	-	-	-	-
Settled						
Total	0.347	0.703	0.896	0.127	0.027	0.010
Residual	-	-	-	-	-	-
Biodegraded	-	-	-	-	-	-
Primary sludge						
Total	11.921	5.302	8.445	3.711	0.521	0.183
Residual	5.560	3.248	7.303	1.642	0.291	0.073
Biodegraded	6.360	2.054	n/a	2.069	0.230	0.110
Waste activated sludge						
Total	3.036	2.084	2.450	1.059	0.147	0.175
Residual	2.288	1.389	2.040	0.659	0.080	0.078
Biodegraded	0.747	0.695	n/a	0.400	0.067	0.098

E1.2

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.025	0.051	0.026	0.001	3.470	7.000	3.540	0.178	138
Residual	no data	no data	no data	no data	no data	no data	no data	no data	-
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	-
Settled									
Total	0.011	0.027	0.019	0.000	2.781	7.000	5.000	0.180	263
Residual	no data	no data	no data	no data	no data	no data	no data	no data	-
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	-
Primary sludge									
Total	0.309	0.521	0.073	0.013	4.155	7.000	0.988	0.176	13
Residual	0.137	0.291	0.073	0.005	3.287	7.000	1.744	0.125	24
Biodegraded	0.172	0.229	-0.004	0.007	5.256	7.000	-0.14	0.240	31
Waste activated sludge									
Total	0.088	0.146	0.043	0.012	4.217	7.000	2.048	0.598	48
Residual	0.055	0.079	0.022	0.005	4.832	7.000	1.903	0.487	88
Biodegraded	0.033	0.067	0.025	0.007	3.486	7.000	2.61	0.729	105

E1.1.3. Method 3: Calculation with elemental analysis and VS measurement

Elemental analysis results

Wastewater type	% Element			
Raw	%C	%H	%N	%P
Total	23.910	4.020	1.430	0.714
Residual	no data	no data	no data	0.000
Primary sludge				
Total	43.94	6.170	2.170	1.070
Residual	22.48	3.990	1.000	1.300
Waste activated sludge				
Total	43.22	5.980	7.150	0.255
Residual	32.30	3.900	3.800	0.000

Element molar masses (g/mol)

C	H	O	N	P
12.01	1.00	16.01	14.01	30.97

Relevant data

Wastewater type	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Op (g/l)	Np (g/l)	P(p) g/l
Raw	-	-	-	-	-	-	
Total	0.928	1.266	0.303	0.051	0.547	0.018	0.009
Residual	-	-	-	-	-	-	-
Biodegraded	-	-	-	-	-	-	-
Settled							
Total	0.703	0.896	0.127	0.027	0.534	0.010	0.005
Residual	-	-	-	-	-	-	-
Biodegraded	-	-	-	-	-	-	-
Primary sludge							
Total	5.302	8.445	3.711	0.521	0.797	0.183	0.090
Residual	3.248	7.303	1.642	0.291	1.147	0.073	0.095
Biodegraded	2.054	n/a	2.069	0.230	-0.350	0.110	-0.005
Waste activated sludge							
Total	2.084	2.450	1.059	0.147	0.697	0.175	0.006
Residual	1.389	2.040	0.659	0.080	0.573	0.078	0.000
Biodegraded	0.695	n/a	0.400	0.067	0.124	0.098	0.006

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.0252	0.0508	0.034	0.001	3.470	7.000	4.706	0.178	138
Residual	no data	no data	no data	no data	no data	no data	no data	no data	-
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	-
Settled									
Total	0.0106	0.027	0.033	0.001	2.781	7.000	8.771	0.180	263
Residual	no data	no data	no data	no data	no data	no data	no data	no data	-
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	-
Primary sludge									
Total	0.309	0.5206	0.050	0.013	4.155	7.000	0.669	0.176	13
Residual	0.1367	0.291	0.0716	0.005	3.287	7.000	1.723	0.125	24
Biodegraded	0.1723	0.2295	-0.022	0.008	5.256	7.000	-0.67	0.240	31
Waste activated sludge									
Total	0.088	0.1464	0.0435	0.012	4.217	7.000	2.083	0.598	48
Residual	0.0549	0.0795	0.0358	0.005	4.832	7.000	3.153	0.487	88
Biodegraded	0.033	0.067	0.0078	0.007	3.486	7.000	0.811	0.729	105

E1.1.4. Method 4: Calculation with elemental analysis and C and COD correlation

			Preliminary formulae				Set y = 7				M.F.
Wastewater type	Sp (g/l)	Cp (g/l)	x'	y'	z'	a'	x	y	z	a	
Raw	_	_									
Total	0.914	0.303	0.0252	0.050	0.017	0.0013	3.470	7.000	2.316	0.178	138
Residual	-	-	no data	no data	no data	no data	no data	no data	no data	no data	-
Biodegraded	-	-	no data	no data	no data	no data	no data	no data	no data	no data	-
Settled											
Total	0.347	0.127	0.011	0.027	0.012	0.001	2.781	7.000	3.101	0.180	263
Residual	-	-	no data	no data	no data	no data	no data	no data	no data	no data	-
Biodegraded	-	-	no data	no data	no data	no data	no data	no data	no data	no data	-
Primary sludge											
Total	11.921	3.711	0.3090	0.520	0.114	0.0131	4.155	7.000	1.536	0.176	13
Residual	5.560	1.642	0.1367	0.291	0.064	0.005	3.287	7.000	1.536	0.125	24
Biodegraded	6.360	2.069	0.1723	0.229	0.050	0.008	5.256	7.000	1.535	0.240	31
Waste activated sludge											
Total	3.036	1.059	0.088	0.146	0.041	0.0125	4.217	7.000	1.970	0.598	48
Residual	2.288	0.659	0.0549	0.079	-0.002	0.0055	4.832	7.000	-0.154	0.487	88
Biodegraded	0.747	0.400	0.033	0.067	0.043	0.0070	3.486	7.000	4.494	0.729	105

E1.2. PARTICULATE ORGANICS COMPOSITIONS: BTG 3

E1.2.1. Method 1: Calculation with U.C.T. laboratory measured data and %C

Wastewater type	fcv	fc	fn	x	y	z	a
Raw							
Total	1.99	0.565	0.033	3.155	7.000	1.252	0.156
Residual	no data	no data	no data	no data	no data	no data	no data
Biodegraded	no data	no data	n/a	no data	no data	no data	no data
Settled							
Total	1.55	0.559	0.030	5.613	7.000	2.660	0.261
Residual	n/a	no data	no data	no data	no data	no data	no data
Biodegraded	no data	no data	no data	no data	no data	no data	no data
Primary sludge							
Total	2.09	0.566	0.033	2.871	7.000	1.089	0.144
Residual	n/a	n/a	no data	no data	no data	no data	no data
Biodegraded	n/a	no data	no data	no data	no data	no data	no data
Waste activated sludge							
Total	1.275	0.463	0.063	3.914	7.000	2.563	0.457
Residual	no data	n/a	n/a	no data	no data	no data	no data
Biodegraded	n/a	n/a	no data	no data	no data	no data	no data

E1.2.2. Method 2: Calculation with elemental analysis and VS and COD correlation

Elemental analysis results

Wastewater type	% Element		
Raw	%C	%H	%N
Total	41.550	6.440	2.490
Residual	no data	no data	no data
Primary sludge			
Total	46.62	6.710	2.000
Residual	no data	no data	no data
Waste activated sludge			
Total	41.260	6.000	5.670
Residual	no data	no data	no data

PST volumes (l)

Raw	20.00
Settled	19.515
PS	0.485

Element molar masses (g/mol)

C	H	N
12.01	1.00	14.01

E1.5

Relevant data

Wastewater type	Sp (g/l)	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Np (g/l)
Raw	-	-	-	-	-	-
Total	1.393	0.701	0.953	0.396	0.061	0.024
Residual	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a
Settled						
Total	0.208	0.134	0.267	0.075	0.015	0.010
Residual	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a
Primary sludge						
Total	49.09	23.534	28.564	13.316	1.917	0.571
Residual	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a
Waste activated sludge						
Total	3.193	2.504	2.812	1.160	0.169	0.159
Residual	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.033	0.061	0.012	0.0017	3.764	7.000	1.315	0.193	114
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Settled									
Total	0.006	0.015	0.004	0.0007	2.861	7.000	1.676	0.332	459
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Primary sludge									
Total	1.109	1.915	0.342	0.041	4.054	7.000	1.250	0.149	4
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Waste activated sludge									
Total	0.097	0.169	0.062	0.0114	4.012	7.000	2.590	0.473	42
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a

E1.2.3. Method 3: Calculation with elemental analysis and VS measurement

Elemental analysis results

Wastewater type	% Element			
Raw	%C	%H	%N	%P
Total	41.550	6.440	2.490	0.714
Residual	no data	no data	no data	No data
Primary sludge				
Total	46.62	6.710	2.000	1.070
Residual	no data	no data	no data	1.300
Waste activated sludge				
Total	41.260	6.000	5.670	0.255
Residual	no data	no data	no data	0.000

Element molar masses (g/mol)

C	H	O	N	P
12.01	1.00	16.01	14.01	30.97

Relevant data

Wastewater type	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Op (g/l)	Np (g/l)	P(p) g/l
Raw	-	-	-	-	-	-	
Total	0.701	0.953	0.396	0.061	0.214	0.024	0.007
Residual	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Settled							
Total	0.134	0.267	0.075	0.015	0.034	0.010	-0.001
Residual	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Primary sludge							
Total	23.534	28.564	13.316	1.917	7.424	0.571	0.306
Residual	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Waste activated sludge							
Total	2.504	2.812	1.160	0.169	1.008	0.159	0.007
Residual	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biodegraded	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.033	0.0613	0.0133	0.0017	3.764	7.000	1.523	0.193	114
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Settled									
Total	0.006	0.0153	0.0021	0.0007	2.861	7.000	0.986	0.332	459
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Primary sludge									
Total	1.1088	1.9147	0.4637	0.041	4.054	7.000	1.695	0.149	4
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Waste activated sludge									
Total	0.097	0.1686	0.063	0.0114	4.012	7.000	2.616	0.473	42
Residual	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	no data	no data	no data	no data	no data	no data	no data	no data	n/a

E1.2.4. Method 5: Calculation with elemental analysis and C and COD correlation+A382

			Preliminary formulae				Set y = 7				M.F.
Wastewater type	Sp (g/l)	Cp (g/l)	x'	y'	z'	a'	x	y	z	a	
Raw	-	-									
Total	1.393	0.396	0.033	0.0613	0.007	0.0017	3.764	7.000	0.81	0.193	114
Residual	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Settled											
Total	0.208	0.075	0.006	0.0153	0.006	0.0007	2.861	7.000	2.77	0.332	459
Residual	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Primary sludge											
Total	49.09	13.316	1.1088	1.9147	0.048	0.041	4.054	7.000	0.18	0.149	4
Residual	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Waste activated sludge											
Total	3.193	1.160	0.097	0.1686	0.061	0.0114	4.012	7.000	2.53	0.473	42
Residual	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Biodegraded	n/a	n/a	no data	no data	no data	no data	no data	no data	no data	no data	n/a

E1.3. PARTICULATE ORGANICS COMPOSITIONS: BTG 4

E1.3.1. Method 1: Calculation with U.C.T. laboratory measured data and %C

Wastewater type	fcv	fc	fn	x	y	z	a
Raw							
Total	0.67	0.269	0.019	2.022	7.000	3.580	0.12
Unbiodegradable	0.87	0.301	0.027	2.010	7.000	2.925	0.15
Biodegradable	0.60	0.257	0.016	2.027	7.000	3.867	0.10
Settled							
Total	0.15	0.096	0.012	0.622	7.000	3.905	0.06
Unbiodegradable	0.57	0.147	0.012	0.737	7.00	2.738	0.05
Biodegradable	0.07	0.1	0.012	0.592	7.000	4.215	0.07
Primary sludge							
Total	1.50	0.546	0.030	5.512	7.000	2.769	0.25
Unbiodegradable	1.05	0.392	0.037	3.238	7.000	3.105	0.26
Biodegradable	1.87	0.670	0.024	8.217	7.000	2.369	0.25
Waste activated sludge							
Total	1.468	0.516	0.073	4.308	7.000	2.139	0.52
Unbiodegradable	1.53	0.295	0.051	1.048	7.000	1.301	0.15
Biodegradable	1.39	0.816	0.102	-8.05	7.000	-1.04	-0.8

E1.3.2. Method 2: Calculation with elemental analysis and VS and COD

Elemental analysis results

Wastewater type	% Element		
Raw	%C	%H	%N
Total	23.47	3.990	1.000
Residual	18.180	2.940	0.860
Primary sludge			
Total	46.05	3.380	1.210
Residual	35.32	4.920	1.490
Waste activated sludge			
Total	35.86	5.230	4.140
Residual	16.480	4.760	1.220

PST volumes (l)

Raw	10.0
Settled	9.87
PS	0.13

Element molar masses (g/mol)

C	H	N
12.01	1.00	14.01

Relevant data

Wastewater type	Sp (g/l)	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Np (g/l)
Raw	-	-	-	-	-	-
Total	1.181	1.761	2.018	0.474	0.081	0.020
Residual	0.416	0.477	0.791	0.144	0.023	0.007
Biodegraded	0.765	1.284	n/a	0.330	0.057	0.013
Settled						
Total	0.167	1.099	1.231	0.105	0.054	0.011
Residual	0.102	0.179	0.463	0.026	0.007	0.002
Biodegraded	0.065	0.921	n/a	0.079	0.047	0.009
Primary sludge						
Total	78.161	52.017	61.722	28.42	2.086	0.747
Residual	24.198	23.144	25.671	9.067	1.263	0.383
Biodegraded	53.96	28.87	n/a	19.356	0.823	0.364
Waste activated sludge						
Total	3.315	2.258	3.248	1.165	0.170	0.134
Residual	1.989	1.303	2.336	0.385	0.111	0.028
Biodegraded	1.326	0.955	n/a	0.780	0.059	0.106

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.039	0.080	0.056	0.0014	3.432	7.000	4.83	0.125	87
Residual	0.012	0.023	0.014	0.000	3.608	7.000	4.08	0.146	301
Biodegraded	0.027	0.057	0.042	0.0010	3.360	7.000	5.15	0.117	122
Settled									
Total	0.009	0.054	0.036	0.001	1.137	7.000	4.70	0.098	130
Residual	0.002	0.007	0.004	0.0001	2.211	7.000	4.10	0.134	1013
Biodegraded	0.007	0.047	0.033	0.001	0.980	7.000	4.89	0.093	149
Primary sludge									
Total	2.367	2.084	1.104	0.053	7.949	7.000	3.70	0.179	3
Residual	0.755	1.262	0.685	0.027	4.188	7.000	3.79	0.151	6
Biodegraded	1.612	0.822	0.417	0.026	13.719	7.000	3.55	0.221	9
Waste activated sludge									
Total	0.097	0.170	0.053	0.010	4.000	7.000	2.16	0.396	41
Residual	0.032	0.111	0.026	0.002	2.020	7.000	1.66	0.128	63
Biodegraded	0.065	0.059	0.028	0.008	7.752	7.000	3.30	0.903	119

E1.3.3. Method 3: Calculation with elemental analysis and VS measurement

Elemental analysis results

Wastewater type	% Element			
Raw	%C	%H	%N	%P
Total	23.47	3.990	1.000	0.714
Residual	18.180	2.940	0.860	0.000
Primary sludge				
Total	46.05	3.380	1.210	1.070
Residual	35.32	4.920	1.490	1.300
Waste activated sludge				
Total	35.86	5.230	4.140	0.255
Residual	16.480	4.760	1.220	0.000

Element molar masses (g/mol)

C	H	O	N	P
12.01	1.00	16.01	14.01	30

Relevant data

Wastewater type	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Op (g/l)	Np (g/l)	P(p) g/l
Raw	-	-	-	-	-	-	
Total	1.761	2.018	0.474	0.081	1.173	0.020	0.01
Residual	0.477	0.791	0.144	0.023	0.304	0.007	0.00
Biodegraded	1.284	n/a	0.330	0.057	0.869	0.013	0.01
Settled							
Total	1.099	1.231	0.105	0.054	0.923	0.011	0.00
Residual	0.179	0.463	0.026	0.007	0.148	0.002	-0.0
Biodegraded	0.921	n/a	0.079	0.047	0.775	0.009	0.01
Primary sludge							
Total	52.017	61.722	28.42	2.086	20.101	0.747	0.66
Residual	23.144	25.671	9.067	1.263	12.098	0.383	0.33
Biodegraded	28.873	n/a	19.36	0.823	8.003	0.364	0.32
Waste activated sludge							
Total	2.258	3.248	1.165	0.170	0.781	0.134	0.00
Residual	1.303	2.336	0.385	0.111	0.778	0.028	0.00
Biodegraded	0.955	n/a	0.780	0.059	0.002	0.106	0.00

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.039	0.080	0.073	0.0014	3.432	7.000	6.37	0.125	87
Residual	0.012	0.023	0.019	0.000	3.608	7.000	5.71	0.146	301
Biodegraded	0.027	0.057	0.054	0.0010	3.360	7.000	6.64	0.117	122
Settled									
Total	0.009	0.054	0.058	0.001	1.137	7.000	7.47	0.098	130
Residual	0.002	0.007	0.009	0.0001	2.211	7.000	9.38	0.134	1013
Biodegraded	0.007	0.047	0.048	0.001	0.980	7.000	7.19	0.093	149
Primary sludge									
Total	2.367	2.0841	1.2555	0.053	7.949	7.000	4.21	0.179	3
Residual	0.755	1.262	0.756	0.027	4.188	7.000	4.19	0.151	6
Biodegraded	1.612	0.822	0.500	0.026	13.719	7.000	4.26	0.221	9
Waste activated sludge									
Total	0.097	0.1697	0.049	0.010	4.000	7.000	2.01	0.396	41
Residual	0.032	0.111	0.049	0.002	2.020	7.000	3.06	0.128	63
Biodegraded	0.065	0.059	0.000	0.008	7.752	7.000	0.01	0.903	119

E1.3.4. Method 4: Calculation with elemental analysis and C and COD

			Preliminary formulae				Set y = 7				M.F
Wastewater type	Sp (g/l)	Cp (g/l)	x'	y'	z'	a'	x	y	z	a	
Raw	-	-									
Total	1.181	0.474	0.039	0.080	0.043	0.0014	3.43	7.000	3.76	0.1	87
Residual	0.416	0.144	0.012	0.023	0.009	0.000	3.60	7.000	2.67	0.1	301
Biodegraded	0.765	0.330	0.027	0.057	0.034	0.0010	3.36	7.000	4.20	0.1	122
Settled											
Total	0.167	0.105	0.009	0.054	0.033	0.001	1.13	7.000	4.28	0.0	130
Residual	0.102	0.026	0.002	0.007	0.001	0.0001	2.21	7.000	1.24	0.1	1013
Biodegraded	0.065	0.079	0.007	0.047	0.032	0.001	0.98	7.000	4.72	0.0	149
Primary sludge											
Total	78.161	28.42	2.367	2.0841	0.814	0.053	7.94	7.000	2.73	0.1	3
Residual	24.198	9.067	0.755	1.262	0.589	0.027	4.18	7.000	3.27	0.1	6
Biodegraded	53.96	19.36	1.612	0.822	0.226	0.026	13.7	7.000	1.9	0.2	9
Waste activated sludge											
Total	3.315	1.165	0.097	0.1697	0.057	0.010	4.00	7.000	2.37	0.3	41
Residual	1.989	0.385	0.032	0.111	-0.008	0.002	2.02	7.000	-0.48	0.1	63
Biodegraded	1.326	0.780	0.065	0.059	0.065	0.008	7.75	7.000	7.77	0.9	119

E1.4. PARTICULATE ORGANICS COMPOSITIONS: BTG 5

E1.4.1. Method 1: Calculation with U.C.T. laboratory measured data and %C

Wastewater type		fc	fn	x	y	z	a
Raw							
Total	0.49	0.243	0.013	2.086	7.000	4.352	0.0
Unbiodegradable	0.57	0.253	0.014	2.055	7.000	4.014	0.1
Biodegradable	0.46	0.238	0.012	2.101	7.000	4.515	0.0
Settled							
Total	0.12	0.150	0.007	1.376	7.000	5.356	0.0
Unbiodegradable	0.43	0.231	-0.002	2.068	7.00	4.748	-0.0
Biodegradable	0.04	0.1	0.009	1.202	7.000	5.509	0.0
Primary sludge							
Total	1.38	0.463	0.027	3.451	7.000	2.419	0.1
Unbiodegradable	0.68	0.272	0.028	2.046	7.000	3.513	0.1
Biodegradable	2.32	0.717	0.026	5.291	7.000	0.988	0.1
Waste activated sludge							
Total	1.468	0.516	0.079	4.276	7.000	2.079	0.5
Unbiodegradable	1.79	0.477	0.069	2.294	7.000	1.201	0.2
Biodegradable	1.05	0.566	0.093	64.50	7.000	28.745	9.0

E1.4.2. Method 2: Calculation with elemental analysis and VS and COD correlation

Elemental analysis results

Wastewater type	% Element		
Raw	%C	%H	%N
Total	17.760	3.610	0.660
Residual	17.080	2.660	0.800
Primary sludge			
Total	38.93	5.680	1.230
Residual	20.64	4.110	1.680
Waste activated sludge			
Total	35.860	5.230	4.140
Residual	29.540	4.510	2.810

PST volumes (l)

Raw	10.0
Settled	9.83
PS	0.17

Element molar masses (g/mol)

C	H	N
12.01	1.00	14.01

Relevant data

Wastewater type	Sp (g/l)	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Np (g/l)
Raw	-	-	-	-	-	-
Total	1.213	2.459	3.365	0.598	0.121	0.022
Residual	0.429	0.758	1.124	0.192	0.030	0.009
Biodegraded	0.784	1.701	n/a	0.406	0.092	0.013
Settled						
Total	0.208	1.758	2.539	0.264	0.073	0.012
Residual	0.150	0.346	0.584	0.080	0.007	0.000
Biodegraded	0.058	1.412	n/a	0.184	0.066	0.012
Primary sludge						
Total	59.371	43.00	51.100	19.89	2.902	0.629
Residual	16.598	24.57	32.388	6.685	1.331	0.544
Biodegraded	42.773	18.42	n/a	13.20	1.571	0.084
Waste activated sludge						
Total	3.315	2.258	3.248	1.165	0.170	0.134
Residual	2.271	1.269	2.048	0.605	0.092	0.058
Biodegraded	1.044	0.989	n/a	0.560	0.078	0.077

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.050	0.121	0.090	0.001	2.870	7.000	5.213	0.091	58
Residual	0.016	0.030	0.024	0.001	3.746	7.000	5.649	0.150	234
Biodegraded	0.034	0.091	0.067	0.001	2.584	7.000	5.090	0.072	77
Settled									
Total	0.022	0.073	0.069	0.001	2.098	7.000	6.556	0.080	96
Residual	0.007	0.007	0.010	0.000	6.285	7.000	9.675	-0.018	947
Biodegraded	0.015	0.066	0.059	0.001	1.628	7.000	6.292	0.091	106
Primary sludge									
Total	1.656	2.900	1.124	0.045	3.999	7.000	2.713	0.108	2
Residual	0.557	1.330	0.811	0.039	2.930	7.000	4.270	0.204	5
Biodegraded	1.100	1.570	0.247	0.006	4.904	7.000	1.10	0.027	4
Waste activated sludge									
Total	0.097	0.170	0.053	0.010	4.000	7.000	2.169	0.396	41
Residual	0.050	0.092	0.020	0.004	3.821	7.000	1.532	0.312	76
Biodegraded	0.047	0.077	0.037	0.0055	4.214	7.000	3.37	0.496	90

E1.4.3. Method 3: Calculation with elemental analysis and VS measurement

Elemental analysis results

Wastewater type	% Element			
Raw	%C	%H	%N	%P
Total	17.760	3.610	0.660	0.714
Residual	17.080	2.660	0.800	0.000
Primary sludge				
Total	38.93	5.680	1.230	1.070
Residual	20.64	4.110	1.680	1.300
Waste activated sludge				
Total	35.860	5.230	4.140	0.255
Residual	29.540	4.510	2.810	0.000

Element molar masses (g/mol)

C	H	O	N	P
12.01	1.00	16.01	14.01	30.97

Relevant data

Wastewater type	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Op (g/l)	Np (g/l)	P(p) g/l
Raw	-	-	-	-	-	-	
Total	2.459	3.365	0.598	0.121	1.694	0.022	0.02
Residual	0.758	1.124	0.192	0.030	0.527	0.009	0.00
Biodegraded	1.701	n/a	0.406	0.092	1.167	0.013	0.02
Settled							
Total	1.758	2.539	0.264	0.073	1.394	0.012	0.01
Residual	0.346	0.584	0.080	0.007	0.266	0.000	-0.00
Biodegraded	1.412	n/a	0.184	0.066	1.128	0.012	0.02
Primary sludge							
Total	43.00	51.10	19.893	2.902	19.032	0.629	0.54
Residual	24.579	32.39	6.685	1.331	15.598	0.544	0.42
Biodegraded	18.424	n/a	13.208	1.571	3.435	0.084	0.12
Waste activated sludge							
Total	2.258	3.248	1.165	0.170	0.781	0.134	0.00
Residual	1.269	2.048	0.605	0.092	0.514	0.058	0.00
Biodegraded	0.989	n/a	0.560	0.078	0.267	0.077	0.00

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.050	0.121	0.1058	0.001	2.870	7.000	6.10	0.091	58
Residual	0.0160	0.030	0.033	0.001	3.746	7.000	7.70	0.150	234
Biodegraded	0.034	0.091	0.0729	0.001	2.584	7.000	5.57	0.072	77
Settled									
Total	0.022	0.073	0.0871	0.001	2.098	7.000	8.31	0.080	96
Residual	0.007	0.007	0.017	0.000	6.285	7.000	15.7	-0.01	947
Biodegraded	0.0153	0.066	0.0704	0.001	1.628	7.000	7.48	0.091	106
Primary sludge									
Total	1.6564	2.900	1.1888	0.045	3.999	7.000	2.87	0.108	2
Residual	0.5566	1.329	0.974	0.039	2.930	7.000	5.12	0.204	5
Biodegraded	1.0998	1.569	0.215	0.006	4.904	7.000	0.96	0.027	4
Waste activated sludge									
Total	0.0970	0.169	0.049	0.010	4.000	7.000	2.01	0.396	41
Residual	0.0504	0.092	0.0321	0.004	3.821	7.000	2.43	0.312	76
Biodegraded	0.047	0.077	0.0167	0.005	4.214	7.000	1.50	0.496	90

E1.4.4. Method 4: Calculation with elemental analysis and C and COD correlation

			Preliminary formulae				Set y = 7				M.F.
Wastewater type	Sp (g/l)	Cp (g/l)	x'	y'	z'	a'	x	y	z	a	
Raw											
Total	1.213	0.598	0.050	0.121	0.082	0.0016	2.87	7.000	4.73	0.0	58
Residual	0.429	0.192	0.0160	0.030	0.019	0.001	3.74	7.000	4.48	0.1	234
Biodegraded	0.784	0.406	0.034	0.091	0.063	0.001	2.58	7.000	4.81	0.0	77
Settled											
Total	0.208	0.264	0.022	0.073	0.066	0.001	2.09	7.000	6.34	0.8	96
Residual	0.150	0.080	0.007	0.007	0.008	0.000	6.28	7.000	7.24	0	947
Biodegraded	0.058	0.184	0.015	0.066	0.059	0.001	1.63	7.000	6.24	0.0	106
Primary sludge											
Total	59.371	19.89	1.6564	2.900	0.988	0.045	3.99	7.000	2.38	0.1	2
Residual	16.598	6.685	0.5566	1.329	0.683	0.039	2.93	7.000	3.60	0.2	5
Biodegraded	42.773	13.20	1.0998	1.569	0.304	0.006	4.90	7.000	1.4	0.0	4
Waste activated sludge											
Total	3.315	1.165	0.0970	0.169	0.057	0.010	4.00	7.000	2.37	0.3	41
Residual	2.271	0.605	0.0504	0.092	-0.001	0.0041	3.82	7.000	-0.08	0.3	76
Biodegraded	1.044	0.560	0.047	0.077	0.059	0.0055	4.21	7.000	5.29	0.4	90

E1.5. PARTICULATE ORGANICS COMPOSITIONS: BTG 6

E1.5.1. Method 1: Calculation with U.C.T. laboratory measured data and %C

Wastewater type	fcv	fc	fn	x	y	z	a
Raw							
Total	0.96	0.370	0.025	3.131	7.000	3.396	0.185
Unbiodegradable	1.22	0.405	0.034	2.821	7.000	2.493	0.202
Biodegradable	0.84	0.354	0.022	3.330	7.000	3.972	0.173
Settled							
Total	0.45	0.276	0.024	3.168	7.000	5.584	0.233
Unbiodegradable	1.34	0.304	0.012	1.295	7.00	1.750	0.04
Biodegradable	0.20	0.3	0.027	5.922	7.000	11.222	0.512
Primary sludge							
Total	1.77	0.520	0.028	3.101	7.000	1.584	0.145
Unbiodegradable	1.13	0.479	0.050	6.246	7.000	4.160	0.559
Biodegradable	2.36	0.557	0.008	2.217	7.000	0.860	0.028
Waste activated sludge							
Total	1.643	0.506	0.087	3.132	7.000	1.447	0.463
Unbiodegradable	1.50	0.446	0.060	2.576	7.000	1.703	0.295
Biodegradable	1.81	0.580	0.121	3.924	7.000	1.082	0.702

E1.5.2. Method 2: Calculation with elemental analysis and VS and COD

Elemental analysis results

Wastewater type	% Element		
Raw	%C	%H	%N
Total	32.2200	4.7300	1.8900
Residual	28.6900	4.6900	1.5800
Primary sludge			
Total	45.9900	6.7200	1.9700
Residual	35.2800	4.4700	1.7500
Waste activated sludge			
Total	44.0100	6.4800	7.2300
Residual	23.6000	4.5700	1.8800

PST volumes (l)

Raw	10.00
Settled	9.360
PS	0.640

Element molar masses (g/mol)

C	H	N
12.01	1.00	14.01

Relevant data

Wastewater type	Sp (g/l)	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Np (g/l)
Raw	-	-	-	-	-	-
Total	1.964	2.046	2.351	0.757	0.111	0.044
Residual	0.797	0.656	0.927	0.266	0.043	0.015
Biodegraded	1.167	1.389	n/a	0.492	0.068	0.030
Settled						
Total	0.609	1.342	1.558	0.371	0.055	0.029
Residual	0.397	0.297	0.441	0.090	0.022	0.006
Biodegraded	0.212	1.045	n/a	0.281	0.033	0.023
Primary sludge						
Total	21.784	12.335	13.944	6.413	0.937	0.275
Residual	6.652	5.912	8.034	2.835	0.359	0.141
Biodegraded	15.132	6.423	n/a	3.578	0.578	0.134
Waste activated sludge						
Total	2.913	1.773	2.040	0.898	0.132	0.147
Residual	1.461	0.973	1.839	0.434	0.084	0.035
Biodegraded	1.452	0.800	n/a	0.464	0.048	0.113

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.063	0.111	0.062	0.003	3.974	7.000	3.928	0.200	63
Residual	0.022	0.043	0.018	0.001	3.569	7.000	2.899	0.168	161
Biodegraded	0.041	0.068	0.044	0.002	4.234	7.000	4.589	0.220	103
Settled									
Total	0.031	0.055	0.050	0.002	3.952	7.000	6.442	0.262	128
Residual	0.008	0.022	0.007	0.000	2.406	7.000	2.115	0.138	320
Biodegraded	0.023	0.033	0.047	0.002	4.982	7.000	10.011	0.345	213
Primary sludge									
Total	0.534	0.936	0.241	0.020	3.993	7.000	1.800	0.147	7
Residual	0.236	0.359	0.189	0.010	4.605	7.000	3.692	0.196	20
Biodegraded	0.298	0.577	0.071	0.010	3.613	7.000	0.863	0.116	12
Waste activated sludge									
Total	0.075	0.132	0.030	0.011	3.962	7.000	1.583	0.558	53
Residual	0.036	0.084	0.023	0.002	3.013	7.000	1.957	0.206	83
Biodegraded	0.039	0.048	0.007	0.008	5.620	7.000	0.950	1.173	146

E1.5.3. Method 3: Calculation with elemental analysis and VS measurement

Elemental analysis results

Wastewater type	% Element			
Raw	%C	%H	%N	%P
Total	32.220	4.730	1.890	0.714
Residual	28.690	4.690	1.580	0.000
Primary sludge				
Total	45.990	6.720	1.970	1.070
Residual	35.280	4.470	1.750	1.300
Waste activated sludge				
Total	44.010	6.480	7.230	0.255
Residual	23.600	4.570	1.880	0.000

Element molar masses (g/mol)

C	H	O	N
12.01	1.00	16.01	14.01

Relevant data

Wastewater type	Xv (g/l)	Xt (g/l)	Cp (g/l)	Hp (g/l)	Op (g/l)	Np (g/l)	P(p) g/l
Raw	-	-	-	-	-	-	
Total	2.046	2.351	0.757	0.111	1.116	0.044	0.017
Residual	0.656	0.927	0.266	0.043	0.332	0.015	0.000
Biodegraded	1.389	n/a	0.492	0.068	0.784	0.030	0.017
Settled							
Total	1.342	1.558	0.371	0.055	0.880	0.029	0.008
Residual	0.297	0.441	0.090	0.022	0.186	0.006	-0.007
Biodegraded	1.045	n/a	0.281	0.033	0.694	0.023	0.015
Primary sludge							
Total	12.335	13.944	6.413	0.937	4.562	0.275	0.149
Residual	5.912	8.034	2.835	0.359	2.474	0.141	0.104
Biodegraded	6.423	n/a	3.578	0.578	2.088	0.134	0.045
Waste activated sludge							
Total	1.773	2.040	0.898	0.132	0.590	0.147	0.005
Residual	0.973	1.839	0.434	0.084	0.420	0.035	0.000
Biodegraded	0.800	n/a	0.464	0.048	0.170	0.113	0.005

Organics compositions preliminary formulae

	Preliminary formulae				Set y = 7				M.F.
Wastewater type	x'	y'	z'	a'	x	y	z	a	
Raw									
Total	0.0631	0.1111	0.0697	0.0032	3.974	7.000	4.392	0.200	63
Residual	0.0221	0.0434	0.0208	0.0010	3.569	7.000	3.347	0.168	161
Biodegraded	0.0409	0.0677	0.0489	0.0021	4.234	7.000	5.063	0.220	103
Settled									
Total	0.0309	0.0547	0.0550	0.0020	3.952	7.000	7.040	0.262	128
Residual	0.0075	0.0218	0.0116	0.0004	2.406	7.000	3.720	0.138	320
Biodegraded	0.0234	0.0328	0.0434	0.0016	4.982	7.000	9.251	0.345	213
Primary sludge									
Total	0.5339	0.9361	0.2849	0.0196	3.993	7.000	2.131	0.147	7
Residual	0.2360	0.3588	0.155	0.0100	4.605	7.000	3.015	0.196	20
Biodegraded	0.2979	0.5773	0.1304	0.0096	3.613	7.000	1.58	0.116	12
Waste activated sludge									
Total	0.0747	0.1321	0.0369	0.0105	3.962	7.000	1.955	0.558	53
Residual	0.0361	0.0840	0.0263	0.0025	3.013	7.000	2.189	0.206	83
Biodegraded	0.0386	0.0481	0.0106	0.0081	5.620	7.000	1.545	1.173	146

E1.5.4. Method 4: Calculation with elemental analysis and C and COD

			Preliminary formulae				Set y = 7				M.F.
Wastewater type	Sp (g/l)	Cp (g/l)	x'	y'	z'	a'	x	y	z	a	
Raw	-	-									
Total	1.964	0.757	0.0631	0.1111	0.054	0.0032	3.974	7.000	3.42	0.200	63
Residual	0.797	0.266	0.0221	0.0434	0.015	0.0010	3.569	7.000	2.36	0.168	161
Biodegraded	1.167	0.492	0.0409	0.0677	0.040	0.0021	4.234	7.000	4.10	0.220	103
Settled											
Total	0.609	0.371	0.031	0.0547	0.048	0.0020	3.952	7.000	6.14	0.262	128
Residual	0.397	0.090	0.0075	0.0218	0.000	0.0004	2.406	7.000	0.16	0.138	320
Biodegraded	0.212	0.281	0.023	0.0328	0.047	0.0016	4.98	7.000	10.13	0.345	213
Primary sludge											
Total	21.784	6.413	0.5339	0.9361	0.146	0.0196	3.993	7.000	1.09	0.147	7
Residual	6.652	2.835	0.2360	0.3588	0.221	0.0100	4.605	7.000	4.31	0.196	20
Biodegraded	15.132	3.578	0.2979	0.5773	-0.075	0.0096	3.613	7.000	-0.9	0.116	12
Waste activated sludge											
Total	2.913	0.898	0.0747	0.1321	0.018	0.0105	3.962	7.000	0.944	0.558	53
Residual	1.461	0.434	0.0361	0.0840	0.019	0.0025	3.013	7.000	1.61	0.206	83
Biodegraded	1.452	0.464	0.0386	0.0481	-0.001	0.0081	5.620	7.000	####	1.173	146

E2. SOLUBLE ORGANICS COMPOSITIONS: BTG 2

E2.1. Batch test experimental data

Ratio's	Total	Unbiodegraded	Biodegraded	BTG
COD/DOC	3.48	3.95	3.42	2
OrgN/DOC	0.156	0.330	0.132	
COD/DOC	4.22	5.86	3.99	3
OrgN/DOC	0.205	0.376	0.181	
COD/DOC	5.12	4.80	5.19	4
OrgN/DOC	0.524	0.496	0.530	
COD/DOC	6.41	4.80	6.95	5
OrgN/DOC	0.608	0.496	0.647	
COD/DOC	3.93	9.58	3.51	6
OrgN/DOC	0.114	0.053	0.119	

E2.2. Data from Ubisi (1997)

	MLE system effluent		
Wastewater batch no.	**Dissolved COD (mg/l)**	**Volatile Dissolved Solids (mg/l)**	**COD/VDS**
1	39	306	0.127
2	38	490	0.078
3	44	638	0.069
4	50	384	0.130
5	49	554	0.088
6	40	500	0.080
7	39	465	0.084
8	47	453	0.104
9	66	470	0.140
10	59	445	0.133
11	46	406	0.113
12	49	364	0.135
13	46	324	0.142
14	45	297	0.152
15	49	235	0.209
16	39	232	0.168
17	44	249	0.177
18	72	343	0.210
19	59	317	0.186
20	48	355	0.135
21	49	315	0.156
22	38	162	0.235
23	33	184	0.179
24	43	294	0.146
25	46	350	0.131
26	51	317	0.161
27	46	357	0.129
28	40	350	0.114
		Average:	0.140
		Standard Dev.:	0.041

E2.3. Organics compositions from COD, DOC and TKN data

Formulae:

1. x = (14y - 28z) / (21 COD/DOC + 36 OrgN/DOC - 56)
2. y = 7
3. z = 2
4. a = [OrgN/DOC (12y - 24z)] / (21 COD/DOC + 36 OrgN / DOC - 56)

Assumptions:

1. y = 7
2. z = 2
3. Unbiodegradable soluble organics composition in WAS = unbiodegradable soluble organics in raw, settled wastewater and primary sludge

Total raw wastewater, settled wastewater and PS dissolved compositions

C(x)	H(y)	O(z)	N(a)	BTG
0.534	7.000	2.000	0.248	2
0.438	7.000	2.000	0.185	3
0.333	7.000	2.000	0.268	4
0.269	7.000	2.000	0.218	5
0.485	7.000	2.000	0.135	6

Unbiodegraded raw wastewater, settled wastewater, PS and WAS as well as total WAS dissolved compositions

C(x)	H(y)	O(z)	N(a)	BTG
0.443	7.000	2.000	0.307	2
0.307	7.000	2.000	0.168	3
0.354	7.000	2.000	0.284	4
0.354	7.000	2.000	0.284	5
0.207	7.000	2.000	0.013	6

Biodegraded raw wastewater, settled wastewater, PS and WAS as well as total WAS dissolved compositions

C(x)	H(y)	O(z)	N(a)	BTG
0.549	7.000	2.000	0.233	2
0.465	7.000	2.000	0.191	3
0.328	7.000	2.000	0.265	4
0.248	7.000	2.000	0.206	5
0.539	7.000	2.000	0.195	6

E2.4. Organics compositions from COD, DOC, TKN and VDS data

Formulae:

1. x = C/VDS (y + 16 z) / [(12 (1 - C/VDS - N/VDS)]
2. y = 7
3. z = z = [y (1 - (COD/VDS)/8 - 8(C/VDS)/12 - 17(N/VDS)/14)] / [2 (1 + COD/VDS - 44(C/VDS)/12 + 10(N/VDS)/14)]
4. a = [(N/VDS) (y + 16z)] / [(14 (1 - C/VDS - N/VDS)]

Table E.2.4.(a) WAS data from laboratory data and data from Ubisi (1997)

COD/VDS	C/VDS	N/VDS	BTG
0.140	0.035	0.012	2
0.140	0.024	0.009	3
0.140	0.029	0.014	4
0.140	0.029	0.014	5
0.140	0.015	0.001	6

Table E.2.4.(a) WAS dissolved compositions from laboratory data and data from Ubisi (1997)

x	y	z	a	BTG
0.182	7.000	3.247	0.052	2
0.118	7.000	3.160	0.038	3
0.146	7.000	3.172	0.062	4
0.146	7.000	3.172	0.062	5
0.070	7.000	3.130	0.003	6

F1. BTG 2

F1.1. %N measured and calculated values comparisons

Waste-water type	Ntp measured (mg/l)	Ntp elemental analysis (mg/l)	TS (mg/l)	% N measured	% N calculated
Raw					
Total	25.8	18.1	1266	1.43	2.03
Residual	no data	no data	no data	no data	no data
Primary sludge					
Total	325	183	8445	2.17	3.84
Residual	224	73	7303	1.00	3.07
Waste activated sludge					
Total	177	175.2	3036	7.15	5.84
Residual	97.4	77.5	2288	3.80	4.25

F1.2. %H measured and calculated values comparisons

Waste-water type	Sp (g/l)	Cp (g/l)	fcv	x'	z'	a'
Raw						
Total	0.914	0.303	0.98	0.025	0.032	0.002
Residual	-	-	no data	no data	no data	no data
Primary sludge						
Total	11.921	3.711	2.25	0.309	0.052	0.023
Residual	5.560	1.642	1.71	0.137	0.066	0.016
Waste activated sludge						
Total	3.036	1.059	1.46	0.088	0.043	0.013
Residual	2.288	0.659	1.65	0.055	0.030	0.007

Waste-water type	Xt (g/l)	y'	% H measured	% H calculated
Raw				
Total	1.266	0.083	4.02	6.58
Residual	no data	no data	no data	no data
Primary sludge				
Total	8.445	0.427	6.17	5.06
Residual	7.303	0.327	3.99	4.48
Waste activated sludge				
Total	3.036	0.151	5.98	4.99
Residual	2.288	0.148	3.90	6.46

E1.3. TSS measured and calculated values comparisons

Waste-water type	Xv (g/l)	Sp (g/l)	%C	%H	%N	Theor. TS (g/l)	Measured TS (g/l)	% Change
Raw								
Total	0.928	0.914	23.91	4.02	1.43	1.500	1.266	15.6
Residual	-	-	no data	no data	no data	no data	n/a	n/a
Primary sludge								
Total	5.302	11.921	43.94	6.17	2.17	8.007	8.445	-5.5
Residual	3.248	5.560	22.48	3.99	1.00	7.488	7.303	2.5
Waste activated sludge								
Total	2.084	3.036	43.22	5.98	7.15	2.471	2.450	0.8
Residual	1.389	2.288	32.3	3.9	3.80	2.438	2.040	16.3

F2. BTG 3

F2.1. %N measured and calculated values comparisons

Waste-water type	Ntp measured (mg/l)	Ntp elemental analysis (mg/l)	TS (mg/l)	% N measured	% N calculated
Raw					
Total	22.8	23.7	953	2.49	2.39
Residual	no data	no data	no data	no data	no data
Primary sludge					
Total	778	571	28564	2.00	2.72
Residual	No data	no data	no data	no data	no data
Waste activated sludge					
Total	158	159.4	3193	5.67	4.95
Residual	no data	no data	no data	no data	no data

F2.2. %H measured and calculated values comparisons

Waste-water type	Sp (g/l)	Cp (g/l)	fcv	x'	z'	a'
Raw						
Total	1.393	0.396	1.99	0.033	0.013	0.002
Residual	n/a	n/a	n/a	no data	no data	no data
Primary sludge						
Total	49.090	13.316	2.09	1.109	0.420	0.056
Residual	n/a	n/a	n/a	no data	no data	no data
Waste activated sludge						
Total	3.193	1.160	1.28	0.097	0.063	0.011
Residual	n/a	n/a	no data	no data	no data	no data

Waste-water type	Xt (g/l)	y'	% H measured	% H calculated
Raw				
Total	0.953	0.073	6.44	7.68
Residual	no data	no data	no data	no data
Primary sludge				
Total	28.564	2.704	6.71	9.47
Residual	No data	no data	no data	no data
Waste activated sludge				
Total	3.193	0.173	6.00	5.41
Residual	no data	no data	no data	no data

E2.3. TSS measured and calculated values comparisons

Waste-water type	Xv (g/l)	Sp (g/l)	%C	%H	%N	Theor. TS (g/l)	Measured TS (g/l)	% Change
Raw								
Total	0.701	1.393	41.55	6.44	2.49	1.004	0.953	5.1
Residual	n/a	n/a	no data	no data	no data	no data	n/a	n/a
Primary sludge								
Total	23.534	49.090	46.62	6.71	2.00	31.589	28.564	9.6
Residual	n/a	n/a	no data	no data	no data	no data	n/a	n/a
Waste activated sludge								
Total	2.504	3.193	41.26	6.00	5.67	2.831	2.812	0.7
Residual	n/a	n/a	no data	no data	no data	no data	n/a	n/a

F.3. BTG 4

F3.1. %N measured and calculated values comparisons

Waste-water type	Ntp (measured)	Ntp (elemental analysis)	TS (mg/l)	% N (measured)	% N calculated
Raw					
Total	33.3	20.2	2018	1.00	1.65
Residual	13.1	6.8	791	0.86	1.66
Primary sludge					
Total	1552	747	61722	1.21	2.51
Residual	849	383	25671	1.49	3.31
Waste activated sludge					
Total	165	134.5	3315	4.14	4.97
Residual	66.8	28.5	1989	1.22	3.36

F3.2. %H measured and calculated values comparisons

Waste-water type	Sp (g/l)	Cp (g/l)	fcv	x'	z'	a'
Raw						
Total	1.181	0.474	0.67	0.039	0.070	0.002
Residual	0.416	0.144	0.87	0.012	0.017	0.001
Primary sludge						
Total	78.161	28.423	1.50	2.367	1.189	0.111
Residual	24.198	9.067	1.05	0.755	0.724	0.061
Waste activated sludge						
Total	3.315	1.165	1.47	0.097	0.048	0.012
Residual	1.989	0.385	1.53	0.032	0.040	0.005

Waste-water type	Xt (g/l)	y'	% H measured	% H calculated
Raw				
Total	2.018	0.137	3.99	6.77
Residual	0.791	0.042	2.94	5.27
Primary sludge				
Total	61.722	3.005	3.38	4.87
Residual	25.671	1.632	4.92	6.36
Waste activated sludge				
Total	3.315	0.158	5.23	4.75
Residual	1.989	0.214	4.76	10.76

E3.3. TSS measured and calculated values comparisons

Wastewater type	Xv (g/l)	Sp (g/l)	%C	%H	%N	Theor. TS (g/l)	Measured TS (g/l)	% Change
Raw								
Total	1.761	1.181	23.47	3.99	1.65	2.436	2.018	17.2
Residual	0.477	0.416	18.18	2.94	0.86	0.965	0.791	18.1
Primary sludge								
Total	52.017	78.161	46.05	3.38	1.21	65.612	61.722	5.9
Residual	23.144	24.198	35.32	4.92	1.49	27.409	25.671	6.3
Waste activated sludge								
Total	2.258	3.315	35.86	5.23	4.14	3.173	3.248	-2.4
Residual	1.303	1.989	16.48	4.76	1.22	3.215	2.336	27.3

F4. BTG 5

F4.1. %N measured and calculated values comparisons

Waste-water type	Ntp measured (mg/l)	Ntp elemental analysis (mg/l)	TS (mg/l)	% N measured	% N calculated
Raw					
Total	31.9	22.2	3365	0.66	0.95
Residual	10.9	9.0	1124	0.80	0.97
Primary sludge					
Total	1157	629	51100	1.23	2.26
Residual	685	544	32388	1.68	2.11
Waste activated sludge					
Total	179	134.5	3315	4.14	5.41
Residual	87.8	57.5	2271	2.81	3.87

F4.2. %H measured and calculated values comparisons

Waste-water type	Sp (g/l)	Cp (g/l)	fcv	x'	z'	a'
Raw						
Total	1.213	0.598	0.49	0.050	0.104	0.002
Residual	0.429	0.192	0.57	0.016	0.031	0.001
Primary sludge						
Total	59.371	19.893	1.38	1.656	1.161	0.083
Residual	16.598	6.685	0.68	0.557	0.956	0.049
Waste activated sludge						
Total	3.315	1.165	1.47	0.097	0.047	0.013
Residual	2.271	0.605	1.79	0.050	0.026	0.006

Waste-water type	Xt (g/l)	y'	% H measured	% H calculated
Raw				
Total	3.365	0.167	3.61	4.96
Residual	1.124	0.054	2.66	4.84
Primary sludge				
Total	51.100	3.359	5.68	6.57
Residual	32.388	1.905	4.11	5.88
Waste activated sludge				
Total	3.315	0.159	5.23	4.79
Residual	2.271	0.154	4.51	6.77

E4.3. TSS measured and calculated values comparisons

Wastewater type	Xv (g/l)	Sp (g/l)	%C	%H	%N	Theor. TS (g/l)	Measured TS (g/l)	% Change
Raw								
Total	2.459	1.213	17.76	3.61	0.66	3.781	3.365	11.0
Residual	0.758	0.429	17.08	2.66	0.80	1.380	1.124	18.5
Primary sludge								
Total	43.003	59.371	38.93	5.68	1.23	53.048	51.100	3.7
Residual	24.579	16.598	20.64	4.11	1.68	36.940	32.388	12.3
Waste activated sludge								
Total	2.258	3.315	35.86	5.23	4.14	3.173	3.248	-2.4
Residual	1.269	2.271	29.54	4.51	2.81	2.410	2.048	15.0

F5. BTG 6

F5.1. %N measured and calculated values comparisons

Wastewater type	Ntp measured (mg/l)	Ntp elemental analysis (mg/l)	TS (mg/l)	% N measured	% N calculated
Raw					
Total	52.1	44.4	2351	1.89	2.22
Residual	22.2	14.6	927	1.58	2.40
Primary sludge					
Total	349	275	13944	1.97	2.50
Residual	296	141	8034	1.75	3.69
Waste activated sludge					
Total	155	147.5	2913	7.23	5.32
Residual	58.1	34.6	1461	1.88	3.97

F5.2. %H measured and calculated values comparisons

Wastewater type	Sp (g/l)	Cp (g/l)	fcv	x'	z'	a'
Raw						
Total	1.964	0.757	0.96	0.063	0.068	0.004
Residual	0.797	0.266	1.22	0.022	0.020	0.002
Primary sludge						
Total	21.784	6.413	1.77	0.534	0.273	0.025
Residual	6.652	2.835	1.13	0.236	0.157	0.021
Waste activated sludge						
Total	2.913	0.898	1.64	0.075	0.035	0.011
Residual	1.461	0.434	1.50	0.036	0.024	0.004

Wastewater type	Xt (g/l)	y'	% H measured	% H calculated
Raw				
Total	2.351	0.141	4.73	6.00
Residual	0.927	0.055	4.69	5.93
Primary sludge				
Total	13.944	1.205	6.72	8.64
Residual	8.034	0.265	4.47	3.29
Waste activated sludge				
Total	2.913	0.167	6.48	5.74
Residual	1.461	0.098	4.57	6.72

E5.3. TSS measured and calculated values comparisons

Wastewater type	Xv (g/l)	Sp (g/l)	%C	%H	%N	Theor. TS (g/l)	Measured TS (g/l)	% Change
Raw								
Total	2.046	1.964	32.22	4.73	1.89	2.516	2.351	6.6
Residual	0.656	0.797	28.69	4.69	1.58	0.994	0.927	6.8
Primary sludge								
Total	12.335	21.784	45.99	6.72	1.97	14.984	13.944	6.9
Residual	5.912	6.652	35.28	4.47	1.75	7.464	8.034	-7.6
Waste activated sludge								
Total	1.773	2.913	44.01	6.48	7.23	2.184	2.040	6.6
Residual	0.973	1.461	23.6	4.57	1.88	1.927	1.839	4.6

G1.1. Particulate organics calculation Method 1

Data used: COD (mg/l), TKN (mg/l), VS (mg/l), TS (mg/l), %Carbon

Original values

BTG	x	y	z	a	M (g/mol)
2	4.077	7.000	2.011	0.585	282.4
3	3.914	7.000	2.563	0.457	340.4
4	4.308	7.000	2.139	0.522	298.5
5	4.276	7.000	2.079	0.565	292.0
6	3.132	7.000	1.447	0.463	206.2

Adjust COD +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	3.329	7.000	1.562	0.477	221.5	-18.4	0.0	-22.4	-18.4	-21.5
3	3.240	7.000	2.046	0.379	273.3	-17.2	0.0	-20.2	-17.2	-19.7
4	3.486	7.000	1.647	0.422	232.2	-19.1	0.0	-23.0	-19.1	-22.2
5	3.465	7.000	1.601	0.458	227.4	-19.0	0.0	-23.0	-19.0	-22.1
6	2.616	7.000	1.137	0.387	164.1	-16.5	0.0	-21.5	-16.5	-20.4

Adjust TKN +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.039	7.000	1.937	0.638	274.4	-0.9	0.0	-3.7	9.1	-2.8
3	3.886	7.000	2.500	0.500	333.6	-0.7	0.0	-2.4	9.4	-2.0
4	4.272	7.000	2.071	0.570	291.2	-0.8	0.0	-3.2	9.2	-2.5
5	4.237	7.000	2.005	0.617	284.1	-0.9	0.0	-3.5	9.2	-2.7
6	4.039	7.000	1.937	0.638	274.4	29.0	0.0	33.9	37.8	33.1

Adjust VS +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	3.537	7.000	2.209	0.507	296.9	-13.3	0.0	9.8	-13.3	5.1
3	3.372	7.000	2.693	0.394	347.5	-13.9	0.0	5.1	-13.9	2.1
4	3.717	7.000	2.325	0.450	311.3	-13.7	0.0	8.7	-13.7	4.3
5	3.693	7.000	2.272	0.488	305.7	-13.6	0.0	9.3	-13.6	4.7
6	2.802	7.000	1.664	0.414	225.7	-10.5	0.0	14.9	-10.5	9.5

Adjust TS +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	5.011	7.000	2.748	0.653	377.0	22.9	0.0	36.6	11.7	33.5
3	4.746	7.000	3.330	0.504	436.9	21.2	0.0	29.9	10.2	28.4
4	5.107	7.000	2.961	0.562	400.8	18.5	0.0	38.5	7.8	34.3
5	5.066	7.000	2.890	0.608	393.0	18.5	0.0	39.0	7.7	34.6
6	3.758	7.000	1.944	0.505	269.9	20.0	0.0	34.3	9.1	30.9

Adjust %Carbon +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	6.271	7.000	2.559	0.818	373.3	53.8	0.0	27.2	39.8	32.2
3	5.915	7.000	3.283	0.628	447.5	51.1	0.0	28.1	37.4	31.5
4	6.778	7.000	2.785	0.747	403.7	57.3	0.0	30.2	43.0	35.2
5	6.707	7.000	2.693	0.805	393.3	56.8	0.0	29.5	42.6	34.7
6	4.405	7.000	1.674	0.592	248.6	40.7	0.0	15.6	27.9	20.6

G1.2. Particulate organics calculation Method 2

Original values

BTG	x	y	z	a	M (g/mol)
2	4.217	7.000	2.048	0.598	288.3
3	4.012	7.000	2.590	0.473	344.8
4	4.000	7.000	2.169	0.396	296.4
5	4.000	7.000	2.169	0.396	296.4
6	3.962	7.000	1.583	0.558	232.6

Data used:

COD (mg/l)
VS (mg/l)
TS (mg/l)
% Carbon
% Hydrogen
% Nitrogen

Adjust COD +10%

Adjusted values / % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	1.699	0.598	249.3	0.0	0.0	-17.0	0.0	-13.5
3	4.012	7.000	2.243	0.473	306.0	0.0	0.0	-13.4	0.0	-11.3
4	4.000	7.000	1.831	0.396	258.7	0.0	0.0	-15.5	0.0	-12.7
5	4.000	7.000	1.831	0.396	258.7	0.0	0.0	-15.5	0.0	-12.7
6	3.962	7.000	1.256	0.558	196.1	0.0	0.0	-20.6	0.0	-15.7

Adjust VS +10%

Adjusted values / % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	2.399	0.598	327.7	0.0	0.0	17.2	0.0	13.7
3	4.012	7.000	2.936	0.473	383.6	0.0	0.0	13.4	0.0	11.2
4	4.000	7.000	2.509	0.396	334.6	0.0	0.0	15.7	0.0	12.9
5	4.000	7.000	2.509	0.396	334.6	0.0	0.0	15.7	0.0	12.9
6	3.962	7.000	1.911	0.558	269.4	0.0	0.0	20.7	0.0	15.8

Adjust TS +10%

Adjusted values / % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	2.458	0.598	334.3	0.0	0.0	20.0	0.0	15.9
3	4.012	7.000	2.977	0.473	388.1	0.0	0.0	14.9	0.0	12.6
4	4.000	7.000	2.650	0.396	350.3	0.0	0.0	22.2	0.0	18.2
5	4.000	7.000	2.650	0.396	350.3	0.0	0.0	22.2	0.0	18.2
6	3.962	7.000	1.959	0.558	274.7	0.0	0.0	23.7	0.0	18.1

Adjust %Carbon +10%

Adjusted values / % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.638	7.000	2.204	0.598	310.8	10.0	0.0	7.6	0.0	7.8
3	4.412	7.000	2.773	0.473	370.1	10.0	0.0	7.1	0.0	7.3
4	4.400	7.000	2.314	0.396	317.6	10.0	0.0	6.7	0.0	7.1
5	4.400	7.000	2.314	0.396	317.6	10.0	0.0	6.7	0.0	7.1
6	4.358	7.000	1.698	0.558	250.2	10.0	0.0	7.3	0.0	7.6

Adjust %Hydrogen +10%

Adjusted values / % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	3.833	7.000	1.968	0.544	274.0	-9.1	0.0	-3.9	-9.1	-5.0
3	3.647	7.000	2.472	0.430	326.6	-9.1	0.0	-4.6	-9.1	-5.3
4	3.637	7.000	2.077	0.360	281.3	-9.1	0.0	-4.2	-9.1	-5.1
5	3.637	7.000	2.077	0.360	281.3	-9.1	0.0	-4.2	-9.1	-5.1
6	3.602	7.000	1.535	0.507	222.2	-9.1	0.0	-3.0	-9.1	-4.5

Adjust %Nitrogen +10%

Adjusted values % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	1.980	0.658	281.6	0.0	0.0	-3.3	10.0	-2.3
3	4.012	7.000	2.535	0.520	339.4	0.0	0.0	-2.1	10.0	-1.6
4	4.000	7.000	2.124	0.435	292.0	0.0	0.0	-2.1	10.0	-1.5
5	4.000	7.000	2.124	0.435	292.0	0.0	0.0	-2.1	10.0	-1.5
6	3.962	7.000	1.521	0.614	226.5	0.0	0.0	-3.9	10.0	-2.7

G1.3. Particulate organics calculation Method 3

Original values

BTG	x	y	z	a	M (g/mol)
2	4.217	7.000	2.083	0.598	292.2
3	4.012	7.000	2.616	0.473	347.7
4	4.000	7.000	2.011	0.396	278.8
5	4.000	7.000	2.011	0.396	278.8
6	3.962	7.000	1.955	0.558	274.3

Data used:
VS (mg/l)
TS (mg/l)
% Carbon
% Hydrogen
% Nitrogen

Adjust VS +10%

Adjusted values % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	2.705	0.598	362.0	0.0	0.0	29.9	0.0	23.9
3	4.012	7.000	3.265	0.473	420.5	0.0	0.0	24.8	0.0	20.9
4	4.000	7.000	2.593	0.396	344.0	0.0	0.0	28.9	0.0	23.4
5	4.000	7.000	2.593	0.396	344.0	0.0	0.0	28.9	0.0	23.4
6	3.962	7.000	2.542	0.558	340.0	0.0	0.0	30.0	0.0	24.0

Adjust TS +10%

Adjusted values % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	2.182	0.598	303.4	0.0	0.0	4.8	0.0	3.8
3	4.012	7.000	2.689	0.473	355.9	0.0	0.0	2.8	0.0	2.3
4	4.000	7.000	2.243	0.396	304.8	0.0	0.0	11.5	0.0	9.3
5	4.000	7.000	2.243	0.396	304.8	0.0	0.0	11.5	0.0	9.3
6	3.962	7.000	2.035	0.558	283.3	0.0	0.0	4.1	0.0	3.3

Adjust %Carbon +10%

Adjusted values % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.638	7.000	1.766	0.598	261.9	10.00	0.00	-15.19	0.00	-10.39
3	4.412	7.000	2.316	0.473	319.0	10.0	0.0	-11.5	0.0	-8.3
4	4.400	7.000	1.711	0.396	250.0	10.0	0.0	-14.9	0.0	-10.3
5	4.400	7.000	1.711	0.396	250.0	10.0	0.0	-14.9	0.0	-10.3
6	4.358	7.000	1.658	0.558	245.8	10.0	0.0	-15.2	0.0	-10.4

Adjust %Hydrogen +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	3.833	7.000	1.854	0.544	261.2	-9.1	0.0	-11.0	-9.1	-10.6
3	3.647	7.000	2.338	0.430	311.7	-9.1	0.0	-10.6	-9.1	-10.4
4	3.637	7.000	1.789	0.360	249.0	-9.1	0.0	-11.1	-9.1	-10.7
5	3.637	7.000	1.789	0.360	249.0	-9.1	0.0	-11.1	-9.1	-10.7
6	3.602	7.000	1.737	0.507	244.9	-9.1	0.0	-11.1	-9.1	-10.7

Adjust %Nitrogen +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	2.030	0.658	287.2	0.0	0.0	-2.5	10.0	-1.7
3	4.012	7.000	2.575	0.520	343.8	0.0	0.0	-1.6	10.0	-1.1
4	4.000	7.000	1.977	0.435	275.5	0.0	0.0	-1.7	10.0	-1.2
5	4.000	7.000	1.977	0.435	275.5	0.0	0.0	-1.7	10.0	-1.2
6	3.962	7.000	1.906	0.614	269.6	0.0	0.0	-2.5	10.0	-1.7

G1.4. Particulate organics calculation Method 4

Original values

BTG	x	y	z	a	M (g/mol)
2	4.217	7.000	1.970	0.598	279.7
3	4.012	7.000	2.533	0.473	338.5
4	4.000	7.000	2.369	0.396	318.9
5	4.000	7.000	2.369	0.396	318.9
6	3.962	7.000	0.944	0.558	161.1

Data used:

COD (mg/l)
TS (mg/l)
% Carbon
% Hydrogen
% Nitrogen

Adjust COD +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	1.055	0.598	177.1	0.0	0.0	-46.5	0.0	-36.7
3	4.012	7.000	1.694	0.473	244.5	0.0	0.0	-33.1	0.0	-27.8
4	4.000	7.000	1.507	0.396	222.3	0.0	0.0	-36.4	0.0	-30.3
5	4.000	7.000	1.507	0.396	222.3	0.0	0.0	-36.4	0.0	-30.3
6	3.962	7.000	-0.038	0.558	51.1	0.0	0.0	-104.1	0.0	-68.3

Adjust TS +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	2.795	0.598	372.0	0.0	0.0	41.8	0.0	33.0
3	4.012	7.000	3.286	0.473	422.8	0.0	0.0	29.7	0.0	24.9
4	4.000	7.000	3.145	0.396	405.8	0.0	0.0	32.8	0.0	27.3
5	4.000	7.000	3.145	0.396	405.8	0.0	0.0	32.8	0.0	27.3
6	3.962	7.000	1.821	0.558	259.3	0.0	0.0	92.8	0.0	60.9

G1. 5

Adjust %Carbon +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.638	7.000	2.814	0.598	379.2	10.0	0.0	42.8	0.0	35.6
3	4.412	7.000	3.333	0.473	432.8	10.0	0.0	31.6	0.0	27.9
4	4.400	7.000	3.169	0.396	413.3	10.0	0.0	33.8	0.0	29.6
5	4.400	7.000	3.169	0.396	413.3	10.0	0.0	33.8	0.0	29.6
6	4.358	7.000	1.735	0.558	254.4	10.0	0.0	83.7	0.0	57.9

Adjust %Hydrogen +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	3.833	7.000	2.109	0.544	289.9	-9.1	0.0	7.1	-9.1	3.7
3	3.647	7.000	2.621	0.430	343.4	-9.1	0.0	3.5	-9.1	1.4
4	3.637	7.000	2.472	0.360	325.5	-9.1	0.0	4.3	-9.1	2.1
5	3.637	7.000	2.472	0.360	325.5	-9.1	0.0	4.3	-9.1	2.1
6	3.602	7.000	1.177	0.507	182.1	-9.1	0.0	24.6	-9.1	13.0

Adjust %Nitrogen +10%

Adjusted values						% Change in values				
BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	4.217	7.000	1.881	0.658	270.4	0.0	0.0	-4.6	10.0	-3.3
3	4.012	7.000	2.462	0.520	331.2	0.0	0.0	-2.8	10.0	-2.2
4	4.000	7.000	2.310	0.435	312.8	0.0	0.0	-2.5	10.0	-1.9
5	4.000	7.000	2.310	0.435	312.8	0.0	0.0	-2.5	10.0	-1.9
6	3.962	7.000	0.861	0.614	152.5	0.0	0.0	-8.9	10.0	-5.3

G2.1. Calculation from COD, DOC and TKN

Data used:
COD (mg/l)
DOC (mg/l)
OrgN (mg/l)

Original values: Determination from UCT data- WAS soluble organics

BTG	x	y	z	a	M (g/mol)
2	0.443	7.000	2.000	0.307	233.6
3	0.307	7.000	2.000	0.168	230.0
4	0.354	7.000	2.000	0.284	232.2
5	0.354	7.000	2.000	0.284	232.2
6	0.207	7.000	2.000	0.013	226.7

Adjust z +10%

Adjusted values | % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	0.384	7.000	2.200	0.266	254.7	-13.333	0.000	10.000	-13.333	9.040
3	0.266	7.000	2.200	0.146	251.6	-13.333	0.000	10.000	-13.333	9.387
4	0.307	7.000	2.200	0.246	253.5	-13.333	0.000	10.000	-13.333	9.174
5	0.307	7.000	2.200	0.246	253.5	-13.333	0.000	10.000	-13.333	9.174
6	0.179	7.000	2.200	0.011	248.7	-13.333	0.000	10.000	-13.333	9.726

G2.2. Calculation from COD, DOC, TKN and VDS

Original values: Determination from UCT and Ubisi (1997) data: WAS soluble organics

BTG	x	y	z	a	M (g/mol)
2	0.182	7.000	3.247	0.052	366.6
3	0.118	7.000	3.160	0.038	355.8
4	0.146	7.000	3.172	0.062	357.9
5	0.146	7.000	3.172	0.062	357.9
6	0.070	7.000	3.130	0.003	351.5

Adjust COD/VDS +10%

Adjusted values | % Change in values

BTG	x	y	z	a	M (g/mol)	x	y	z	a	M (g/mol)
2	0.201	7.000	3.222	0.057	364.1	10.067	0.000	-0.783	10.067	-0.697
3	0.130	7.000	3.127	0.042	352.4	9.646	0.000	-1.039	9.646	-0.980
4	0.161	7.000	3.140	0.068	354.6	9.801	0.000	-1.013	9.801	-0.933
5	0.161	7.000	3.140	0.068	354.6	9.801	0.000	-1.013	9.801	-0.933
6	0.077	7.000	3.095	0.004	347.6	9.373	0.000	-1.108	9.373	-1.081

H1.1. Compound molar mass (M, g/mol)

M (g/mol) = M_{carbon} (x) + $M_{hydrogen}$ (y) + M_{oxygen} (z) + $M_{nitrogen}$ (a)

H1.2. Compound molar concentration (mol/l):

Compound concentration (mol/l) = compound VS (g/l) / compound *M* (g/mol) = Compound COD (g/l) / compound theoretical COD (g/mol)

H1.3. Element concentration from elemental analysis data and TS

Element concentration (e.g. g/l carbon) = element % by mass x wastewater TS concentration (g/l)

H1.4. Moles of element in a preliminary formula

Mass (%) of element = [moles of element in formula x molar mass of element (g/mol)] / mass (g) of one mol of compound,
where the individual mass percents of elements in the compound must add up to 100 %
(Silberberg 2006)

thus,

moles of element in formula = [mass (%) of element x mass (g) of compound] / molar mass of element (g/mol)

H2. 1

The following elemental molar masses were used in all derivations:

M_{carbon} = 12 g/mole
$M_{hydrogen}$ = 1 g/mole
$M_{nitrogen}$ = 14 g/mole
M_{oxygen} = 16 g/mole

H2.1. Compound theoretical COD ($COD_{theoretical,}$ g/mol)

$C_xH_yO_zN_a + (2x – z)\ H_2O \rightarrow x\ CO_2 + (y + 4x – 2z – 3a)\ H^+ + (y + 4x – 2z – 3a)\ e^- + a\ NH_3$
$\underline{(y + 4x – 2z – 3a)\ H^+ + (y + 4x – 2z – 3a)\ e^- + ¼\ (y + 4x – 2z – 3a)\ O_2 \rightarrow ½\ (y + 4x – 2z – 3a)\ H_2O}$
$C_xH_yO_zN_a + ¼\ (y + 2(2x – z) – 3a)\ O_2 \rightarrow ½\ (y – 3a)\ H_2O + x\ CO_2 + a\ NH_3$

Thus, the compound theoretical COD (gCOD/mol compound) = 16 x 2 x ¼ (y + 2(2x – z) – 3a) = 8 (y + 2(2x – z) – 3a)

H2.2. Conversion of VFA concentrations to COD concentrations (Sbsa)

VFA molecular formula : $C_2H_4O_2$ (Ascetic acid)
Theoretical COD : 8 [4 + 2 (4 - 2) - 0] = 64 g COD / mol compound
Molar mass (M) : 2 x 12 + 4 x 1 + 2 x 16 = 60 g compound / mol

Conversion : Sbsa (g/l) = [VFA (g/l) ÷ 60 (g/mol) x 64 (gCOD/mol)]

H2.3. Particulate organics compositions methods

Method 2: Derivation of formula for the calculation of z

Compound concentration (mol/l) = compound VS (g/l) / compound *M* (g/mol) = Compound COD (g/l) / compound theoretical COD (g/mol)

thus Stp (g/l) / $COD_{theoretical}$ (g/mol) = Xv (g/l) / *M* (g/mol)
Stp / [8 y + 32 x – 16 z – 24 a] = Xv / [12 x + y + 16 z + 14 a]
Stp (12 x + y + 16 z + 14 a) = Xv (8 y + 32 x – 16 z – 24 a)

thus z = [Xv (32 x + 8 y – 24 a) – Stp (12 x + y + 14 a)] / [16 Sp + 16 Xv] multiply by Xv / Xv

$$\underline{z = [\ x\ (\ 32 – 12\ fcv\ ) + y\ (\ 8 – fcv\ ) – a\ (\ 24 + 14\ fcv\ )\ ]\ /\ [\ 16\ fcv + 16\ ]}$$

Method 3: Derivation of formula for the calculation of z

In this derivation it is assumed that the mass of oxygen in a compound equals the balance between organics mass per litre measured as volatile solids (Xv, g/l) and the masses of compound measured in elemental analysis, viz. carbon, hydrogen, nitrogen and phosphorus.

thus the concentration of oxygen in a particulate organic compound, O (g/l) = Xv – (C_f) (Xt) – (H_f) (Xt) – (N_f) (Xt) – (P_f) (Xt)

where: C_f = % C / 100
H_f = % H / 100
N_f = % N / 100
P_f = % P / 100

thus $\underline{z = [Xv - Xt (C_f + H_f + N_f + P_f)] / M_{oxygen}}$

Method 4: Derivation of formula for the calculation of z

Compound concentration (mol/l) = compound C (g/l) / M_{carbon} (g/mol) = Compound COD (g/l) / compound theoretical COD (g/mol)

thus $Stp\ (g/l) / COD_{theoretical}\ (g/mol) = Ctp\ (g/l) / M_{carbon}\ (g/mol)$
$Stp / [8 y + 32 x - 16 z - 24 a] = Ctp / 12$
$Stp (12) / Ctp = 8 y + 32 x - 16 z - 24 a$

thus $\underline{z = [(8 - 3 Stp / Ctp) x + 2 y - 6 a] / 4}$

H2.4. Soluble organics compositions method

1. $COD / OrgN = [8y + 32x - 16z - 24a] / (14 a)$
2. $COD / DOC = [8y + 32x - 16z - 24a] / (12 x)$

Solve for a in (1) and (2) and setting resultant equations equal yields

From (2) $a = [2 y + 8 x - 4 z - 3 x (COD / DOC)] / 6$ ……………………..(3)

$\underline{x = [14y - 28z] / [21 (COD/DOC) - 56 + 36 (OrgN / DOC)]}$ ……………………..(4)

Setting (4) into (3) yields

$\underline{a = (OrgN/DOC) [12y - 24z] / [21 (COD/DOC) + 36 (OrgN / DOC) - 56]}$

H2.5. Data isolation and comparison equations

% H calculation

1. From method 4: $y = 2 z - 4 x + (1.5 Stp/Ctp) x + 3 a$
2. From method 1: $y (fcv - 8) = x (32 - 12 fcv) + z (- 16 - 16 fcv) + a (- 24 - 14 fcv)$

(1) into (2) yields

$\underline{z = [x ((12 - 1.5 fcv) Stp / Ctp - 8 fcv) - 17 a fcv] / [18 fcv]}$

TSS calculation

1. From method 4: $z = (2 y + (8 - 3 Stp / Ctp) 3 - 6 a)$

2. From method 3: $z = [Xv - Xt (\%C + \%H + \%N) / 100] / 16$

(1) = (2) and $Xv = Xt - Xi$ yields

$\underline{Xt = (Stp - Xi) / [11 / 3 (\% C / 100) + (9 (\% H / 100) - 5 / 7 (\% N / 100) - 1]}$